LMVD POTAMOLOGY STUDY (T-1)

A Report Submitted to
The Department of the Army
St. Louis District, Corps of Engineers
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by

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PREFACE

This study, "LMVD Potamology Study (T-1)" was conducted by an interdisciplinary team of engineers and scientists for the U.S. Army Corps of Engineers under Contract No. DACW 43-75-C-0105, dated 21 March 1975. The study was undertaken by the team of specialists for the purpose of assimilating data to be used to obtain a better understanding of the mechanisms and relationships that result in large scale change in the regime of an alluvial river due to man-made modifications. This study was limited to the compilation and processing of data relevant to dikes and revetments, levees, geology, morphology and hydrology.

The study was coordinated under the leadership of Dr. Paul R. Munger, who served as Project Director and editor of the report. Dr. Glendon T. Stevens served as Project Co-Director. Various disciplinary areas of the report were prepared by the following persons:

Hydrology Hydraulics	Dr. Glendon T. Stevens Dr. Clifford D. Muir Dr. Jerome A. Westphal Professor John B. Heagler, Jr.
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Special acknowledgments are due the following persons for their assistance and cooperation during the tenure of this study: Mr. Norbert C. Long, who served as the Contracting Officer's Representative until March 31, 1976; Mr. Jack R. Niemi, the Authorized Representative of the Contracting Officer who served in that capacity from April 1, 1976 through completion of the study; Mr. C.N. Strauser, Project Administrator; St. Louis District, Corps of Engineers personnel, Miss Jean Finn, Mr. Gary Schwartz, Mr. Michael Dace III and Mr. Gary Dyhouse; Memphis District personnel, Mr. David McNutt, Mr. Bobby Littlejohn; Vicksburg District personnel, Mr. Patrick Harris, Mr. Brian Winkley; LMVD Potamologist, Mr. James Tuttle; New Orleans District personnel, Mr. Billy Garrett, Mr. John Miller, Mrs. Pearl Burke; special consultants who assisted so effectively in locating the necessary data, Mr. Roger Lyon (Memphis), Mrs. Margaret Palmer and Mr. Austin Smith (Vicksburg), and Mr. Robert Turina (St. Louis); Mr. Melvin Jansen and Mr. Howard McCormick of the U.S.G.S. Water Resources Division (Rolla, Missouri); Mr. Robert G. Livingston, U.S. Army Engr. Topo. Labs (Retired), who assisted in obtaining aerial photography and in editing the report; and the many undergraduate and graduate students from the University of Missouri-Rolla, who assisted in the compilation and processing of data, along with students from Memphis State University and Tulane University. In particular, for their contributions in overseeing the work of a number of undergraduate students, the following graduate students deserve being cited: Mr. Leonard Woolsey, Mr. Paul H. Leaver, Mr. Jerry Maurseth and Mr. William Wilkerson, all of the University of Missouri-Rolla.

Without the cooperation and assistance of all of the above named persons, this study would not have been possible. In addition, the excellent cooperation and assistance provided by a number of federal, state and local agencies in obtaining information essential to this study is deeply appreciated.

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I. SUMMARY AND CONCLUSIONS

The primary purpose of this project was to collect and assemble data pertaining to hydrologic, hydraulic, geologic and morphologic factors which relate to the Mississippi River downstream from Alton, Illinois and to present them in a format which would be amenable to detailed analysis at a future time. Except for selected comparisons, analysis of the data was beyond the scope of work.

Hydrologic data are presented in a variety of graphical and tabular formats. Formats were selected such that stage, flow, precipitation, and precipitation-runoff relationships could easily be analyzed for both spatial (according to position in the basin) and temporal comparisons.

Vertical velocity distributions in cross sections at St. Louis and Chester during 1935 and 1973 apparently do not follow the Prandtl-von Karman universal velocity distribution law. This may be a source of error in comparisons of discharges made by different flow-measurement techniques.

In overbank areas near Vicksburg, relationships between river stage and overbank flow rates are well defined. There are no discernible depth-velocity relationships in the same overbank areas.

In the St. Louis district during the period from the late 1800's to the present, the specific effect of levees on scour and deposition on the overbank is indistinguishable from effects of other influencing factors.

There have been no discernible trends in water-surface-profile changes in the Middle Mississippi Reach since 1967.

In the St. Louis Reach, there has been an average bank-width reduction of about 29 percent (3320 feet to 2370 feet) since 1908. This reduction appears to be in response to dike construction. In the Memphis and Vicksburg Reaches, there is no apparent association between average bank width and dike construction.

Occurrences of overbank flow of sufficient magnitude to evaluate the possible influence of levees on stage-discharge relationships were too few.

At Hermann, Missouri, channel conveyance continually decreased from 1930 to 1973 as is reflected by increases in stage of about 2 feet to 3.5 feet for flows ranging from 64,700 cfs to 337,000 cfs, respectively.

For the period, 1881-1934, at St. Louis, stages for flows between 280,900 cfs and 501,300 cfs appear to have increased while stages for flows less than 209,200 cfs appear to have decreased. However, in the period, 1934 to 1973, channel conveyance steadily increased as is reflected by a stage decrease of 1.4 feet or more for all flows less than 501,300 cfs. The trend of increasing channel conveyance began at a time approximately coincident with accelerated dike construction activity which was observed in the period, 1925 to 1940.

Channel conveyance at Chester, Illinois has not changed significantly since 1943.

At Thebes, Illinois, stages for flows between 481,000 cfs and 572,000 cfs did not change significantly from 1934 to 1962, but increased by about 2.5 feet in the period from 1962 to 1974. For the entire 1934 to 1974 period, stages for mid-range flows (about 220,000 cfs) remained essentially unchanged, while stages for flows between 87,000 cfs and 135,000 cfs decreased a total of about 3 feet. Similar stage-discharge patterns with respect to time are observed at Metropolis, Illinois, on the Ohio River. Backwater from the Ohio River occasionally influences flows in the Mississippi River at Thebes. Therefore, it appears that factors which change stage-discharge relationships in the lower Ohio River may affect stage-discharge relationships in the Mississippi River above their confluence, and vice versa.

At Memphis, Tennessee, channel conveyance increased significantly during the period, 1933 to 1971, as is reflected by stage decreases of 3 feet and 6 feet for flows ranging from 1,070,000 cfs to 260,000 cfs, respectively.

At Vicksburg, Mississippi, channel conveyance increased during the period, 1931 to 1942, as is reflected by stage decreases of about 10 feet for flows of 1,340,000 cfs and less. This trend reversed in 1942 or 1943 so that by 1973 stages had increased by about 5 feet from the 1942 values.

There is no consistent pattern of association between either dike construction or average top-bank width and stage-discharge changes with respect to time. It appears that changes in stage-discharge relationships are primarily influenced by factors, as yet unidentified, in the close vicinity of the respective points of records. Therefore, stage-discharge relationships at any given station do not necessarily reflect conditions for any appreciable distance from the station.

Because of flood protection implications, it is recommended that causal factors relating to stage increases at Thebes and Vicksburg be investigated in detail.

Surficial soils adjacent to the river were classified and mapped through use of infrared color photography. This information is presented on coded overlays.

Lithology of the river bed is presented in cross-section format. Lithologic data were derived from reports of levee borings and borings associated with bridge construction. Data from borings in the channel are few. Due to variable nature of alluvial deposits, extrapolation of information obtained from borings on the floodplain to the channel has a low reliability in terms of precise interpretation.

Contour maps representing the bedrock surface and associated bluff geology have been prepared for the reach from Alton, Illinois to Cairo, Illinois. It appears that the valley is more deeply entrenched than was previously indicated (Fisk, 1944). Control points are too few to permit contouring of the bedrock surface between Thebes Gorge and Cairo.

Morphology data are presented in formats designed to facilitate identification of changes in river features over time. Invert profiles show changes over a period of approximately 40 years for 5 irregularly spaced time intervals which were chosen on the basis of available data and occurrences which may have caused changes in the river morphology. Channel cross sections were prepared at intervals of about 30 miles throughout the study reach for the same approximate time periods chosen for the invert profiles. Changes in 1) bar and chute development, 2) meander pattern, 3) thalweg, and 4) energy dissipaters (within channel confines) are presented on overlays for time periods comparable to those used for profiles and cross sections. Energy dissipaters outside the channel during 1974 are also shown on an overlay.

The morphology overlays clearly show significant changes have occurred at various locations along the river in each of the various time intervals considered. Although no attempt was made to determine causal factors for the observed changes, it is clear that these data in this format will be useful for such an analysis.

Dike, revetment, and levee information was tabulated showing date of construction, location, construction history (including modifications), materials used, physical characteristics, and current operational status. Levee crevasses were also tabulated, showing date of breach, location, type of breach, flood stage, size and type of area flooded, damage incurred, and physical features of levee and breach. Although information in many cases was missing, these historical presentations are essentially complete.

Information collected, compiled, and presented in this study should prove useful in evaluation of past engineering activities and in anticipation of effects of future engineering activities. These data could readily be used in providing a current base line for the Mississippi River, in which case the data file should be kept updated and developed, particularly in areas where data deficiencies are noted.

II. INTRODUCTION

The Mississippi River, America's greatest river, has the third largest drainage area in the world, exceeded in size only by the watersheds of the Amazon and Congo Rivers. It has, without question, played a major role in the physical and economical growth of the Nation. It is a navigation artery of great importance to the Nation's transportation system as well as a major supplier of water for the cities and industrial communities that have located along its bank. In its lower valley, the Mississippi River flows through one of the most fertile regions on earth. In recent years the recreational worth of this mighty river has increased tremendously. All of these factors point up the importance of the Mississippi River to the Nation's general economy and the economy of the lower valley.

But a river is a greater asset to navigation as a controlled river. Its waters form a navigation artery of tremendous worth as long as the channel is safe and dependable. A river is beneficial to the area through which it flows as long as it is made to work for the region and is not allowed to destroy it.

As a result of many years of work by the U.S. Army Corps of Engineers, the Mississippi River is being controlled in time of high water by levees and floodwalls which are designed to protect the alluvial valley against the project flood, except where it enters the natural backwater areas or is diverted purposely into floodway areas. Revetments have been utilized to minimize meanderings which would cut into and destroy protection levees and to provide a favorable channel alignment for navigation. Dikes have been built to contract channel crossings, encourage closure of back channels and chutes, and to provide better channel alignment for navigation. Though not complete, these works have generally been very successful. However, the Mississippi River is a dynamic river, continually changing its bed configurations, moving bars and islands, making point bar cutoffs, and generally attempting to break out and resume its cross-valley wanderings.

Two major goals of Corps of Engineers work in the Lower Mississippi Valley are to produce and maintain a stable river system capable of safely conveying project flood flows to the gulf and to develop and maintain a safe and dependable navigation channel of authorized dimensions. Although tremendous strides have been made toward realization of these two goals, considerable work remains to be done.

The major flood on the Mississippi River in the spring of 1973 produced stages which made it apparent that the prevailing stage-discharge relationship was several feet higher than the stage-discharge relationship on which the levee grades and other flood control features had been based in the middle portion of the Lower Mississippi River and in the Atchafalaya Basin Floodway. In addition to deterioration problems observed during the 1973 flood, contraction works, revetments, and other features have aroused the concern of conservation interests and raised questions regarding flood flow capacities in the Upper Mississippi River. Also, excessive shoaling problems are occurring in the Lower Mississippi River below New Orleans, Louisiana. Questions have also been raised regarding the possibility of the deterioration problem migrating downstream and affecting the Baton Rouge to New Orleans reach of the river.

A revitalized and expanded potamology program designed to obtain a better understanding of the mechanisms and relationships that give rise to large scale change in the regime of an alluvial river as a result of man-made modifications has been formulated, and this study covers a portion of the studies included in the expanded potamology program. This study has resulted in the compilation and processing of a large volume of data. In some cases, lack of data was apparent and in a few others, data were not available until too late to be included. It appears that detailed study of the data assembled would not only be desirable, but might reveal yet a better and clearer understanding of this many-faceted problem.

The areal extent of the study was that portion of the Mississippi River and the adjacent confined floodplain as required between Alton, Illinois and the Gulf of Mexico (Head of Passes), and including the Atchafalaya River. Study sites were selected to include locations of varying physical characteristics to provide sufficient coverages to represent the entire river.

Four districts of the Crops of Engineers were included: St. Louis, Memphis, Vicksburg and New Orleans. The jurisdiction of each district is as follows:

New Orleans--Atchafalaya River and mile 0 to mile 320.5, above Head of Passes

Vicksburg--Mile 320.5 to mile 599.0, above Head of Passes

Memphis--Mile 599.0 to mile 954.0 at Cairo, Illinois*, above Head of Passes

St. Louis--Mile 0 at Cairo, Illinois to mile 202.0 at Alton, Illinois.

*Cairo, Illinois represents mile 0 for the St. Louis District and is at mile 954.0 above Head of Passes. River mileage downstream and upstream from Cairo is with respect to the 1929 datum.

III. HYDROLOGY

Glendon T. Stevens

The drainage basin of the Mississippi River comprises approximately that portion of the United States lying between the Allegheny and the Rocky Mountains, except the Great Lakes and Hudson Bay drainages, with a total area of about 1,240,000 square miles. This covers about two-fifths of the total area of the United States proper. Water from part or all of 31 states, comprising the Mississippi River drainage basin, passes through the Mississippi River into the Gulf of Mexico (Figure 3.1). For convenience in this study, the entire drainage area has been divided into eight sub-areas as follows;

Region No.	Drainage Area	Drainage Area Sq. Mile
I	Upper Missouri	458,000
II	Lower Missouri	62,000
III	Upper Arkansas-Red	153,000
IV	Lower Arkansas-Red-White	117,000
V	Upper Mississippi	182,000
VI	Lower Mississippi	64,000
VII	Ohio	145,000
VIII	Tennessee-Cumberland	59,000

Figure 3.1 and the sub-basin areas were extracted from "Water Atlas of the United States" (Geraghty, et.al., 1973).

The purpose of this section of the LMVD (T-1) contract is to collect and display data that may be utilized in the design and operation of various control structures that will enhance navigation and flood protection on the Mississippi River.

The data needed to complete this section of the study consists of rainfall, mean-daily discharge and mean-daily stage.

The period of record for this section was chosen to be 1930, or the

Figure 3.1 Mississippi River Drainage Basin (from Geraghty, et al., 1973)

first date measurements were made (if after 1930), through the latest published date. This period was selected because the discharge data were thought to be more reliable and consistent. Prior to this time span, measuring equipment and techniques used to determine discharge varied; thus, the mean-daily discharge, mean-daily stage and rainfall data recorded prior to the 1930's were not included.

Rainfall data for the 31 states that make up the Mississippi River Basin were obtained from the National Weather Service for the period of record. These data were utilized in determining the following (*-work required under the contract):

1. The average annual precipitation for each of the eight regions that make up the Mississippi River drainage basin.

2. The average annual rainfall for:

    a. The Missouri River Basin (Reg. 1 and 2)
    b. The Ohio River Basin (Reg. 7 and 8)
    c. The Atchafalaya River Basin (Reg. 3 and 4)
    d. The Mississippi River Basin above St. Louis (Reg. 1, 2, and 5)
    e. The Mississippi River Basin above Memphis (Reg. 1, 2, 5, 7, and 8)
    f. The Mississippi River Basin above New Orleans (Reg. 1, 2, 5, 6, 7, and 8)

3. The average annual precipitation data for each of the eight regions were plotted on extreme value distribution paper, utilizing the Weibull plot position formula.

4. Data from steps 1 and 2 were plotted as a time series.

5* The data from step 2 are presented graphically, along with runoff, as a time series.†

The mean-daily stage and mean-daily discharge data needed to complete this section of the potamology study were obtained for the period of record from the United States Corps of Engineers and the United States Geological Survey, Water Resources Division. Mean-daily stage and mean-discharge data were collected for eighteen locations on the Mississippi

River and its major tributaries. Locations on the Mississippi River were Keokuk, Iowa; Alton, Illinois; St. Louis, Missouri; Chester, Illinois; Thebes, Missouri; Memphis, Tennessee; Vicksburg, Mississippi; Helena, Arkansas; Arkansas City, Arkansas; and Red River Landing, Louisiana. Locations on the major tributaries were Meredosia, Illinois on the Illinois River; Hermann, Missouri on the Missouri River; Metropolis, Illinois on the Ohio River; Paducah, Kentucky on the Tennessee River; Little Rock, Arkansas on the Arkansas River; Clarendon, Arkansas on the White River; Alexandria, Louisiana on the Red River; and Simmesport, Louisiana on the Atchafalaya River. Data collected for each of the above-mentioned stations are displayed in the following forms (*-work required under the contract).

1* For each location, the United States Geological Survey, Water Resource Division eight-digit station number, bankfull stage and drainage area (square miles).

2* The average mean-daily stage and average mean-daily discharge for each year.

3* The average mean-daily stage and average mean-daily discharge for the low-water season (July-November) for each year.

4* The annual volume (inches over drainage basin) of runoff.

5* The number and listing of days per year that the mean-daily stage exceeded bankfull.

6* Percent of time per year mean-daily stage exceeded bankfull.

7* A histogram of mean-daily stage and mean-daily discharge showing the number of times per year that the stage and discharge were within predetermined intervals.

8* The volume (inches over drainage basin) of runoff for each month per year.

9* The average monthly volume of runoff for the period of record.

10* The percent of runoff for each month per year.

11* The average monthly percent runoff for the period of record.

12* The long-term yearly average

a. mean-daily stage (feet)
b. mean-daily flow (1000 cfs)
c. runoff (inches)
d. low-water season mean-daily stage and mean-daily discharge
e. high-water season mean-daily stage and mean-daily discharge

13* The deviation of the yearly averages of items 12, a, b, c, d and e from the long-term averages.

14. A complete listing of recorded mean-daily stages and mean-daily discharges.

15. The yearly minimum and maximum mean-daily stages.

16. The yearly minimum and maximum mean-daily discharges.

17. The long-term average mean-daily stage for each day of a calendar year.

18. The long-term average mean-daily discharge for each day of a calendar year.

19. The average mean-daily stage and average mean-daily discharge for the high-water season (December-June) for each year.

20. The deviation of the monthly average mean-daily stage and monthly average mean-daily discharge from the long-term yearly average for each year.

21. The long-term monthly, average mean-daily stage and mean-daily discharge.

22. The monthly average mean-daily stage and monthly average mean-daily discharge for each year.

23. The deviation of the mean-daily stage and mean-daily discharge

for each month of each year from the long-term mean-daily stage and mean-daily discharge for each month.

24. The mean-daily stage and mean-daily discharge data have been analyzed to determine

    a. the 1, 7, 14, 30, 60, 90 and 120 consecutive day minimums.
    b. the 1, 7, 14, 30, 60, 90, 120, 150 and 180 consecutive maximums

25. Data from 24a and 24b above have been plotted on extreme value distribution paper, utilizing the Weibull plot position formula.††

Data as presented in this section are amenable to making many hydrologic studies and comparisons. The following is a brief list of some of the studies that could and possibly should be undertaken:

A. Using the average annual precipitation data presented, one could study and predict the probability of the joint occurrence of various events. A study of this nature would be worthwhile in the design of flood protection structures and floodplain management.

B. The annual precipitation data, coupled with other pertinent data, could be utilized in studying the wet and dry cycle, thus assisting in developing information that could be utilized in reservoir regulation and operation.

C. Rainfall and runoff data could be utilized in studying the ever-changing land use management practices and possibly the study of the changing sediment (wash) load carried by the Mississippi River and its tributaries.

D. The data presented herein should be coupled with data from Morphology and Geology sections and a study conducted to understand more fully energy dissipaters as to type, location, development, etc.

E. The long-term average mean-daily discharge and mean-daily stage for day of the year would be useful in developing:

a. The long-term average mean-daily discharge hydrograph
b. The long-term average mean-daily stage hydrograph
c. The long-term average mean-daily stage-discharge relationship (rating curve)

The major stumbling block which all encounter who study the response of a river to changes made by man is that of sufficient and adequate data and its acquisition. Therefore, the first two recommendations which this or any other study team could make are:

1. That a comparison of the various types of measuring equipment and techniques used in determining discharge throughout the years in which measurements have been made should be undertaken. Such a study would result in the development of relationships between the various techniques and equipment used to measure discharge. These relationships could then be utilized in adjusting discharge data to the technique and equipment presently used.
2. That a central computerized data bank should be established. This data bank should contain all measured data that have been or will be collected on the Mississippi River and should have the retrieval capability that would make it useful to all.

Note: †A listing of the computer programs used in processing the data can be found in Appendix 3.1. The computer printout of the results obtained from the various calculations made with the rainfall data can be found in Appendix 3.2.

††The computer printout of the results obtained from the various calculations made with the mean-daily discharge and mean-daily stage can be found in Appendix 3.3 which contains four volumes. Tributary data are found in volumes 1 and 2. Volume 3 contains those stations upstream from Memphis. Volume 4 contains Memphis and those stations downstream.

IV. HYDRAULICS

Clifford D. Muir and Jerome A. Westphal

While this section relates directly to contract items specified under hydraulics, the directly related subject of 1) river confinement by levees, 2) comparison of dike construction history with associated changes in top bank width, and 3) comparison of dike construction history with changes in stage-discharge relationship, are included in discussions within this section of the report.

The limited number of overbank velocity measurements obtainable within the time frame of the project proved to be a major constraint on efforts to develop velocity relationships on overbank areas. Most of the available data were flow rates in the overbank area. However, complete flood-stage measurements of velocities and associated depths for the St. Louis and Chester gage locations were obtained for years after 1935. Also, velocities in the overbank area were obtained for the Vicksburg area for the years 1929, 1933, 1935, and 1973.

Estimated velocity distributions at the St. Louis gage are shown on Figures 4.1a and 4.1b for July 1, 1942 and May 1, 1973, respectively. Isovels were contoured on the basis of point velocities taken for discharge measurements. Because of the flood wall at St. Louis, there is relatively little overbank area. There were apparently no striking changes in cross-section shape or velocity distributions at the section between 1942 and 1973.

Estimated velocity distributions at the Chester gage were made in the same manner as at the St. Louis gage and are shown on Figures 4.2a and 4.2b for July 17, 1951 and May 14, 1973, respectively. Although

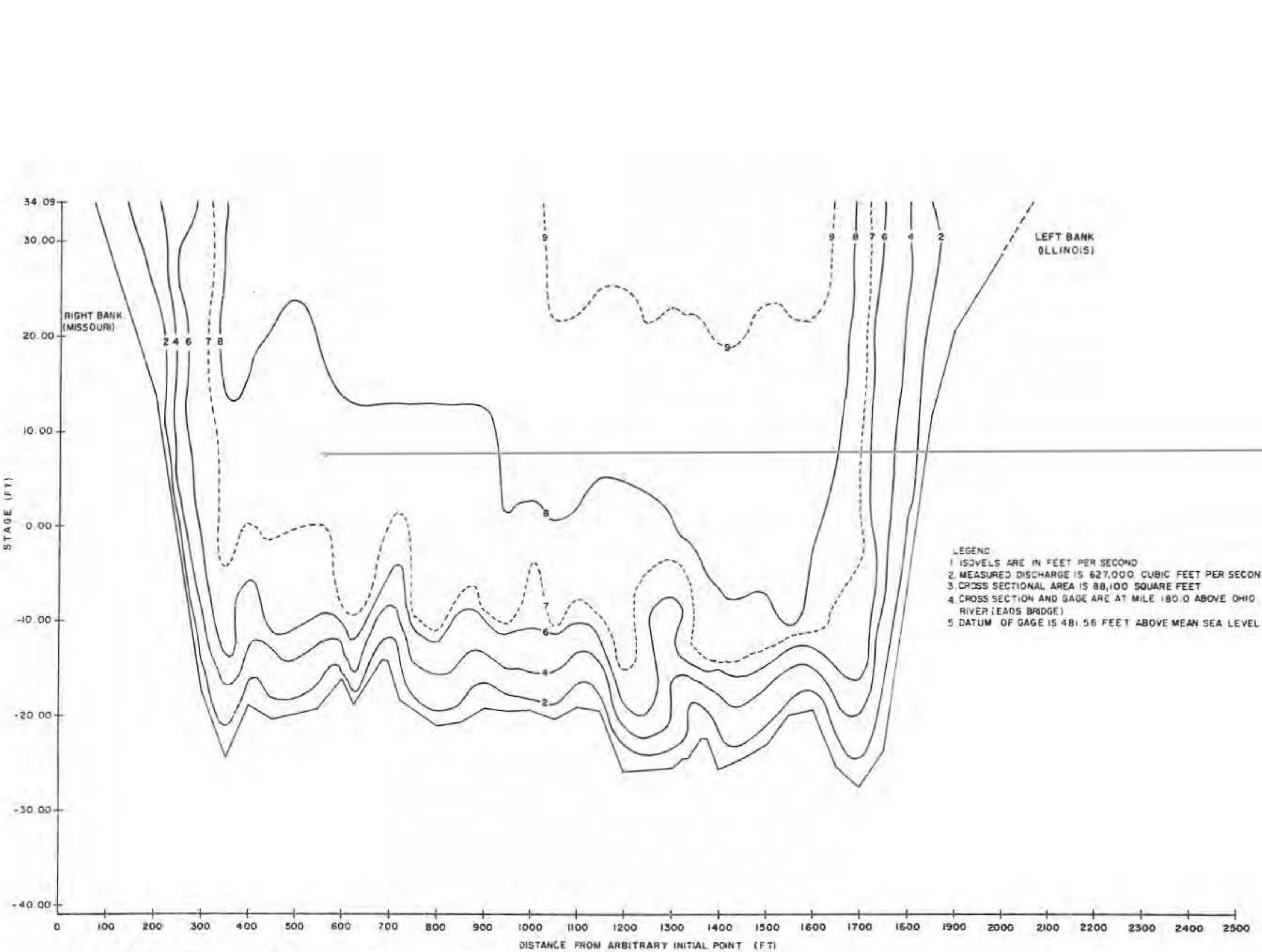

Figure 4.1a Estimated Velocity Distributions in the Mississippi River for July 1, 1942 near St. Louis, Missouri

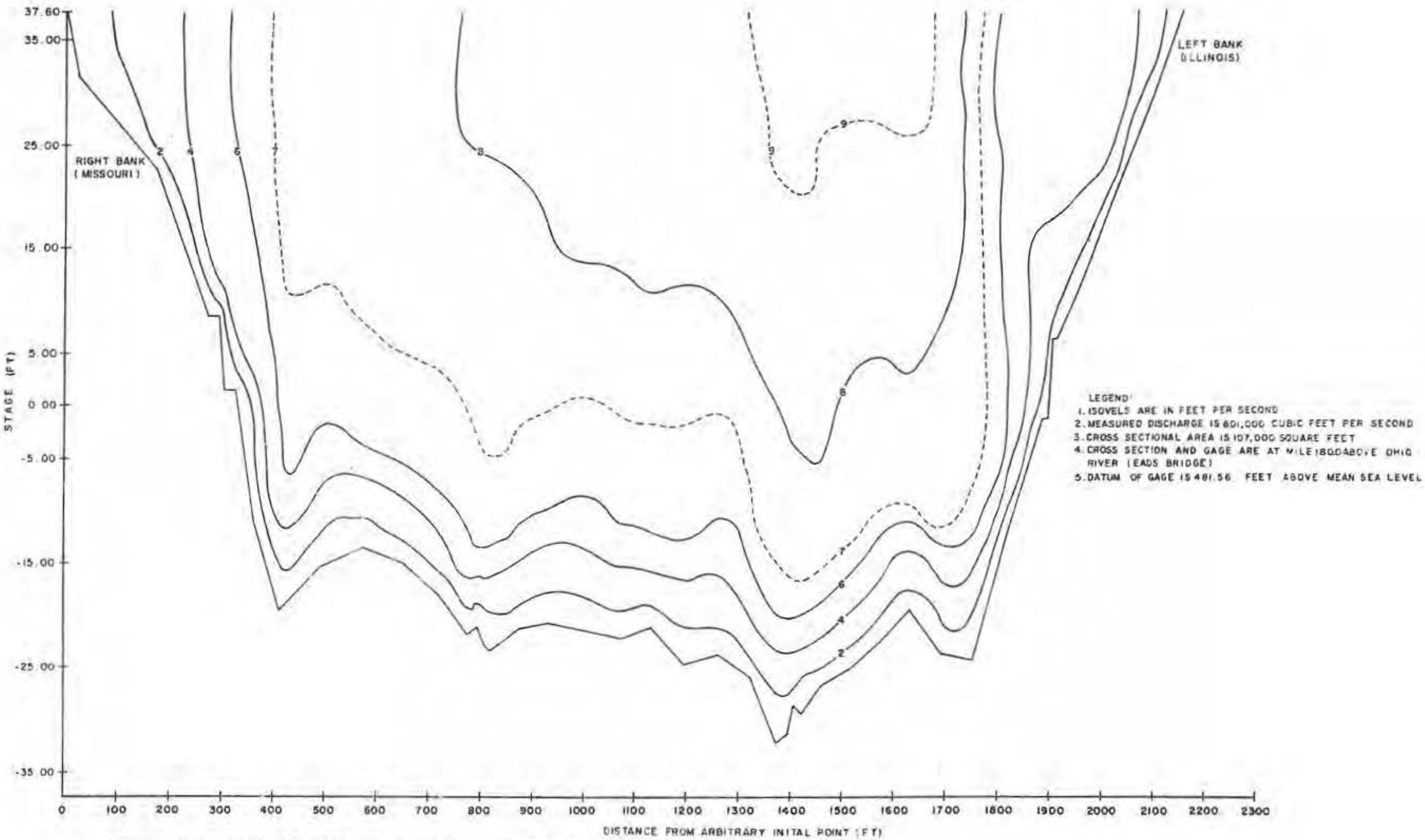

Figure 4.1b Estimated Velocity Distributions in the Mississippi River for May 1, 1973 near St. Louis, Missouri

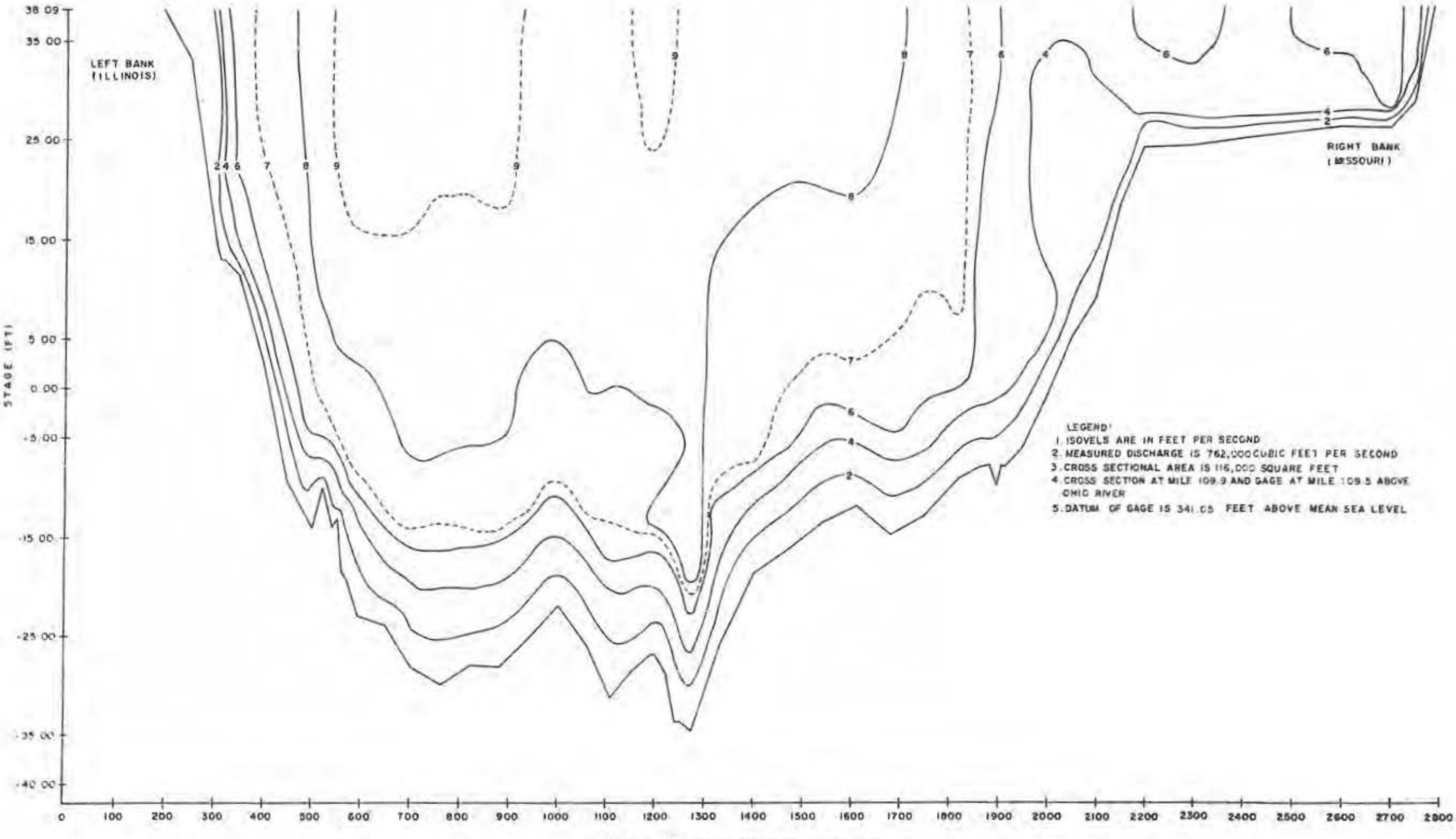

Figure 4.2a Estimated Velocity Distributions in the Mississippi River for July 17, 1951 near Chester, Illinois

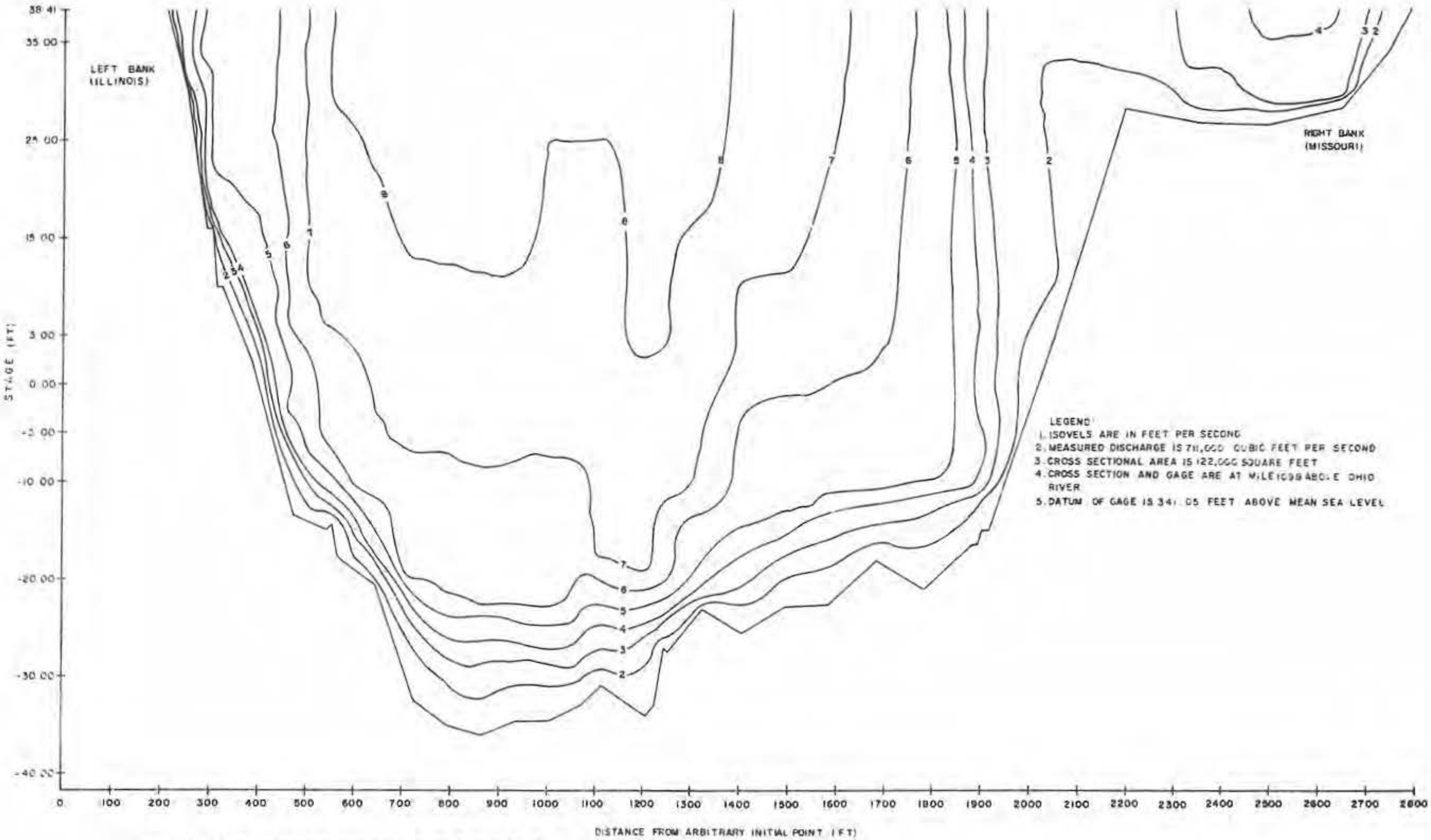

Figure 4.2b Estimated Velocity Distributions in the Mississippi River for May 14, 1973 near Chester, Illinois

the thalweg has apparently migrated toward the left bank (Illinois side) in the period between 1951 and 1973, cross-sectional area and shape are nearly the same for the two dates. The similarity of isovel patterns is probably a reflection of the similarity of cross-section geometry.

Typical overbank velocities for several locations at Vicksburg are included in Tables 4.1, 4.2, and 4.3. Attempts to correlate velocity on the overbank with depth of flow were unproductive. For the range of observations made thus far, there is no discernible functional relationship between depth of flow on the overbank and overbank velocities. Before difinitive statements can be made in this regard, detailed information regarding energy dissipaters are needed. For example, in the St. Louis District where brush had been cleared in front of the levees, a secondary channel developed during flood stages. To overcome overbank velocities and secondary channels, the St. Louis District has constructed spur levees and abatis dikes and has encouraged willow growth in old borrow pits. Therefore, overbank velocities at a given site probably reflect local conditions more than the generalized influence of levees or confinement.

Maximum velocities on the overbank are less than main channel maximum velocities. The 1933 overbank maximum velocity of 2.55 ft/sec at Vicksburg corresponded to a main channel maximum velocity of 7.98 ft/sec. The Chester overbank maximum for May 14, 1973, appeared to be about one-half the main-channel maximum.

A comparison of flow rates in the overbank area and river stage in the vicinity of Vicksburg is presented in Figure 4.3. The 1973 values were for a cross section 0.4 miles downstream from the Vicksburg Bridge. Zero gage at this section was 46.25 feet above mean sea level. The 1929

TABLE 4.1

OVERBANK FLOW

LOWER DELTA POINT, LA. JUNE 7, 1929

STAGE 55.1 FT.

Distance from River Toward Levee (ft)	Depth (ft)	Mean Velocity (fps)
0	6	0.60
500	8	0.37
1000	14	0.47
1500	15	0.43
2000	17	0.13
2500	18	0.13
3000	17	0.43
3500	18	0.47
4000	19	0.64
4500	20	0.80
4600	16	0.53
4700	12	1.01
4800	11	1.07
4900	11	1.21
5000	12	1.34
5100	11	1.53
5200	11	1.64
5300	9	1.81
5400	7	1.14
5500	5	1.58
5700	0	0.00

TABLE 4.2

OVERBANK FLOW
LOWER DELTA POINT, LA.

Date	Stage (ft)	Distance from River Toward Levee (ft)	Depth (ft)	Mean Velocity (fps)
June 5, 1929	55.10	0	4	0.68
		500	6	1.22
		1000	12	0.32
		1500	17	0.58
		2000	19	0.78
		2500	17	0.35
		3000	17	0.65
		3500	19	0.68
		4000	19	0.58
		4500	18	0.55
April 22, 1933	48.03	100	6.5	0.77
		160	5.5	1.50
		250	6.2	2.05
		275	4.7	2.35
		390	5.5	1.88
		450	5.0	2.22
		530	5.3	2.09
		595	5.5	2.40
		620	5.5	2.46
		660	5.5	2.24
		705	5.5	2.55
		750	0.0	0.00

TABLE 4.3

OVERBANK FLOW

VICKSBURG-HIGHWAY BRIDGE; MAY 14, 1973

Distance from River Toward Levee (ft)	Depth (ft)	Mean Velocity (fps)
0	6.0	.216
200	5.4	.320
400	5.6	.560
600	4.9	.720
800	6.2	.510
1000	11.6	.720
1200	12.8	.710
1400	13.2	.560
1600	11.4	.590
1800	12.1	.710
2000	12.2	.640
2200	13.4	.780
2400	15.2	.500
2600	15.5	.590
2800	16.8	.500
3000	16.7	.910
3200	16.0	.820
3400	16.0	1.100
3600	16.7	.930
3800	17.8	.558
4000	18.7	.940
4200	12.1	.880
4400	8.3	1.290
4600	10.1	1.26
4800	8.6	.864
4900	7.6	1.170
5000	4.1	1.188
5050	Close to 0	

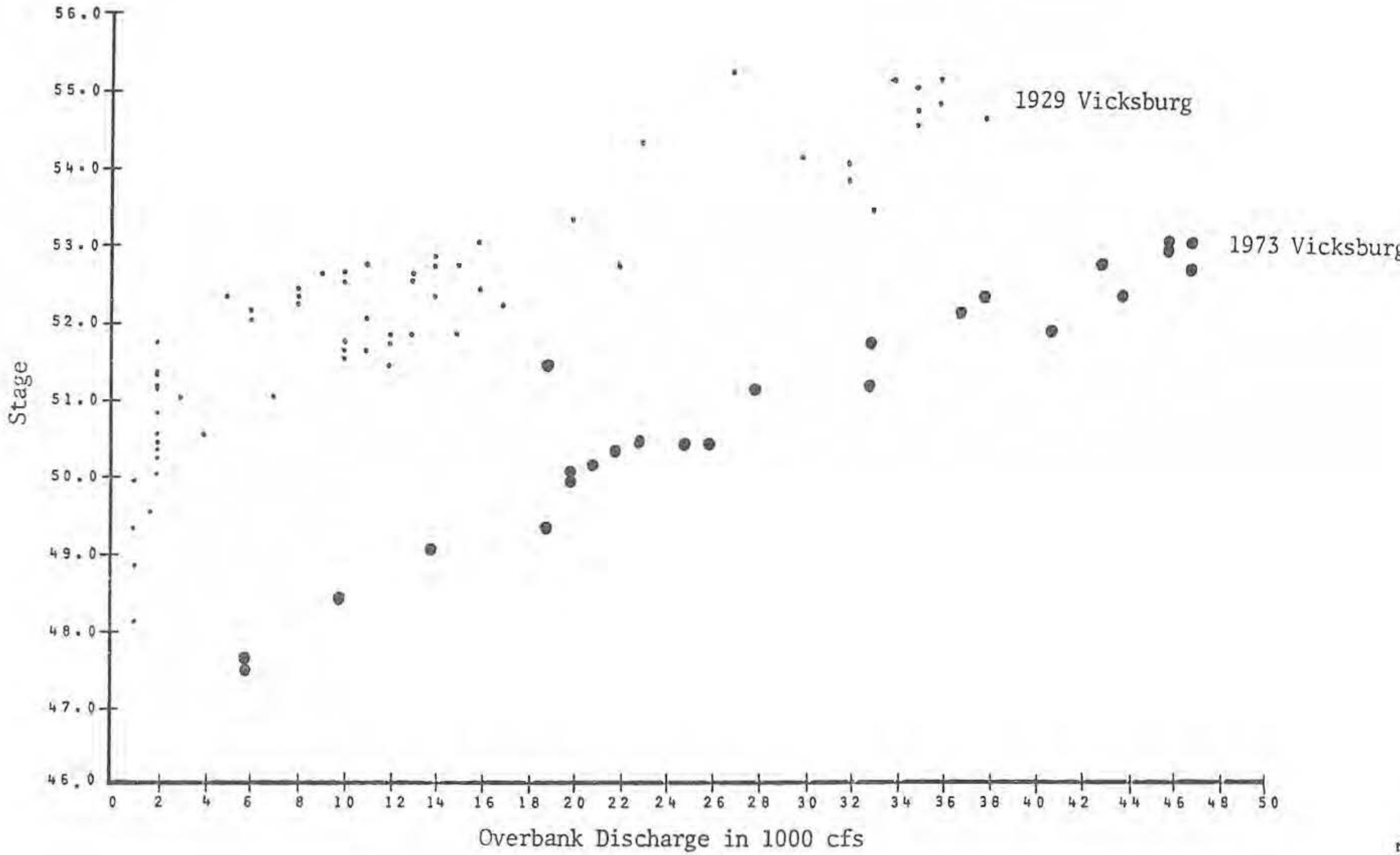

Figure 4.3. River Stage Versus Overbank Discharge Near Vicksburg for 1929 and 1973

values were taken at Lower Delta Point (precise location unknown). Zero gage at Lower Delta Point was 46.16 feet above mean Gulf level. The 1929 data were much more variable than the 1973 data, possibly because of variation of flow-measurement techniques in 1929. However, stage-discharge relationships are reasonably well defined for both periods. Therefore, it appears that on the overbank, localized influences such as vegetation and channelization are sufficient to mask depth-velocity relationships but do not affect the relationship between average flow rate and river stage.

River confinement by levees is both detrimental and beneficial. It prevents the enrichment of agricultural lands which accompanies the deposition of waterborne fine material on protected areas. However, the rather large benefits derived from flood protection cannot be disregarded. According to personal communication from Mr. Michael Dace, III, of the St. Louis District, some farmers whose lands are unprotected by federal levees would accept spur levees over the more expensive closed levees. The purpose would be to allow controlled flooding with the accompanying benefit of deposition of fine materials.

Deposition of coarse materials on agricultural land is detrimental. In the absence of data necessary to evaluate the main channel as a source of coarse sediments which are deposited on overbank areas during floods, a theoretical approach must be used. The problems are 1) to determine the amount of coarse sediments in suspension above banks and 2) to determine if these sediments would be deposited on overbank areas.

An equation commonly used to calculate particle concentrations is:

$$\frac{C}{C_a} = \left\{\frac{(d-y)}{y} \; \frac{a}{(d-a)}\right\}^z \tag{4.1}$$

where C = the concentration of particles of a given size at a distance y above the bed,

d = mean depth of flow,

y = height of point above river bed,

a = some reference point above the river bed,

C_a = the concentration of particles of a given size at reference point a, and

w = settling velocity of the particles.

The exponent $z = w/ku_*$ (4.2)

where u_* is the shear velocity expressed as $u_* = \sqrt{gRS}$, and (4.3)

S = slope of the hydraulic grade line,

R = hydraulic radius (R = d for rivers),

g = acceleration due to gravity, and

k = von Karman's universal constant.

Toffaleti (1963) developed the following simplified relationships for the lower Mississippi River:

$$C = b(d/y)^z \tag{4.4}$$

where b is a constant equal to the particle concentration when d/y equals unity, and

$$z = \frac{\bar{U}w}{252Sd} \; . \tag{4.5}$$

Toffaleti (1968) states that the distribution of particles less than 0.062 millimeters was fairly uniform at Simmesport on the Atchafalaya River. He listed typical sediment size ranges and classifications as:

Description	Size Range (mm)	Geometric Mean Diameter (mm)	(ft)
Silts and Clays (S&C)	0.062		
Very Fine Sand (VFS)	0.062-0.125	0.0880	0.00029
Fine Sand (FS)	0.125-0.250	0.177	0.00058
Medium Sand (MS)	0.250-0.500	0.354	0.00116
Coarse Sand (CS)	0.500-1.000	0.707	0.00232

Using a typical section at Talbert's Landing on the Mississippi River it was assumed that bed-load gradation would be similar to that at Simmesport shown above. The following table shows the fraction of bed material and settling velocities for particle sizes in the assumed gradation:

Geometric Mean Diameter (ft)	Fraction of Bed Mtl.	Settling Velocity (ft/sec)	
		70^oF	80^oF
0.00029	0.071	0.023	0.025
0.00058	0.283	0.069	0.075
0.00116	0.564	0.171	0.183
0.00232	0.078	0.356	0.373

Other assumptions made for calculations were as follows:

	Case I	Case II
Q (main channel)	1,395,800 cfs	1,008,200 cfs
River width	3,830 ft	3,730 ft
Temperature	70°F	80°F
Slope	0.0000382	0.0000382
Area of flow	188,400 ft^2	173,900 ft^2
Ht. of water surface above elevation at which overbank flow begins	10 ft	3.5 ft

The assumed flows and widths correspond to data given for May 5, 1973 and June 12, 1973, respectively. The coefficient b from equation 4.4 was assumed to be the same as that determined for the commensurate particle size by Toffaleti (1968).

The above assumptions were used in equations 4.4 and 4.5 to make determinations of sediment transport. The resulting determinations are given in tabular form. Quantities are given in both tons per day per square foot ($t/d/ft^2$) and parts per million (ppm).

Sediment Transported

Height (ft) Above River Bed	Case I Geometric Mean Diameter (ft)				Case II Geometric Mean Diameter (ft)			
	0.00029		0.00058		0.00029		0.00058	
	$t/d/ft^2$	ppm	$t/d/ft^2$	ppm	$t/d/ft^2$	ppm	$t/d/ft^2$	ppm
1	7.79	389	7.29	364	4.24	721	4.34	227
10	4.95	274	0.87	43	2.84	181	0.62	30.0
30	3.40	170	0.19	9.5	2.00	128	0.15	9.6
39.2	3.00	150	0.12	6.0				
43.1					1.65	105	0.09	5.8
46.2					1.62	103	0.08	5.10
49.20	2.69	134	0.08	3.99				

To examine the possibility of material being lifted or maintained in suspension, Toffaleti's (1968) version of Einstein's weight-to-lift ratio was used. This equation is

$$\frac{W}{L} = \frac{T}{U^2} 10^4 D \qquad (4.6)$$

where W = weight of sediment particle underwater,

L = lift force on bed particle,

T = temperature dependent variable (0.063 for temperature = $70^{\circ}F$), and

D = particle size diameter.

Assuming a maximum weight-to-lift ratio (W/L) of unity and T equal to 0.063, the minimum velocities required to move sediments on the overbank at a water temperature equal to $70^{\circ}F$ may be calculated from equation 4.6. For geometric mean diameters of 0.00029 ft. and 0.00058 ft. the minimum velocities are 0.43 ft/sec and 0.60 ft/sec, respectively.

Overbank velocities given for the Vicksburg area in tables 4.1, 4.2, and 4.3, indicate average velocities which are greater than those needed to transport fine sand. Such overbank velocities will not only transport the suspended sediment reaching the overbank but will cause local scour. Deposition will occur only where velocities are less than about 0.43 ft/sec and will be a combination of material supplied by mainstream flow and scour from the overbank. Therefore, deposition of sediment on the overbank will generally be determined by the local configuration (either manmade or natural) of a particular area.

The preceding determinations are very sensitive to assumptions and tend to overestimate the amount of sediment in transport. They indicate the presence of fine sand above bank in the main channel. However, the concentration of fine sand and larger materials at or above the river bank elevation is relatively small. Because it appears from theoretical considerations that concentrations of fine sands are very small near the surface in the main channel, and because velocities on the overbank appear to be greater than the minimum required to keep fine sands in suspension, it is unlikely that the main channel is a significant source of sands deposited on the overbank during floods.

To evaluate effects of confinement and nonconfinement on sediment deposition in overbank areas, 13 cross sections were selected for comparisons of 1974 conditions with those existing during the decade 1879 to 1889. Cross sections were taken at intervals of approximately 10 miles beginning at mile 44.2 and ending at mile 169.8 above Cairo. At most of the cross sections,surveys made during the 1800's did not extend the full width of the flood plain.

At any given cross section, deposition and scour depend on relatively localized factors such as alignment of the river, channel stabilization measures instituted, and development associated with the various forms of land use on the flood plain.

The majority of channel configuration changes are attributable to channel stabilization structures, except at Kaskaskia Island where the Mississippi River captured a part of the Kaskaskia River and formed a cutoff which shortened the Mississippi River by about 11 miles. The old channel subsequently filled with sediment. The majority of changes on the flood plain are attributable to activities of riparian owners and installation of drainage facilities which were accomplished under authority of the various drainage districts.

The specific effect of levees is indistinguishable from effects of other factors which influence scour and deposition on the overbank. Although the topographic data were insufficient for detailed analysis of change, it appears that in spite of considerable flood-plain development, there has been relatively little change in the valley cross sections during the last 100 years.

Water-surface profiles for annual high and low stages in the Middle Mississippi River for the period, 1967 through 1974, are shown in Figures 4.4 through 4.11. The method used for Figures 4.4 through 4.7 was to select annual maximum and minimum stages at St. Louis gage, then plot corresponding stages at all other stations for that date. For Figures 4.8 through 4.11, annual maximum and minimum stages at each station were plotted irrespective of date of occurrence. Average slope of the annual water-surface profiles shown in Figures 4.4 through 4.7 and the average slope of these for the entire period from 1967 through 1974 is presented in Table 4.4. Also shown in Table 4.4 are slopes of annual maximum and minimum water-surface profiles and the average slope for the period, 1967 through 1974, for selected reaches of the Upper Mississippi, Missouri, and Illinois Rivers.

Although there is considerable variability in slope of the water-surface profile from year to year in each reach, there is no discernible time trend. However, as shown in Figure 4.4, average slope of the high-water profile is steeper than the low-water profile for the Middle

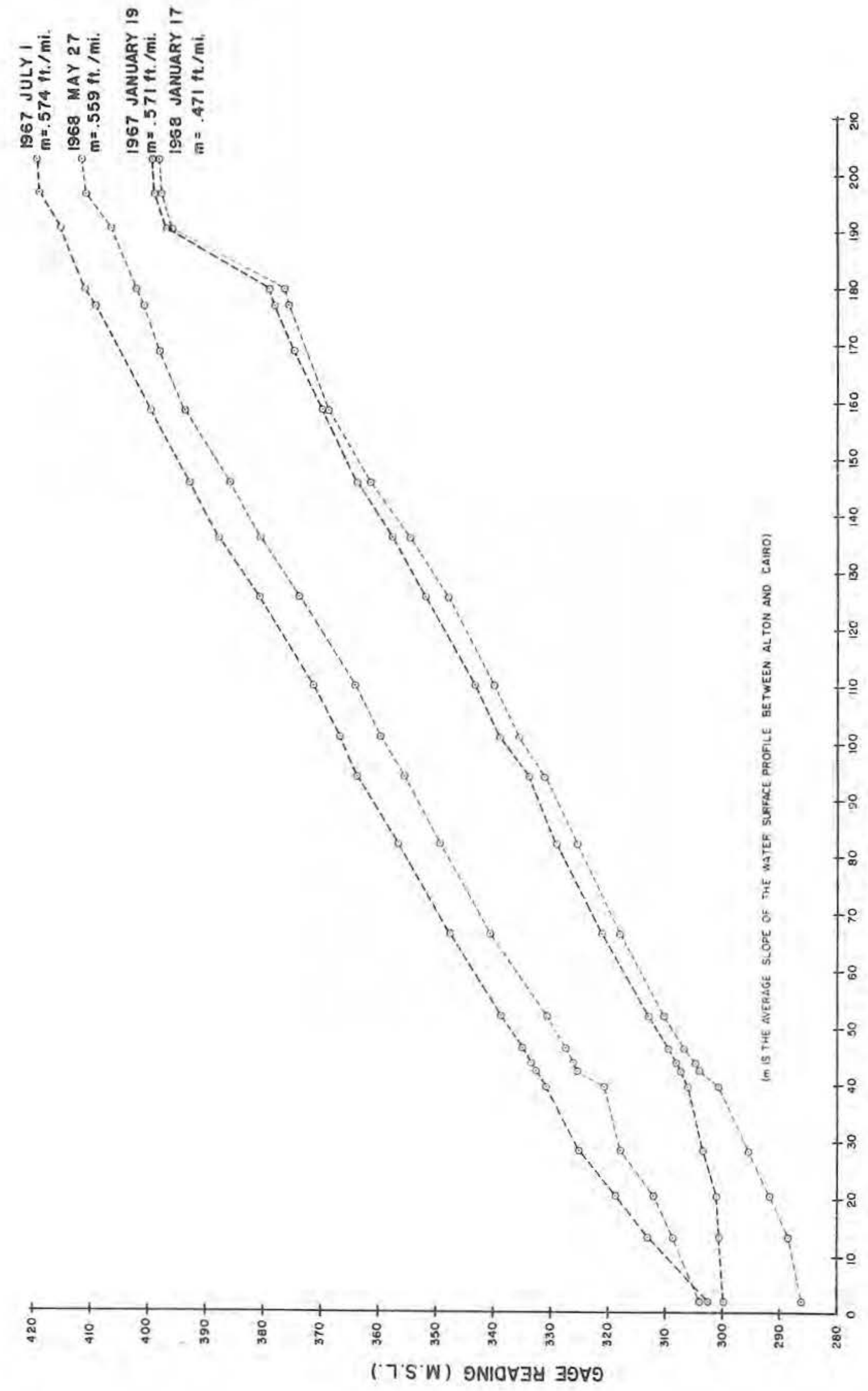

Figure 4.4 Surface Profiles of the Mississippi River Between Alton and Cairo for Maximum and Minimum Stages at St. Louis for 1967 and 1968

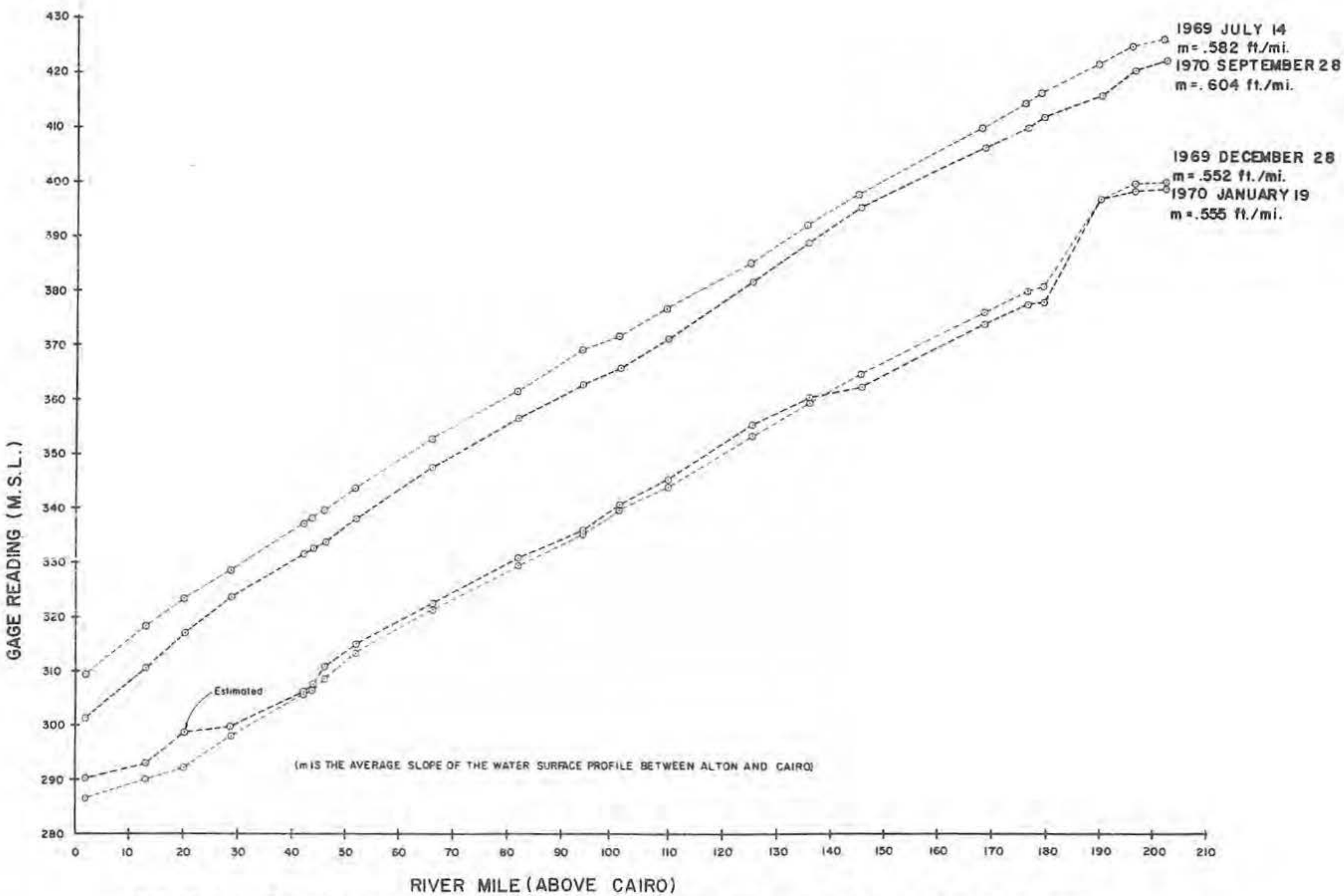

Figure 4.5 Surface Profiles of the Mississippi River Between Alton and Cairo for Maximum and Minimum Stages at St. Louis for 1969 and 1970

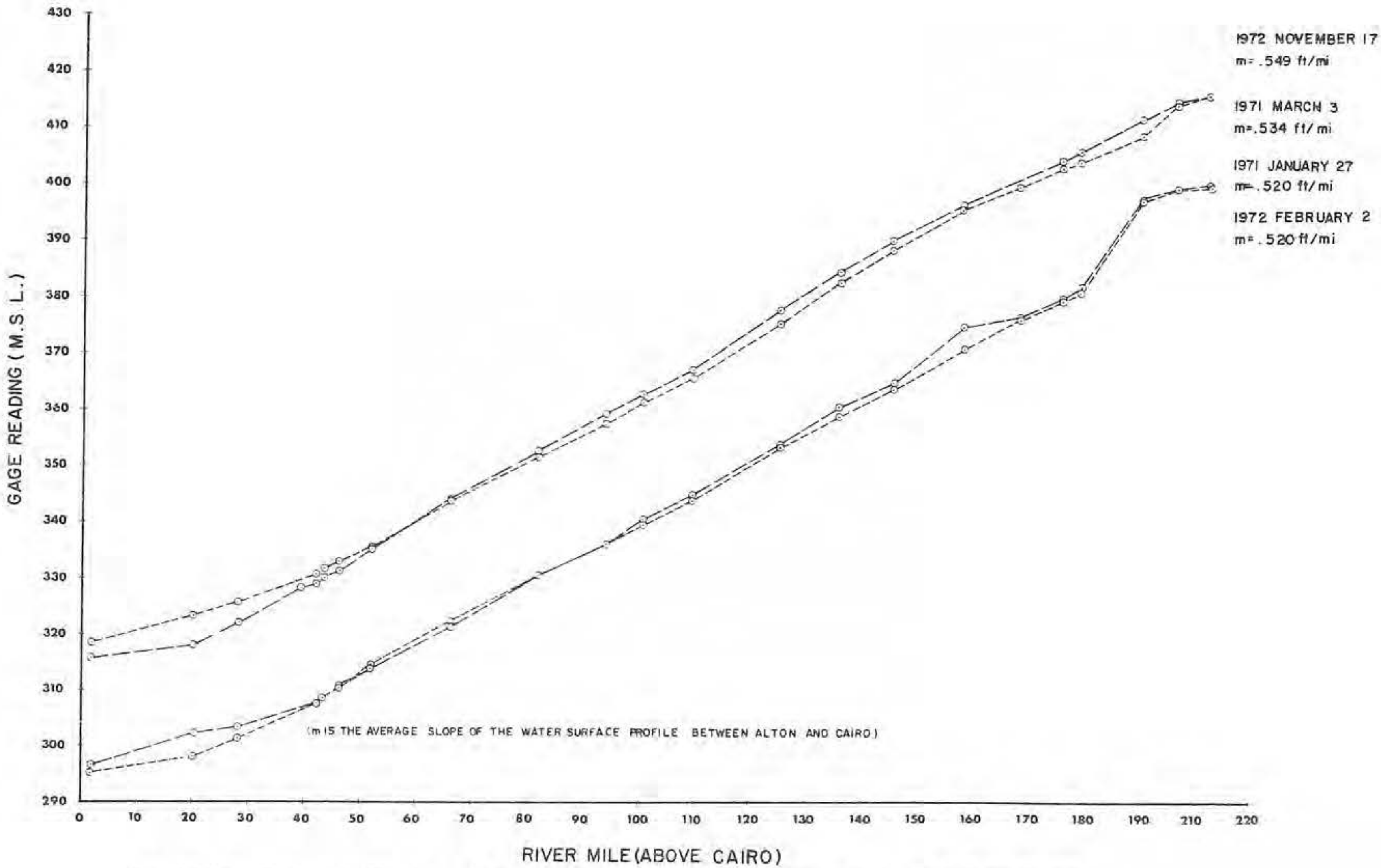

Figure 4.6 Surface Profiles of the Mississippi River Between Alton and Cairo for Maximum and Minimum Stages at St. Louis for 1971 and 1972

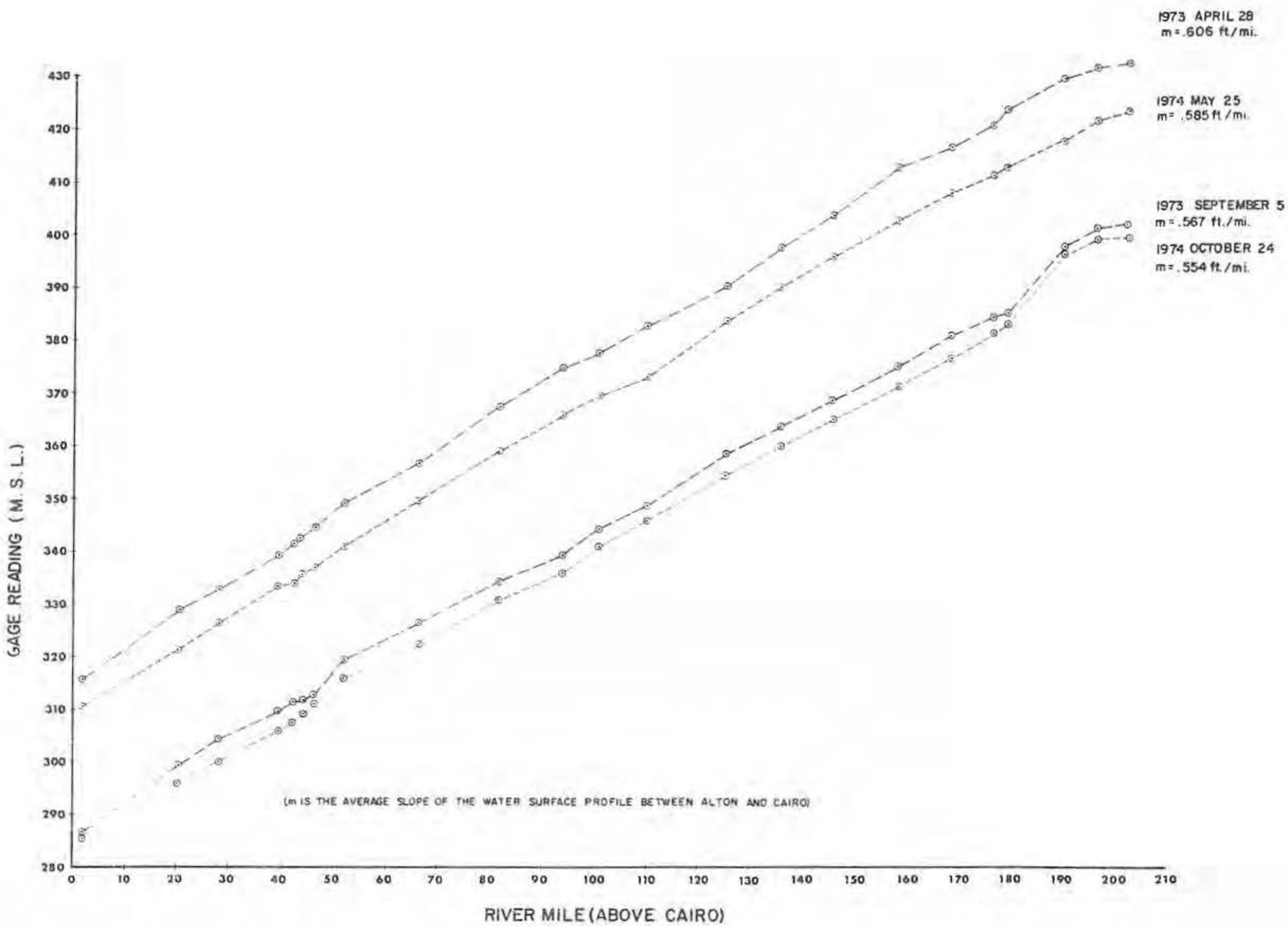

Figure 4.7 Surface Profiles of the Mississippi River Between Alton and Cairo for Maximum and Minimum Stages at St. Louis for 1973 and 1974

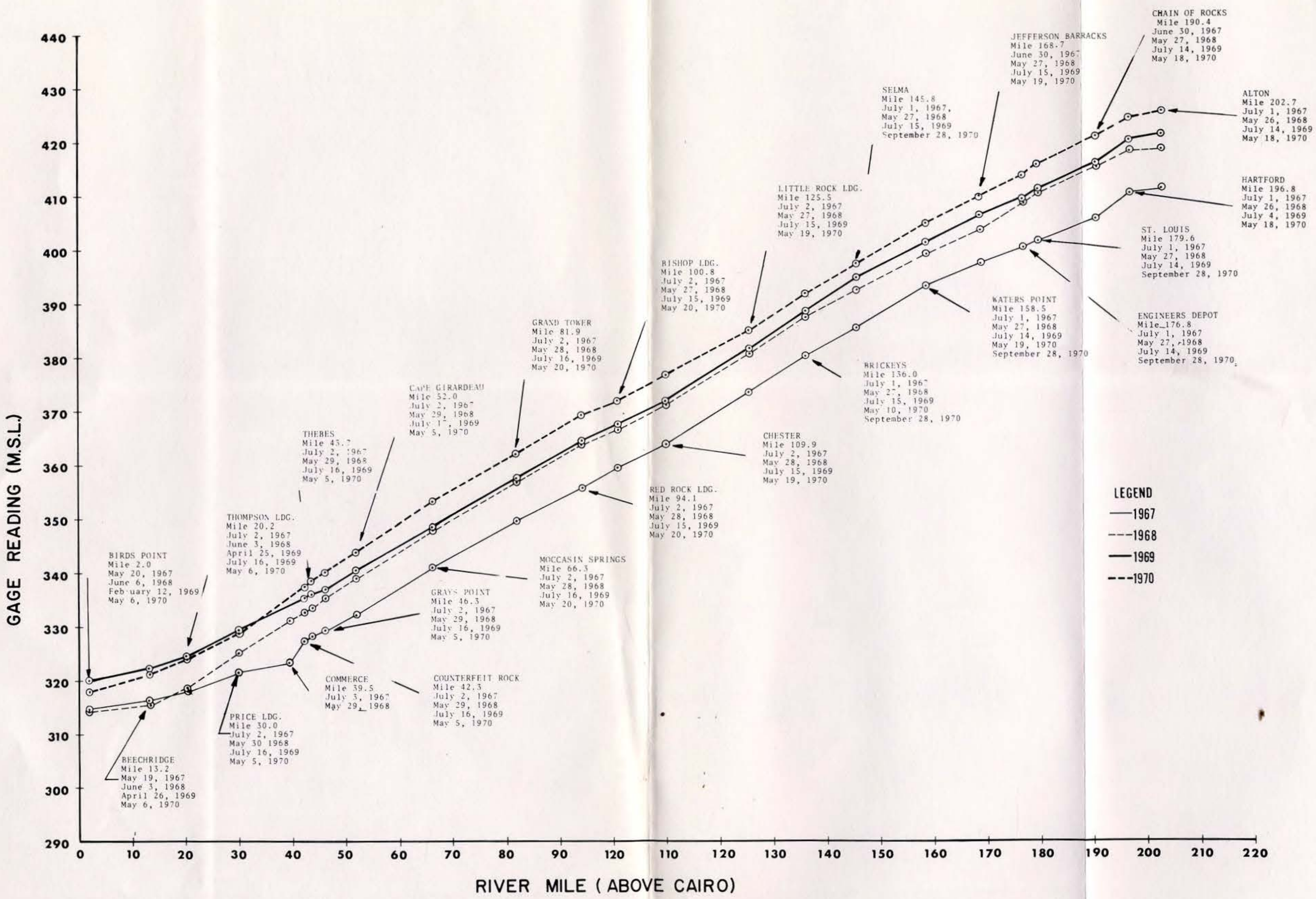

Figure 4.8 Surface Profiles of Mississippi River at Stations Between Alton and Cairo for Maximum Stages for 1967 Through 1970

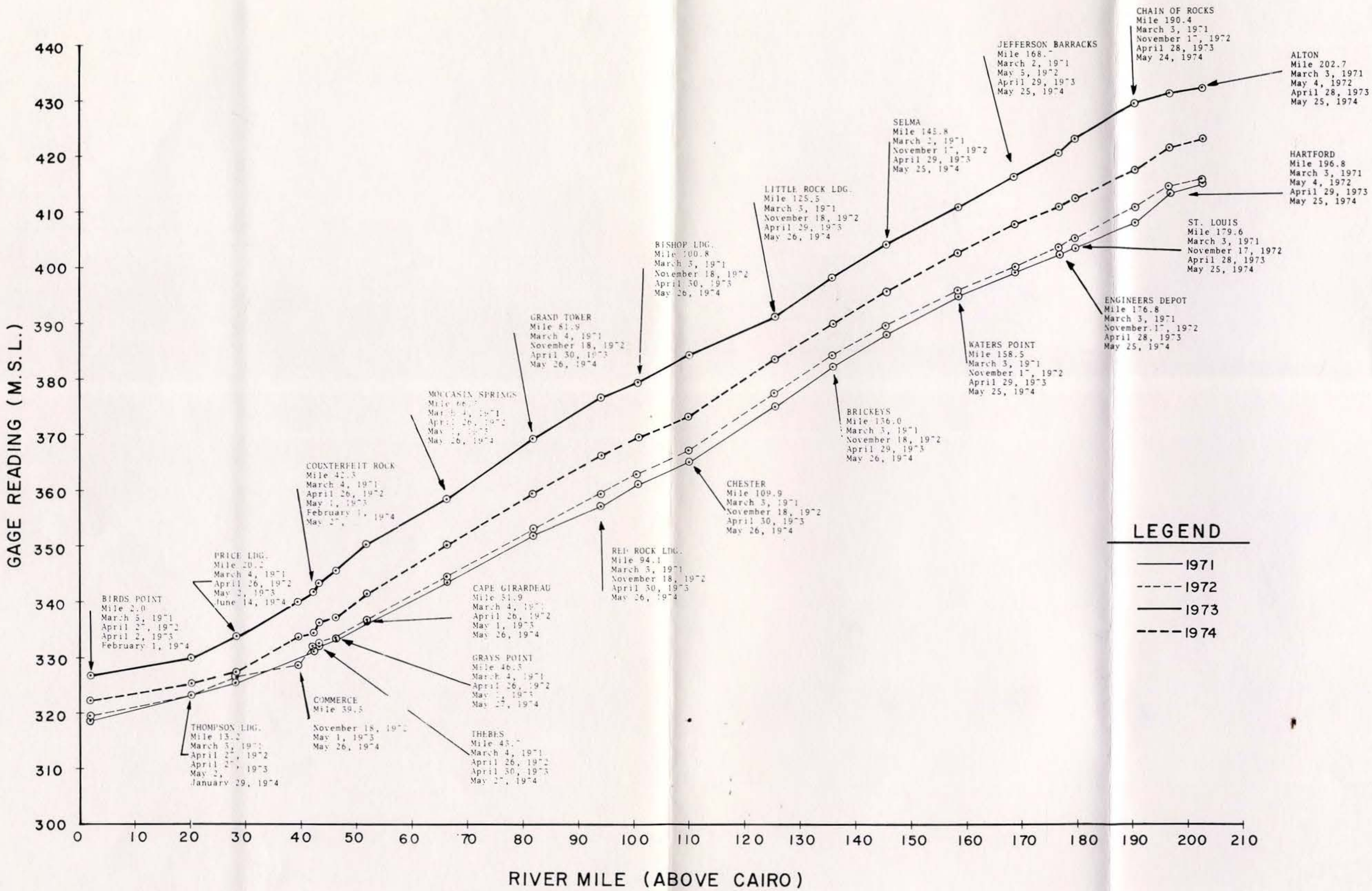

Figure 4.9 Surface Profiles of the Mississippi River at Stations Between Alton and Cairo for Maximum Stages for 1971 Through 1974

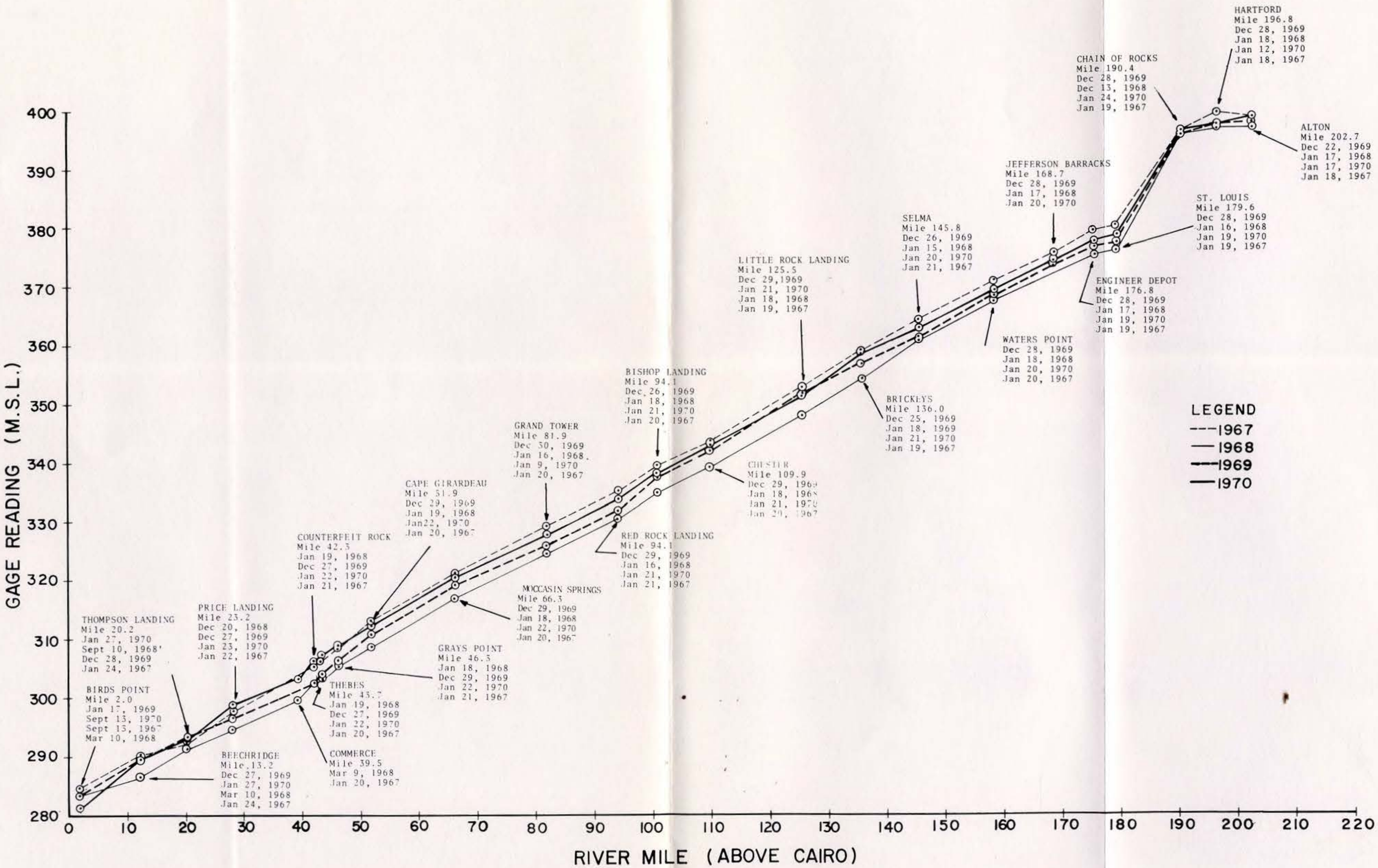

Figure 4.10 Surface Profiles of the Mississippi River at Stations Between Alton and Cairo for Minimum Stages for 1967 Through 1970

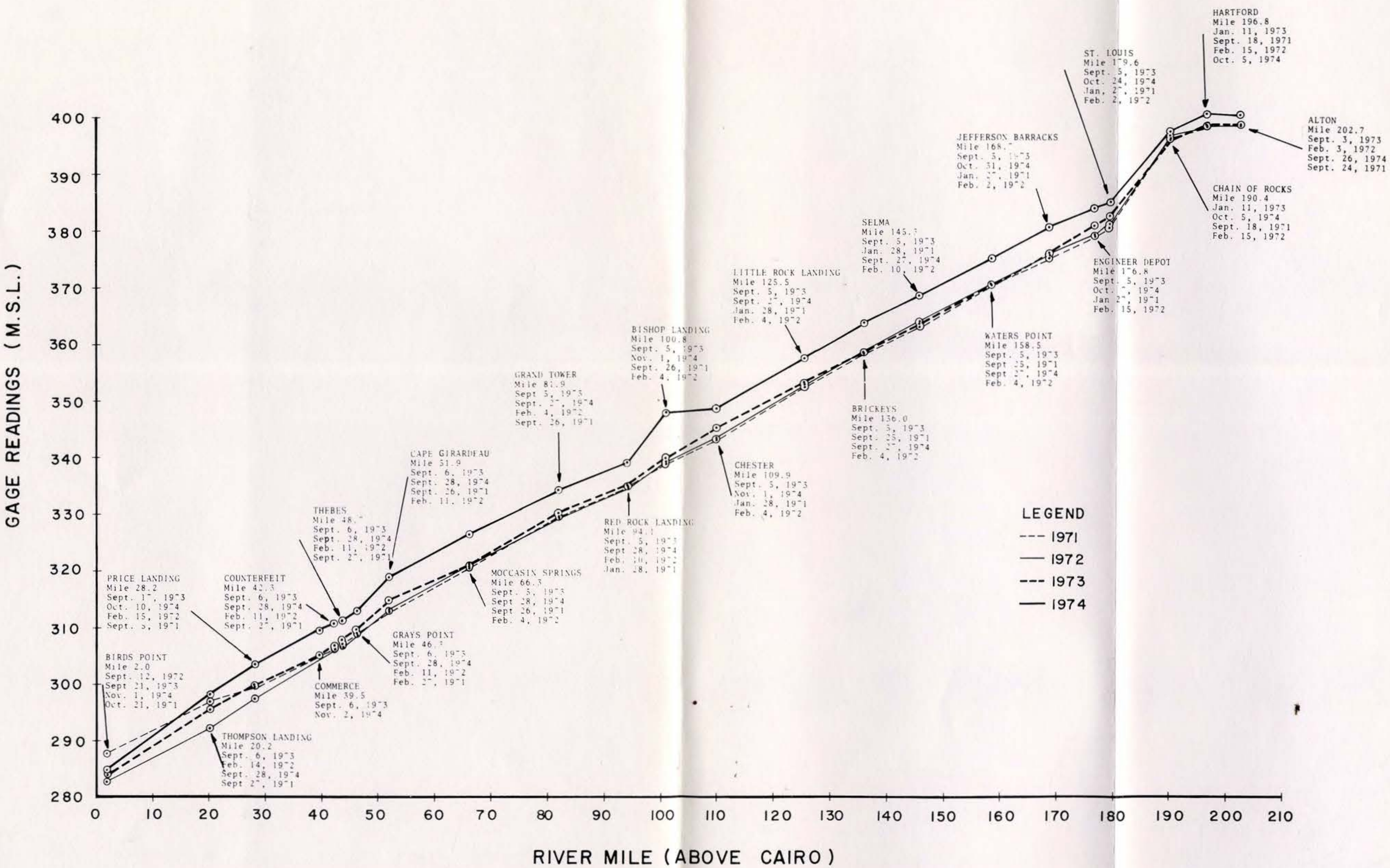

Figure 4.11 Surface Profiles of the Mississippi River at Stations Between Alton and Cairo for Minimum Stages for 1971 Through 1974

Table 4.4 Average Slope of Water-surface Profiles for High- and Low-flow Conditions in Selected River Reaches for Individual Years Between 1967 and 1974 and Average Slope for Each Flow Condition for the Period.

		1967	1968	1969	1970	1971	1972	1973	1974	AVE
Mississippi River from Alton, Illinois to Birds Point, Missouri	High	.574	.559	.582	.604	.519	.531	.588	.566	.565
	Low	.571	.471	.552	.555	.557	.530	.507	.589	.542
From Hermann on the Missouri River to St. Louis on the Mississippi River	High	.880	.878	.811	.830	.851	.866	.781	.810	.838
	Low	.948	.934	.941	.938	.929	.923	.928	.941	.935
Mississippi River from Hannibal, Missouri to Alton, Illinois	High	.317	.456	.402	.415	.473	.467	.402	.432	.421
Mississippi River from Keokuk, Iowa to Alton, Illinois	High	.426	.451	.413	.419	.470	.470	.415	N.A.	.438
From Meredosia on the Illinois River to Alton on the Mississippi River	High	.087	.216	.109	.204	.192	.198	.142	.178	.166

Mississippi Reach (Alton to Birds Point), whereas the situation is reversed in the Missouri River Reach because the St. Louis gage is below the mouth of the Missouri River and the Chain of Rocks topographic control.

The primary function of dikes has been stabilization of the navigation channel. To a lesser extent, they have been used to initiate chute closures and to create storage space for dredging spoils. The earliest record of dike construction in the Mississippi River between Alton, Illinois and Head of Passes, Louisiana is in 1834 when dikes were constructed near river mile 194 above Cairo, Illinois. Most dike construction has occurred between the mouth of the Missouri River and Cairo (St. Louis Reach), a distance of about 195 river miles. Between 1870 and 1900, dike construction in the St. Louis Reach amounted to about 300 dikes with a cumulative length of about 285,000 feet. During this period, most construction took place upstream from Crystal City, Missouri (river mile 149) and tended to concentrate opposite settlements. About 27,000 feet of the total for this period were built upstream from the present Market Street gage (mile 179.7) to keep the river next to St. Louis harbor facilities.

Between 1900 and 1924 only about 60,000 feet of dikes were added to the St. Louis Reach. As shown in Figure 4.12, accelerated construction activity began about 1925 and continued through 1940. During that period, about 469,000 feet were built to bring the cumulative length to about 766,000 feet. From 1940 to 1955, construction activity decreased markedly. Only 85,000 feet were added during this period. Rate of construction increased again between 1955 and 1970. Beginning in 1970, construction of new dikes decreased by more than an order of magnitude from

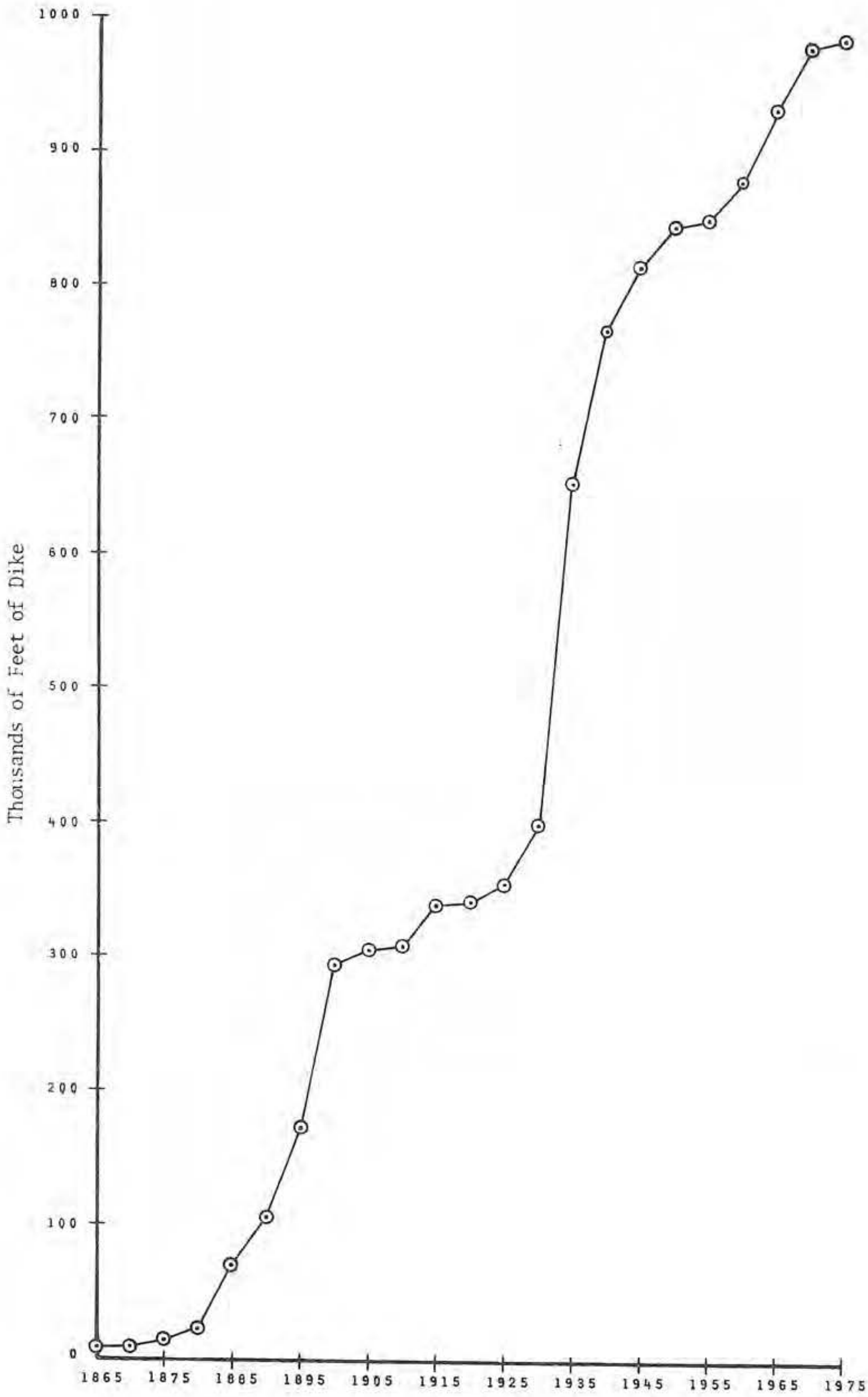

Figure 4.12. Cumulative Length of Dikes Constructed in St. Louis Reach, 1865-1975

the previous 5-year period. By 1975, about 1100 dikes with a cumulative length of 982,000 feet had been built in the St. Louis Reach.

Figure 4.13a shows the average top-bank widths of the St. Louis Reach as scaled from hydrographic surveys and aerial photographs at intervals of about 2 miles for selected years between 1908 and 1974. Top-bank width was taken as the distance between first vegetation. The average width decreased from about 3320 feet in 1908 to about 2370 feet in 1974, a decrease of about 29 percent. However, it should not be inferred from Figure 4.13a that the rate of decrease was necessarily uniform. There are insufficient determinations to describe the time distribution of change. It is clear that river width in this reach has decreased in response to dike construction activity.

As shown in Figure 4.14 for the reach between the White River and Cairo, Illinois (Memphis Reach; river mile 596 to 954 above Head of Passes), although dike construction was initiated in 1900 there was relatively little construction activity until 1956. In 1955 there were about 11,000 feet of dikes. Between 1956 and 1974, approximately 222 dikes with a cumulative total length of 505,000 feet were added. Figure 4.13b shows average top-bank width of the Memphis Reach for selected years. Unlike the St. Louis Reach, there is no obvious relationship between average top-bank width and dike construction for the Memphis Reach.

In the reach between Old River Structure and the White River (Vicksburg Reach; river mile 321 to 596), records show a construction date for only one dike prior to 1962. Hydrographic surveys show a limited number of dikes prior to 1962 but construction dates are not indicated. Between 1962 and 1974, there were 123 dikes built with a cumulative

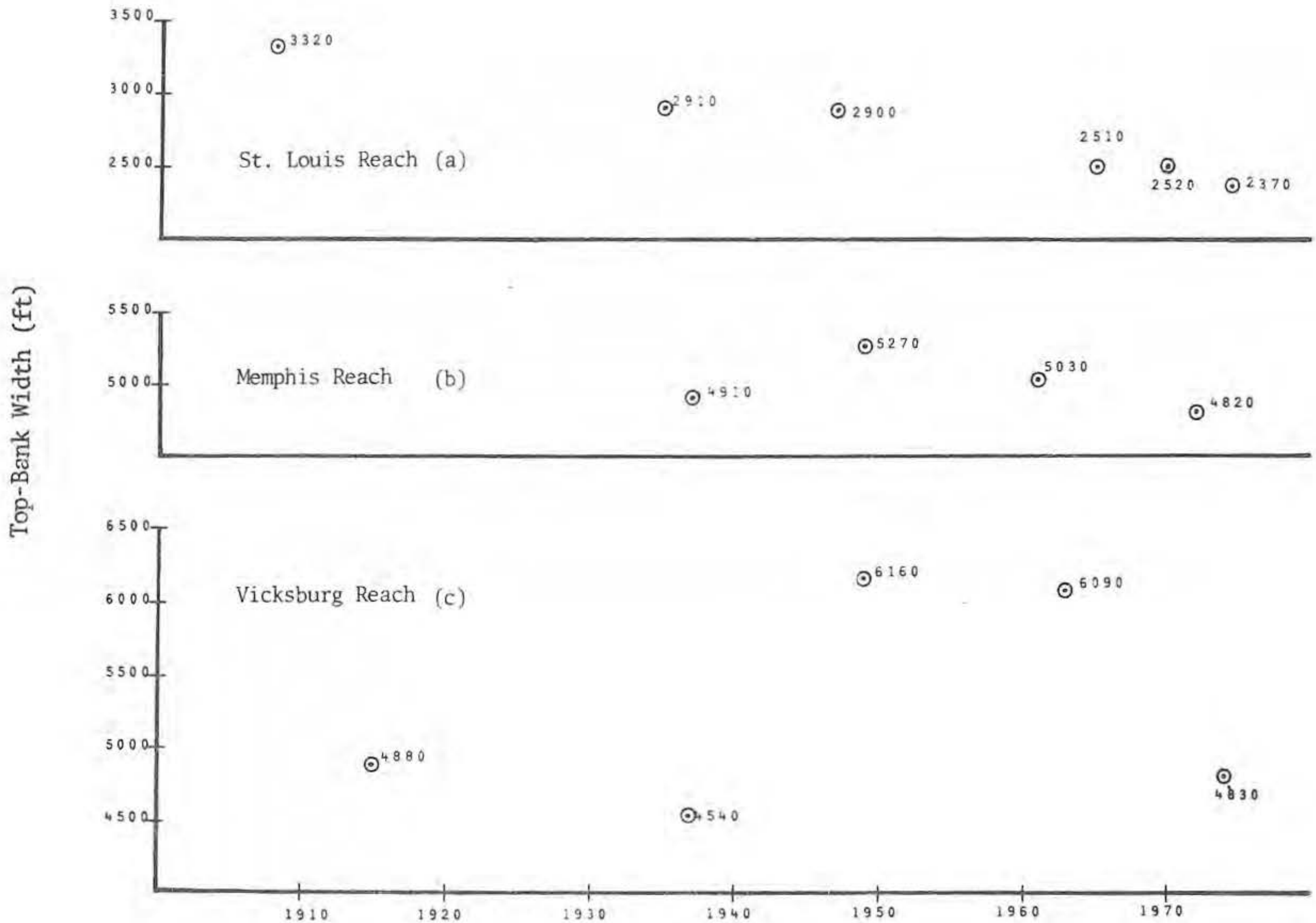

Figure 4.13 - Average Top-Bank Widths of the Mississippi River

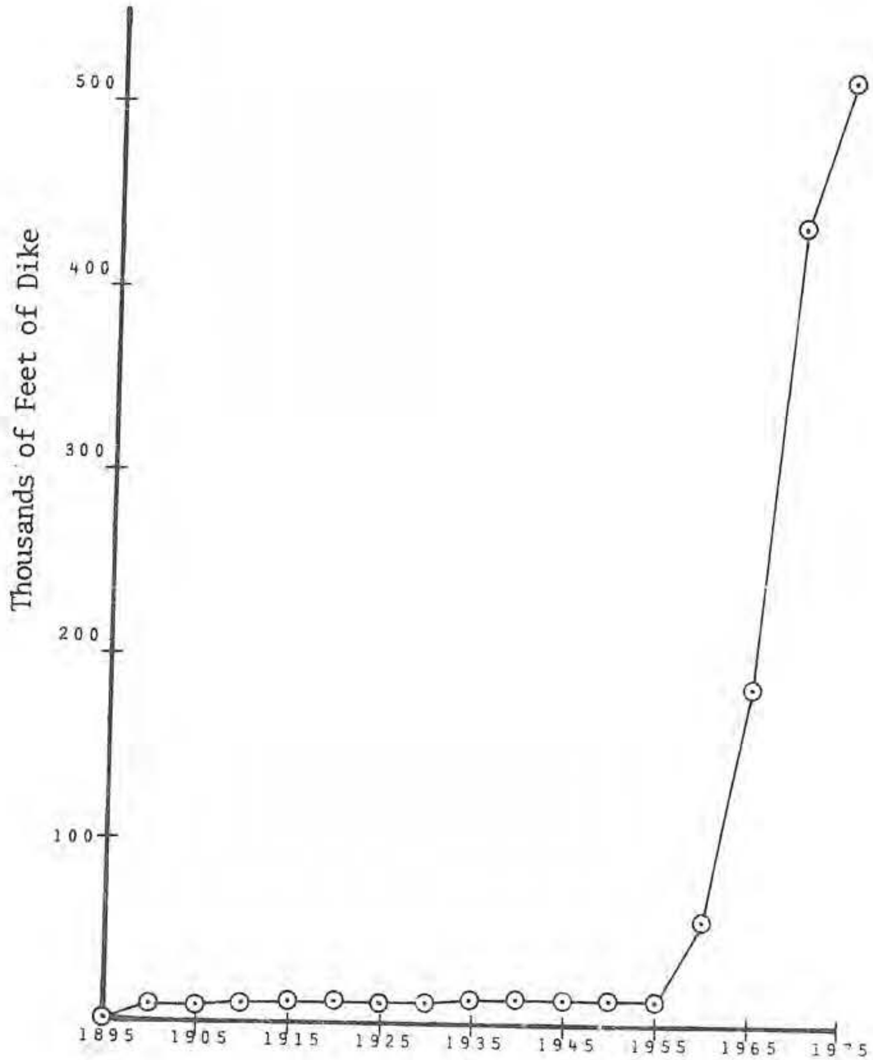

Figure 4.14 - Cumulative Length of Dikes Constructed in the Memphis Reach, 1900-1975

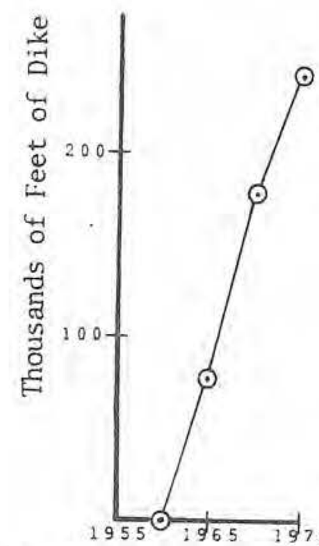

Figure 4.15 - Cumlative Length of Dikes Constructed in the Vicksburg Reach, 1955-1975

length of about 243,000 feet. Figure 4.15 shows the cumulative length of dikes constructed in this reach between 1955 and 1975. Figure 4.13c shows average top-bank widths for Vicksburg Reach for selected years. The decrease between 1963 and 1974 is nearly as large as the increase between 1937 and 1959. Dike construction in the St. Louis Reach was about 5030 feet/mile, in the Memphis Reach about 1400 feet/mile, and in the Vicksburg Reach about 890 feet/mile. In the Memphis Reach, average top-bank width is about twice and dike density in terms of feet per mile is only about one-fifth that in the St. Louis Reach. Therefore, a causal relationship between dike construction and changes in top-bank width in the Memphis Reach should not be inferred without further analysis. Because cumulative length of dikes per mile in the Vicksburg Reach was less than in the Memphis Reach and large bank-width changes have been observed both prior to and after dike construction, any association between dike construction and reduction of top-bank width in the Vicksburg Reach after 1963 is probably unwarranted at this time.

Because dikes constrict the channel (at least in the vicinity of individual dikes) it was necessary to determine if there have been associated changes in stage-discharge relationships over time. The analytical procedure was the same for all stations. The mean-daily discharges were plotted against mean-daily stages for every year of continuous record. Plots were on both arithmetic and logarithmic coordinates. The "average" stage-discharge curve for each year was estimated for fitting a smooth curve to the data by eye. Because the plotted points were approximately linear on the logarithmic coordinates, an estimated straight line of best fit was used. Flow rates were selected to be representative of low, medium bankfull, and overbank conditions. These fixed flow rates were used in conjunction with the stage-discharge curves to estimate prevailing stage for each flow rate for each year. Stages were then plotted as a function of time.

There was a number of years when bankfull conditions were not realized. Stages for these years were extrapolated from the logarithmic plots for the year in question. This method nearly always resulted in reasonable values of stage for bankfull flow conditions. For flows greater than bankfull, the difference between estimated stages was often 4 feet or more for adjacent years. This was particularly evident when extrapolations were made from rating curves developed for drought years. Because of the extreme variability of above bankfull estimates and because there are relatively few observations above bankfull to use as controls, it was not possible to make an evaluation of changes in flood stages with respect to time as influenced by levee construction. Therefore, no inferences were drawn with respect to effects of levee construction on stage-discharge relationships.

The procedure outlined above was followed for the following stations:

1. Hermann on the Missouri River
2. St. Louis
3. Chester
4. Thebes
5. Metropolis on the Ohio River
6. Memphis
7. Vicksburg

Continuous records were not kept for the above stations until 1930 or later. For that reason and because flow-measuring techniques were not standardized for earlier years, the principal part of the stage-change analysis is based on the post-1930 record.

Figure 4.16 shows stage versus time for selected flows in the Missouri River at Hermann, Missouri. Flood stage at Hermann is 21 feet. Discharge at flood stage is approximately 211,800 cfs. Stages were not estimated for overbank conditions unless an observed flow was greater than 211,800 cfs. For the period, 1930 to 1974, it appears that stages have increased for all flows between 64,700 cfs and 337,000 cfs. Stage increases have ranged from about 2 feet for 64,700 cfs to about 3.5 feet for 337,000 cfs. It was not within the scope of this project to collect data which might relate to stage behavior at this station.

Figure 4.17 shows stage versus time for selected flows in the Mississippi River at St. Louis, Missouri. It is clear from the plotted data that, since 1934, stages have decreased for flows less than 280,900 cfs. With the statistic Z at the 2-percent level of significance as a test criterion, a downtrend with time was also found to exist for bank-full conditions (501,300 cfs). It appears that since 1934, stages have decreased about 1.4 feet for all flows between 501,300 cfs and 154,800 cfs.

Prior to 1934, relatively few flow measurements were made at the St. Louis gage. For those years when there were sufficient data to define a stage-discharge relationship, it was possible to estimate stages corresponding to the same flow rates which were used for the post-1934 stage-change analysis (Fig. 4.17). Those estimates are shown in the following table:

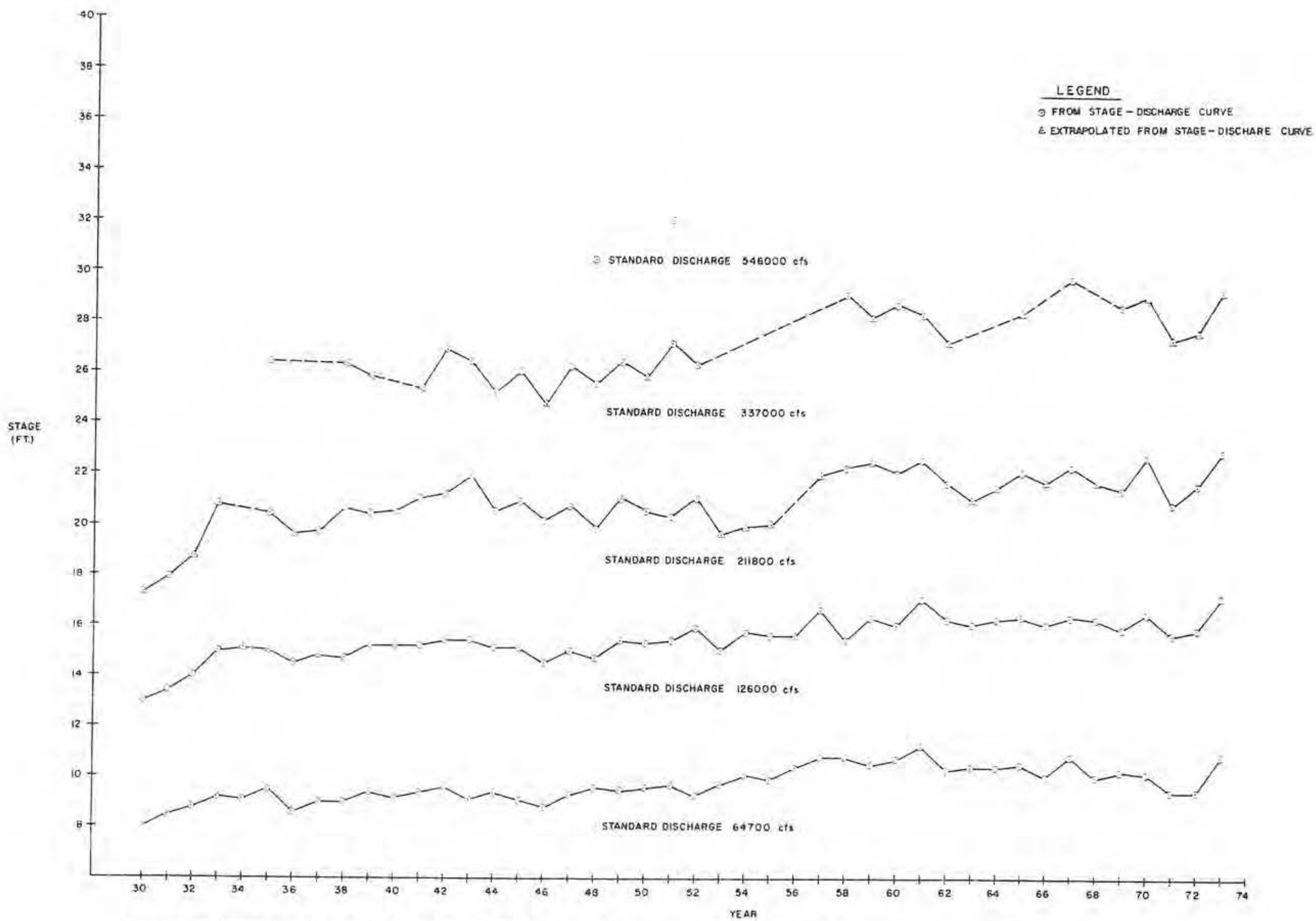

Figure 4 16 Estimated River Stage for Selected Flows in the Missouri River at Hermann Between 1930 and 1974

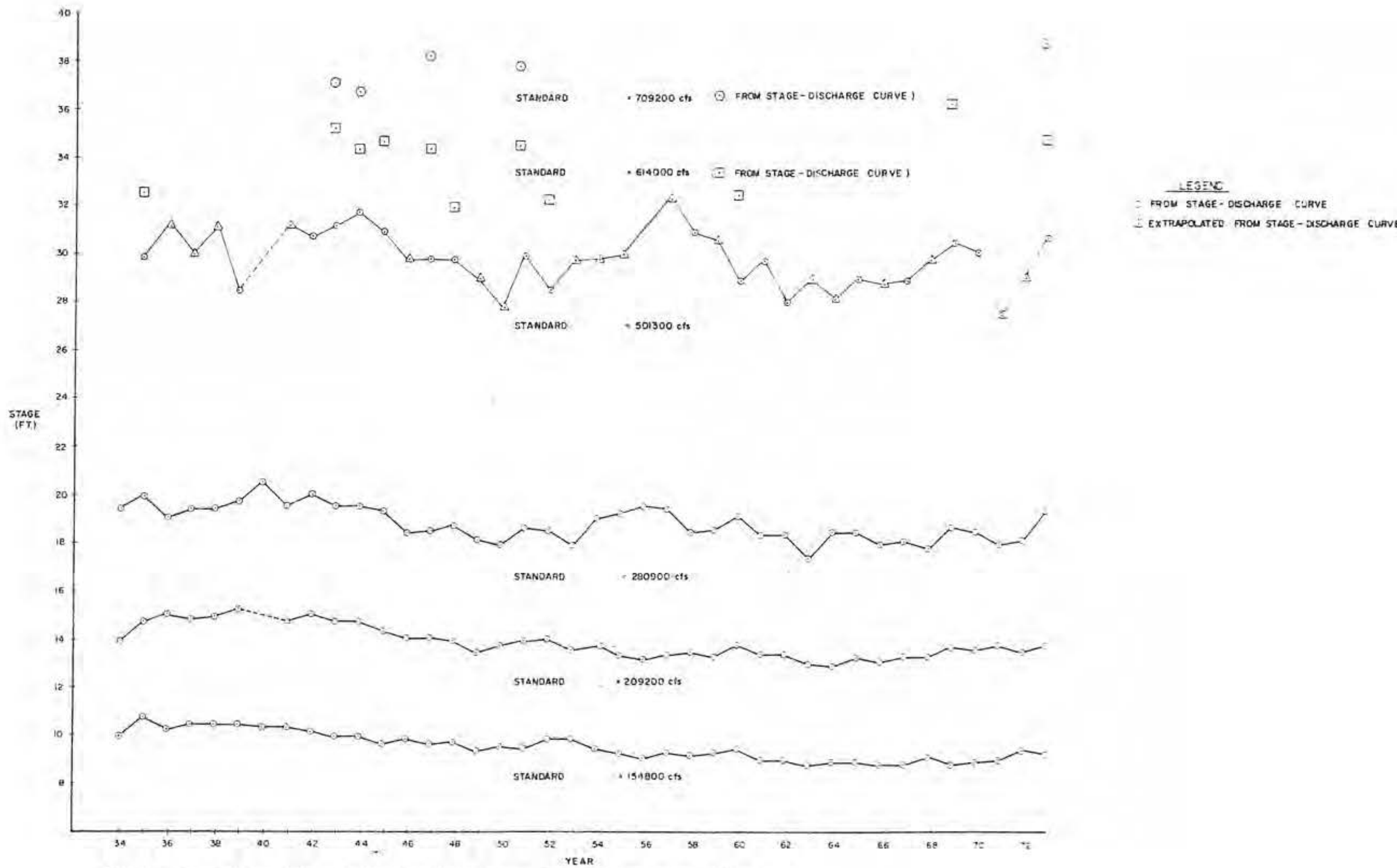

Figure 4.17 Estimated River Stage for Selected Flows in the Mississippi River at St. Louis Between 1934 and 1973

Discharge (cfs)	(Stages are in feet) 1881	1900	1903	1904	1934
501,300	25.2	26.5	27.8	28.5	29.9
280,900	18.0	18.7	20.0		20.0
209,200	15.1	15.4	16.0		14.8
154,800	11.5	12.5	12.2		10.8

The indication is that, for flows greater than 280,900 cfs, stages increased during the period from 1881 to 1934. During the same period, flows less than about 209,200 cfs probably passed the St. Louis gage at progressively lower stages.

Prior to about 1930, velocities were measured with a variety of equipment and in accordance with a variety of field procedures. Methods for calculating flow rates from velocity and sounding data were not standardized. Although equipment and field and calculation procedures are now standardized, the U.S. Geological Survey still occasionally describes accuracy of their published mean daily discharge figures at St. Louis as "good". This classification means that 95 percent of the mean daily flows are within 10 percent of the true value. If pre-1934 flows were determined according to contemporary techniques, they would probably differ from those shown in the preceding table. It seems reasonable to expect that the difference could be 20 percent or more.

If flows measured prior to 1934 are in error, then stages which correspond to flows shown in the preceding table are in error. As discussed previously, plots of mean daily stage versus mean daily discharge for each year after 1934 were nearly linear on logarithmic coordinates. A straight line fitted to these data implies an approximate exponential relationship between stage and flow of the form

$$S = MQ^n$$

where S = stage,

Q = flow rate,

n = slope of the straight line fitted to a plot of the logarithm of stage versus the logarithm of discharge, and

M = a constant (the stage which prevails when the flow rate is unity).

If the exponential relationship between stage and discharge is assumed to be a valid approximation, the stage-estimate error resulting from a flow measurement error can be expressed as

$$E_s = \{(\frac{Q_m}{Q_t})^n - 1\} \times 100$$

where E_s = percent error in stage estimate,

Q_m = measured flow rate,

Q_t = true flow rate, and

n = exponent as determined from the stage-discharge relationship.

Exponents (n) for the post-1934 years range from 0.42 to 0.51. If the same general stage-discharge relation is assumed to hold for the pre-1934 period and if the flow measurement error is taken to be 20 percent (Q_m/Q_t = 0.8 or 1.2), then the percent error in stage estimate (E_s) can be shown to be approximately ±10 percent. Therefore, if flow measurements prior to 1934 were systematically 20 percent too high, estimated stages shown in the previous table should be increased by about 10 percent, whereas the converse is true if measured flows were less than the true flows. The following tables show stage-change trends as they might appear if the pre-1934 measurements were 20 percent too high and 20 percent too low, respectively.

For $Q_m/Q_t = 1.2$ (Measured flows greater than the true value):

Discharge (cfs)	1881	1900	1903	1904	1934
	(Stages are in feet)				
501,300	27.7	29.2	30.6	31.4	29.9
280,900	19.8	20.6	22.0		20.0
209,200	16.6	16.9	17.6		14.8
154,800	12.7	13.8	13.4		10.8

For $Q_m/Q_t = 0.8$ (Measured flows less than the true value):

Discharge (cfs)	1881	1900	1903	1904	1934
	(Stages are in feet)				
501,300	22.7	23.8	25.0	25.6	29.9
280,900	16.2	16.9	18.0		20.0
209,200	13.6	13.9	14.4		14.8
154,800	10.3	11.2	11.0		10.8

Figures in the two preceding tables demonstrate that differences between early and contemporary flow determinations (if they exist) would lead to conclusions about direction and rate of change of stage between 1881 and 1934 which are different from those indicated by the existing record. Therefore, unqualified acceptance of pre-1934 stage-change behavior is not justifiable without corroborating evidence that early and contemporary flow determinations are reasonably comparable.

Figure 4.18 shows stage versus time for selected flows in the Mississippi River at Chester, Illinois. Flood stage at Chester is 27.0 feet which corresponds to a flow of about 440,000 cfs. With the statistic Z at the 20-percent level of significance as a test criterion, there

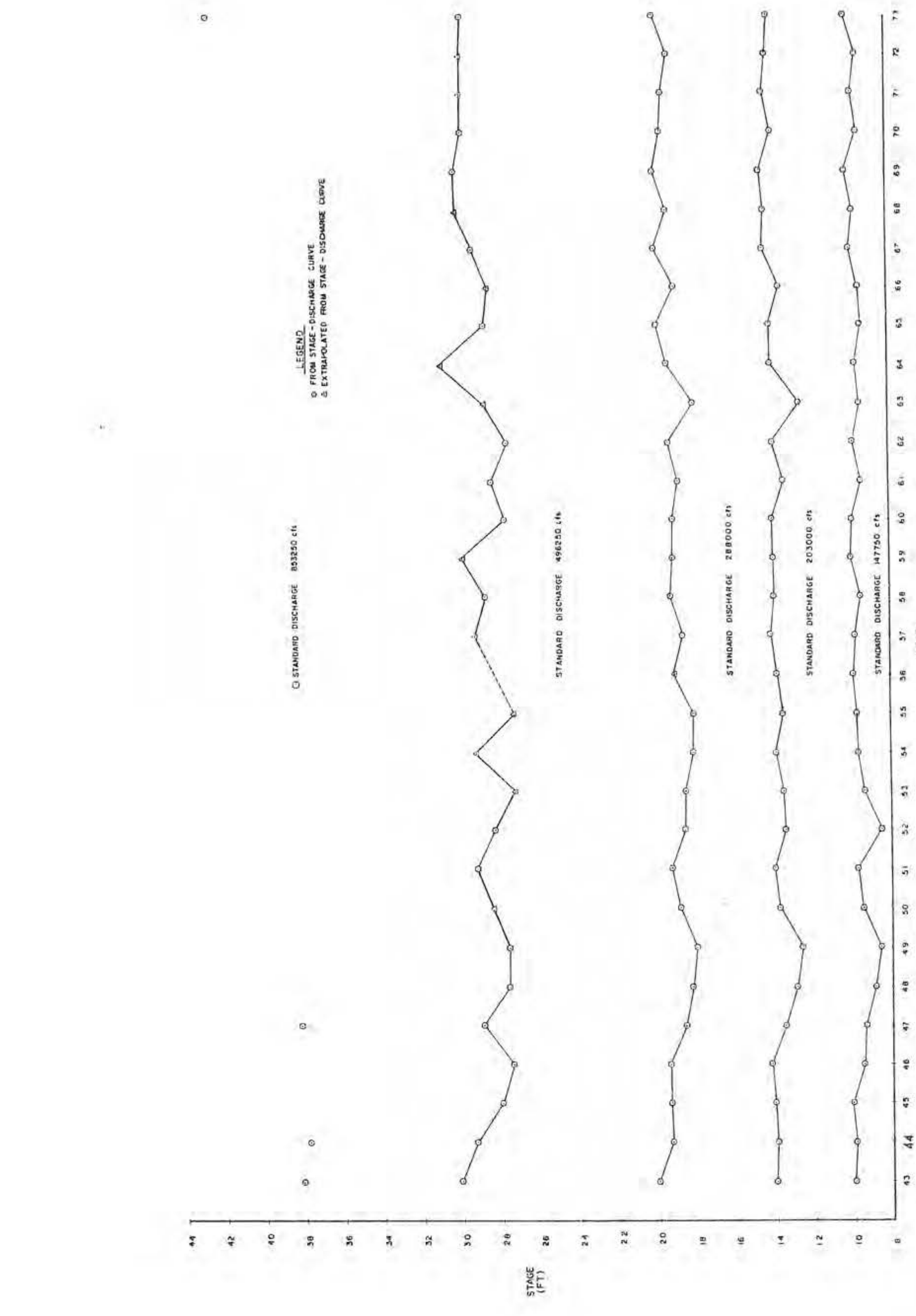

Figure 4-18 Estimated River Stage for Selected Flows in the Mississippi River at Chester Between 1943 and 1973

were no discernible trends in stages for flows less than 496,250 cfs for the period, 1943 through 1973.

Figure 4.19 shows stage versus time for selected flows representing low, mid-range, and bankfull conditions in the Mississippi River at Thebes, Illinois. Stages for low flows appear to have decreased between 1934 and 1973. For instance, with the statistic Z at the 1-percent level of significance as a test criterion, stages for flows between 87,000 cfs and 135,000 cfs decreased about 3 feet and 3.5 feet, respectively, between 1934 and 1973. However, stages for mid-range flows (about 219,000 cfs) remained practically unchanged over the same period.

Flood stage at Thebes is about 33.0 feet. In 1941 a stage of 33.0 feet corresponded to a flow of nearly 572,000 cfs,whereas by 1973 the same stage corresponded to a stage of about 481,000 cfs. Although it appears that the bankfull capacity has decreased since 1934, the decline has not been continuous. From 1934 to about 1963, stages for flows between 481,000 cfs and 572,000 cfs remained essentially unchanged. Because stages for mid-range flows also remained nearly constant, it may be inferred that stages for all intervening flows from about 219,000 cfs to about 572,000 cfs remained relatively stable over the period. However, between 1963 and 1973, stages for the approximate bankfull condition (481,000 cfs to 572,000 cfs) increased steadily to about 2.5 feet over the 1962 condition. Therefore, it appears that for the post-1963 period, stages for mid-range flows remained constant while stages increased for those higher flows near the bankfull condition.

Because of backwater effect from the Ohio River it is common to find 2 feet or more variation in stage at Thebes for discharges greater

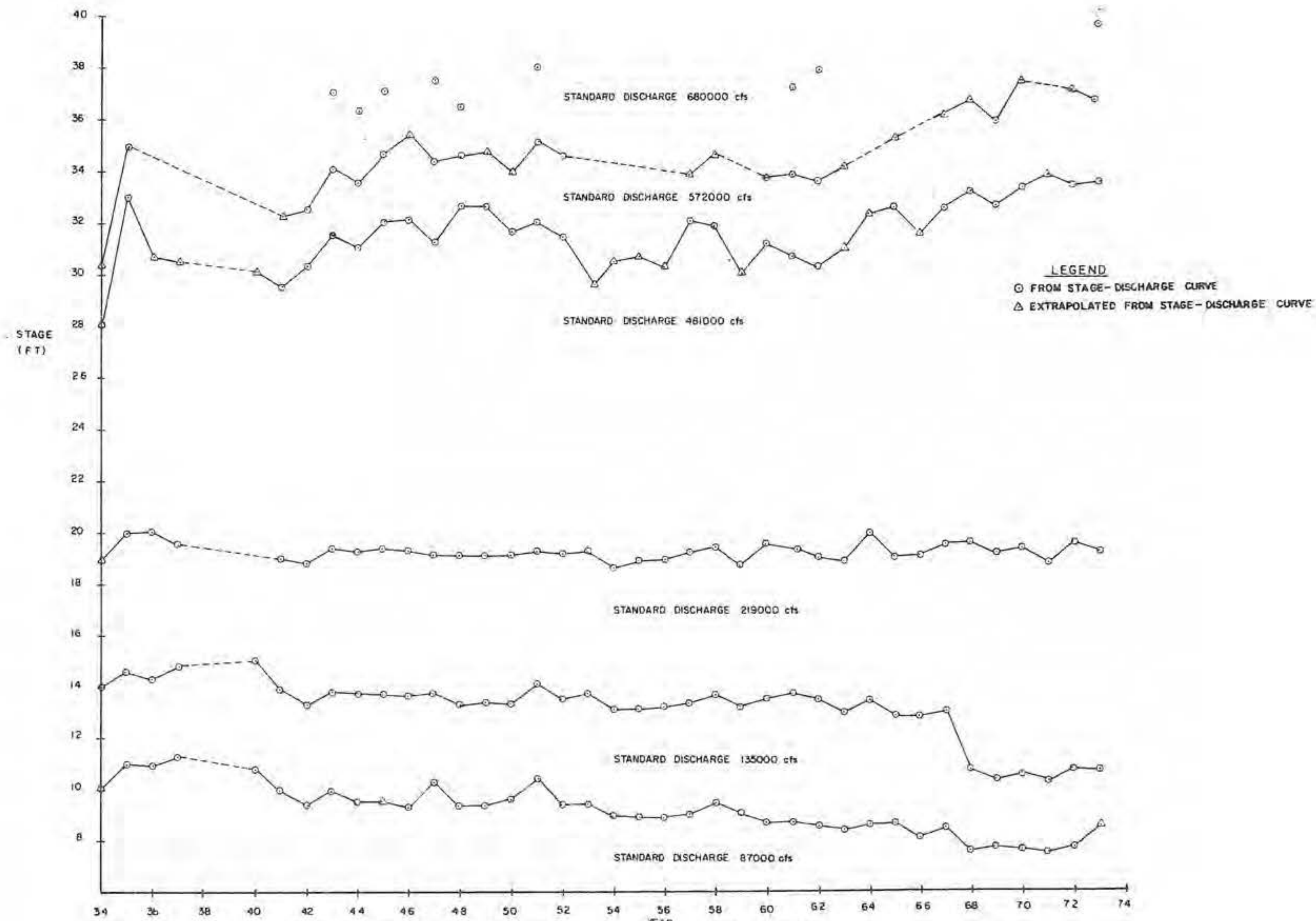

Figure 4.19 Estimated River Stage for Selected Flows in the Mississippi River at Thebes Between 1934 and 1973

than 431,000 cfs. For this reason, and because pertinent flow data for the period prior to 1934 are few, existing stage-discharge data are insufficient for a comparison of pre-1934 and post-1934 stages for flows considered herein.

Figure 4.20 shows stage versus time for selected flows of the Ohio River near Metropolis, Illinois. Flood stage is 43 feet. The pattern is very similar to that of the Mississippi River at Thebes. As at Thebes, stages for low flows (66,600 cfs) have decreased and stages for flows about midway between bankfull and low flows have remained about the same for the period, 1936 through 1973. However, stages for flows near bankfull (774,000 cfs) appear to have increased nearly uniformly since 1936, whereas the corresponding increase at Thebes began about 1963.

Because mean annual flow from the Ohio River is about 46 percent greater than that in the Mississippi River at Thebes, it is possible that those factors which cause changes in the stage-discharge relation in the Ohio River near its confluence with the Mississippi River also will be reflected by similar changes in the stage-discharge relation at Thebes. This speculation is based on similarities in stage-behavior patterns between Metropolis and Thebes. In order to assess the validity of such a possibility, it would be necessary 1) to determine which factors are associated with the stage-behavior pattern at Metropolis, 2) to determine if the observed patterns are representative of the intervening reaches between Metropolis and Thebes and the confluence of the Ohio and Mississippi Rivers, and 3) to analyze the relative time distribution of flow and sediment load from the Mississippi and Ohio Rivers past their confluence.

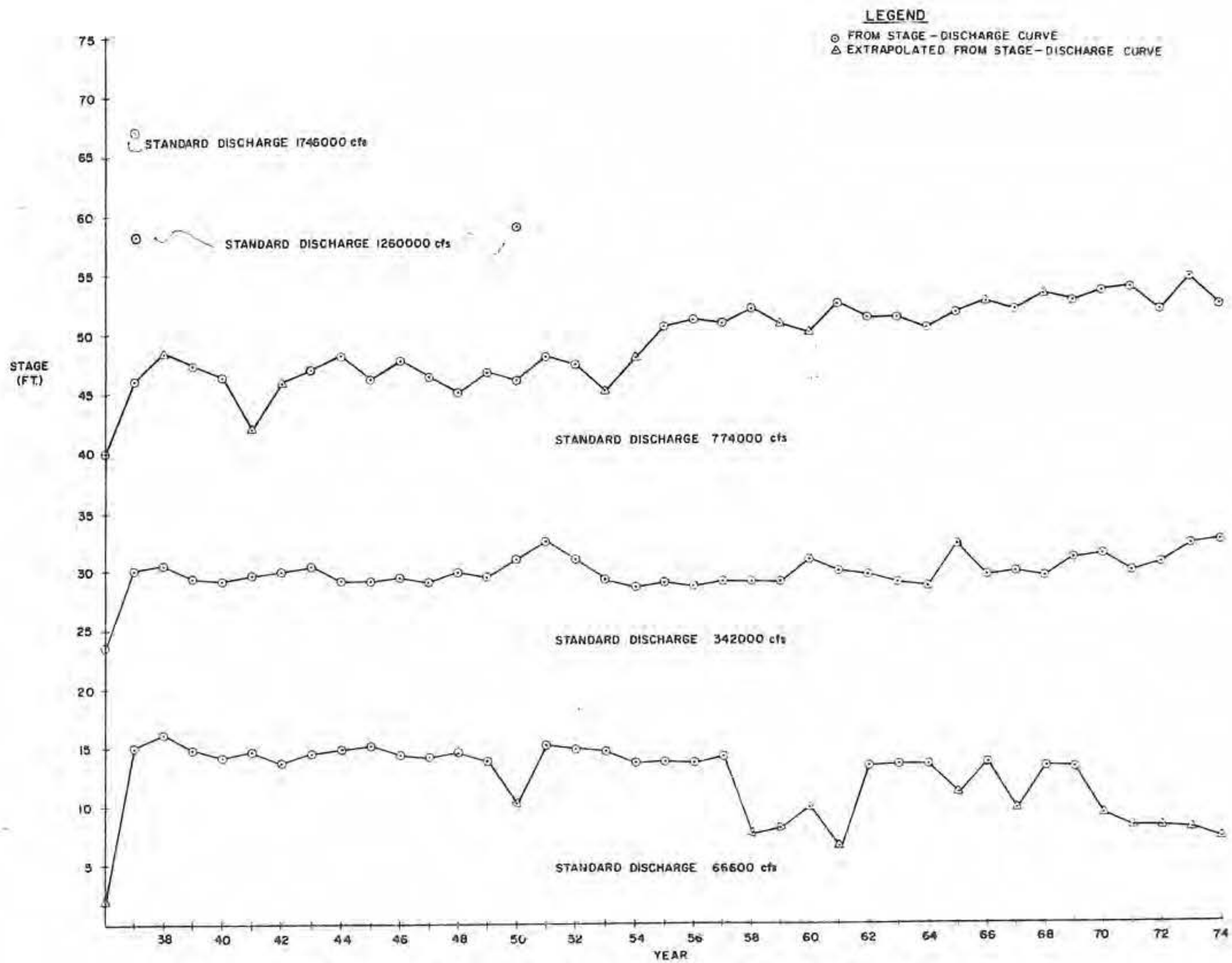

Figure 4.20 Estimated River Stage for Selected Flows in the Ohio River at Metropolis Between 1936 and 1974

Figure 4.21 shows stages versus time for selected flows in the Mississippi River near Memphis, Tennessee during the period, 1933 through 1971. Flood stage at Memphis is 34 feet. Stages for all flows below bankfull have continuously declined since 1933. Stage declines for the period, 1933 through 1971, range from about 3 feet for flows of 1,070,000 cfs to about 6 feet for flows of 260,000 cfs. Records show that in 1890 a flow of 1,070,000 cfs passed Memphis with a stage of 31.5 feet. For that flow rate the 1890 stage was greater than the 1933 stage, but it was less than the 1971 stage. Therefore, it appears that even though there was a decrease in channel capacity, it was temporary. Higher flow rates could be sustained within banks at the Memphis gage in 1971 than could be sustained in 1890.

Figure 4.22 shows stages versus time for selected flows in the Mississippi River near Vicksburg, Mississippi. Flood stage at Vicksburg is 43 feet. All stages for flows near bankfull and below have a similar behavior pattern. In the period, 1931 to about 1942, stages for flows of 1,340,000 cfs or less declined approximately 10 feet. Prior to 1931, stages for 1,340,000 cfs range from estimated extremes of 52 feet in 1858 to 46.9 feet in 1909. In 1913, the stage for 1,340,000 cfs was slightly greater than 48 feet, whereas in 1927 and 1929 it varied between 49 feet and 52 feet. Apparently, whatever factors may have caused the downtrend in stages between 1931 and 1942 manifested themselves after 1931. Beginning in 1942, there was a trend reversal showing steady increase in stages. By 1972 stages for flows near bankfull and below had recovered between 4 feet and 5 feet from the 1942 condition.

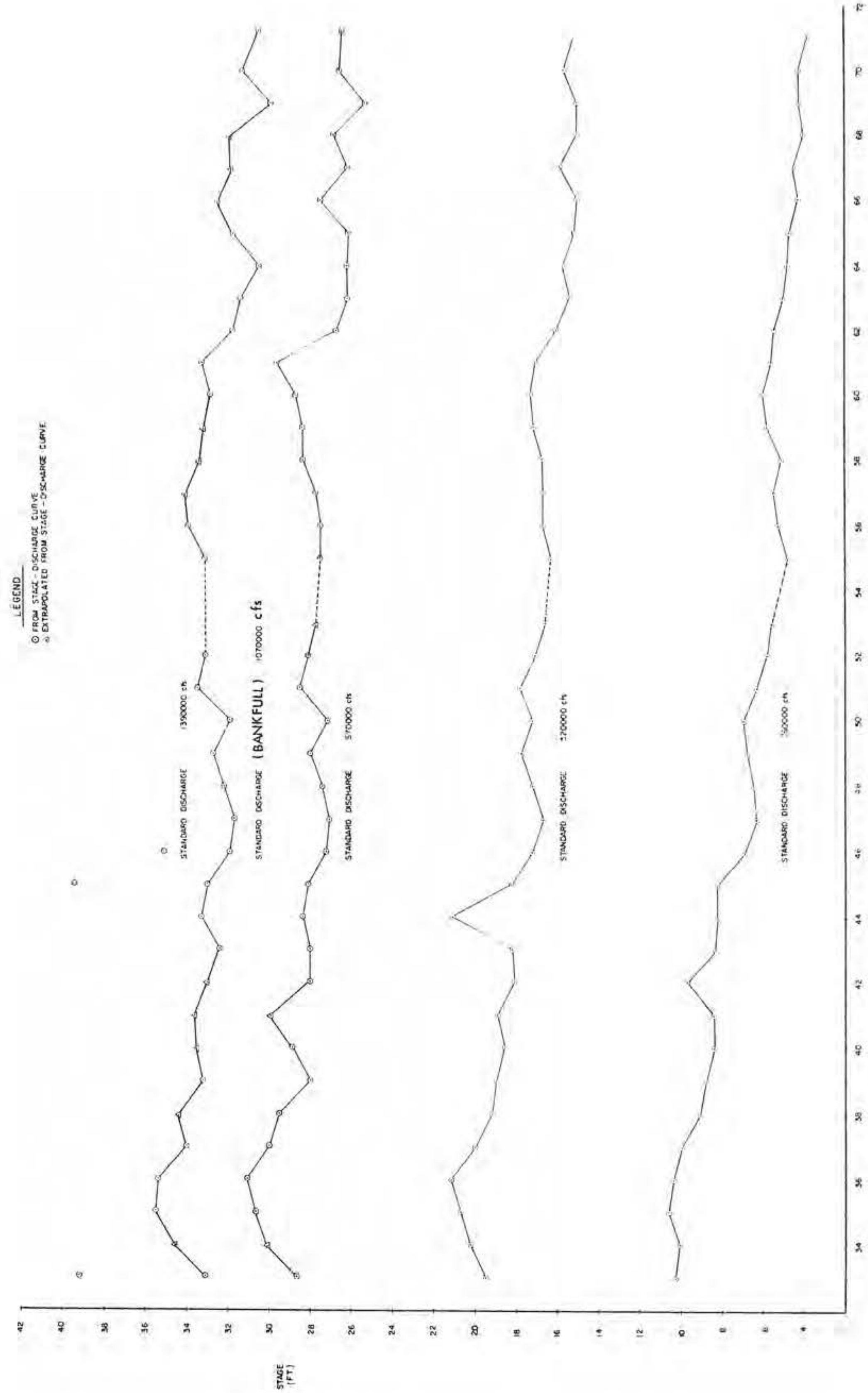

Figure 4.21 Estimated River Stage for Selected Flows in the Mississippi River at Memphis Between 1933 and 1971

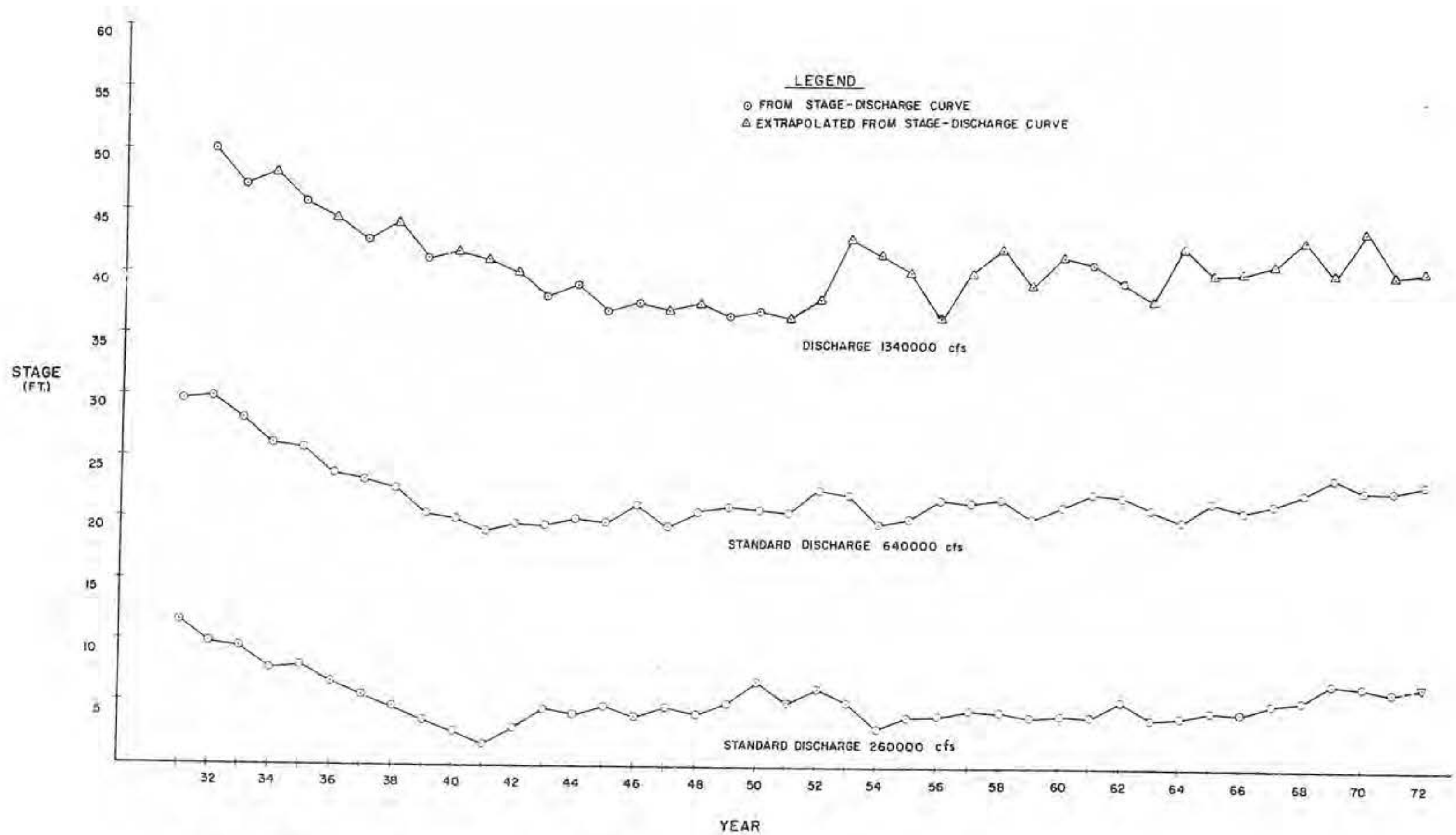

Figure 4.22 Estimated River Stage for Selected Flows in the Mississippi River at Vicksburg Between 1931 and 1972

St. Louis, Chester, and Thebes gages are all in the St. Louis Reach which has received most of the dike construction effort on the Mississippi River. Although average top-bank width appears to have decreased in response to dike construction activity by about 29 percent since 1908, the change in stage-discharge relations with time is different at each of the stations. In the Memphis Reach where dike construction activity has been only about 28 percent of that in the St. Louis Reach (in terms of length of dike per mile), changes in stage-discharge relations with time are similar to those observed at St. Louis but much more pronounced. In the Vicksburg Reach where dike construction was only about 18 percent of that in the St. Louis Reach (in terms of length of dike per mile), changes in stage-discharge relations with respect to time show an initial downtrend in stage for any given flow (less than 1,340,000 cfs) followed by an uptrend or rebound at about one-half the rate of the initial downtrend. Neither trend appears to be associated with dike construction activities in the reach.

The present analysis suggests that generalizations about effect of dikes on stage-discharge relations are not justified. It appears that other important, but so far unidentified, factors also influence stage-discharge relations. The Ohio River-Mississippi River responses near their confluence may be an example of mutual interference wherein modifications in one stream may cause a response in both. Because of the diversity in stage-discharge responses between stations, it appears that localized conditions may be the most important influence on these relations at individual stations. If this is so, then it is unlikely that an individual point of record is representative of conditions throughout a reach.

Whatever the reason, it appears that conveyance properties of the channel below flood stage have been increasing at the St. Louis and Memphis gages since about 1930. Channel conveyance at the Chester gage has remained unchanged over the period, 1943 through 1973. Conveyance properties at bankfull conditions appear to be decreasing at Thebes and Vicksburg gages. In the latter cases, the trend of decreased conveyance should be evaluated in terms of current and future protection afforded against flood hazard.

V. GEOLOGY

David J. Barr

A. Introduction

1. Scope

The geology section of the LMVD contract consists of the following components:

1. Classification and mapping of surficial soil materials along the Mississippi River from Alton, Illinois to the Gulf of Mexico, including the Atchafalaya River; Appendix H.
2. Preparation of geologic profile of river bed soil strata along the study reach from existing borings; Appendix I.
3. Map of the bedrock and bluff geology in that portion of the study reach above Cairo, Illinois; Appendix J.

All geologic materials mapping has been accomplished with previously existing data and without the benefit of field investigation. Consequently, mapping detail as well as mapping accuracy is variable throughout the study reach. The geologic mapping has served to pinpoint those areas for which existing geologic data are deficient.

2. Relation to Morphology Study

The geology study was conducted in close association with the morphology study. Maps produced in response to study requirements were all made to the same 1:62,500 scale ratio. Inasmuch as geologic and morphologic river parameters are interrelated, the several map overlays can be superimposed to provide a graphic means of correlating morphologic response to geologic condition.

B. Surficial Soil Mapping

1. Sources of Information

Surficial soil maps of the entire study reach were prepared entirely from interpreted aerial photography. No field investigation was conducted. The general character of the alluvial materials was such that small scale color infrared photography was deemed to be the most suitable data from which to interpret surficial soil materials, as well as many associated morphologic features. The primary photographic sources of data were obtained from four NASA high altitude aircraft missions encompassing the study reach. Pre-1973 flood and post-1973 flood color infrared photography was obtained for the initial map preparation. In August of 1975, it was learned that high altitude color infrared photography was flown for the Corps of Engineers in the fall of 1974. Inasmuch as this was low water photography it, without a doubt, represented the most recent and best available data for surficial soil materials interpretation and mapping. Thus, selected frames of this photography were obtained to revise and complete the surficial mapping objective. The three NASA missions are identified and described as follows:

Pre-1973 Flood

NASA Flt: 73-027, 25 Feb. 1973, Frames 9131-9195, EROS I.D. 573000987, Aerochrome Infrared, 2443 film.

Post-1973 Flood

NASA Flt: 73-057, 11 April 1973, Frames 8898-9008, EROS I.D. 573001087, Aerochrome Infrared, 2443 film.

NASA Flt: 73-058, 12 April 1973, Frames 9025-9087, EROS I.D. 573001092, Aerochrome Infrared, 2443 film.

NASA Flt: 74-014, 4 Feb. 1974, Frames 5774-5853, EROS I.D. 574001598, Aerochrome Infrared, 2443 film.

Low-Water Photography

NASA Mission 289, Fall 1974, Color Infrared Film

This NASA photography has been reproduced at an approximate 1:62,500 scale ratio with full coverage provided to each of the Lower Mississippi River Division Corps Districts. Since each District has a flight line map and an established frame code corresponding to 15' topo. quad. sheets, the following table includes the 15' quad. name on some portion of which a surficial soil materials map has been prepared; the Corps of Engineers, Quad. No.; and the NASA Mission 289 line, roll and frame number corresponding to the topo. quad. overlay.

Quad. Name	T-1 Project Overlay No.	Quad No.	NASA Flight	Film Roll No.	Frame No.
*Baldwin	SM 1	Q-0	69	08	158, 160
*Alton	SM 2	P-0.3	68	08	143
--		P-0.2	68	08	139,141
--		O-0.2	67	08	106, 108
Kimmswick	SM 3	O-0.1	67	08	110
Crystal City	SM 4	O-0.0	67	08	112, 115, 117
Renault	SM 5	P-0	68	08	137
Weingarten	SM 6	P-1	68	08	131, 133, 135
Chester	SM 7	Q-1	69	08	162, 164
Campbell Hill	SM 8	R-1	70	09	034
Altenburg	SM 9	R-2	70	18	023
				09	032
Alto Pass	SM 10	S-2	71	09	072
Cape Girardeau	SM 11	R-3	70	18	019, 021
Jonesboro	SM 12	S-3	71	09	078
Thebes	SM 13	S-4	71	09	074, 076
Charleston	SM 14	S-5	71	09	080
Cairo	SM 15	T-4	72	09	093, 095, 097
Wickliffe	SM 16	T-5	72	09	097
Hickman	SM 17	T-6	51	18	094
Bayouville	SM 18	S-6	51	09	087, 084, 086
Reelfoot Lake	SM 19	S-7	50	18	026, 028
New Madrid	SM 20	R-6	49	18	011
Portageville	SM 21	R-7			
Caruthersville	SM 22	R-8	70	18	013, 015
Hales Point	SM 23	R-9	49	18	003, 005, 007
Blytheville	SM 24	Q-9	48	18	169, 171
Osceola	SM 25	Q-10	48	18	173
Evadale	SM 26	P-10	47	17	156, 158, 160
Millington	SM 27	Q-11	48	12	011
				18	175
Jericho	SM 28	P-11	47	12	014
Memphis	SM 29	P-12	47	12	016, 018
Edmondson	SM 30	O-12	46	12	034, 036
Horseshoe Lake	SM 31	O-13	46	12	032
Clayton	SM 32	O-14	46	02	168
				12	028, 030

*Omitted because majority of area is urban in nature and insufficient data were available for overlay.

Quad. Name	T-1 Project Overlay No.	Quad No.	NASA Flight	Film Roll No.	Frame No.
Latour	SM 33	N-14	45	12	065, 067
Farrel	SM 34	N-15	45	12	069, 071
Hennico	SM 35	L-16	43	12	148, 150
				17	084
Modoc	SM 36	M-15	44	12	108
Mellwood	SM 37	M-16	44	12	106
Pace (Gunnison)	SM 38	M-17	44	12	100, 102, 104
Big Island	SM 39	L-17	43	12	150, 152
Lamont	SM 40	L-18	43	12	154
Greenville	SM 41	L-19	43	12	156
Readland (Avon)	SM 42	L-20	43	12	158, 160
Lake Province	SM 43	L-21	43	12	162
Alsatia (Fitler)	SM 44	L-22	43	12	164
Talla Bana	SM 45	L-23	43	12	166
Vicksburg	SM 46	M-23	44	07	214, 216
Yokena	SM 47	M-24	44	07	218, 220
Davis Island	SM 48	L-24	34	12	168
				18	108
St. Joseph	SM 49	L-25	11	07	193
			43	16	110, 112
Locust Ridge	SM 50	K-25	42	16	083, 085
Natchez	SM 51	K-26	10	06	005
Kingston	SM 52	K-27	10	06	007, 009, 011
Ferriday	SM 53	J-26	9	06	61
Monterey	SM 54	J-27	9	06	059
Artonish	SM 55	J-28	9	07	055, 057
Batchelor	SM 56	J-29	9	07	170
Fordoche	SM 57	J-30	9	07	172, 174
St. Francisville	SM 58	K-29	10	06	013
New Roads	SM 59	K-30	10	06	015, 017, 019
Cross Lake (Crosse Tete)	SM 60	K-31	10	06	021
Zachary	SM 61	L-30	11	07	183, 185
Baton Rouge	SM 62	L-31	11	14	001, 003
White Castle	SM 63	L-32	11	14	005, 007
Donaldsonville	SM 64	M-32	12	14	030
Thibodeaux	SM 65	M-31	12	05	032, 034
Mount Airy	SM 66	N-32	13	03	016, 018
Bonnet Carre	SM 67	O-32	14	02	128, 130
Hahnville	SM 68	O-33	14	02	122, 124, 126
New Orleans	SM 69	P-33	15	02	099, 101, 103
Garataria	SM 70	P-34	15	02	105
St. Bernard	SM 71	Q-33	16	02	077
Pt. La Hache	SM 72	Q-34	16	02	075
Ft. Livingston	SM 73	Q-35	16	02	069, 071, 073
Black Bay	SM 74	R-34	17	02	060
Empire	SM 75	R-35	1	02	062, 064
Venice	SM 76	S-35	18	02	043
West Delta	SM 77	S-36	18	02	037, 039, 041
East Delta	SM 78	T-36	19	02	025, 027
Greton Island	SM 79	T-35	19	02	021, 023

ATCHAFALAYA

Quad. Name	T-1 Project Overlay No.	Quad. No.	NASA Flight	Film Roll No.	Frame No.
Moreariville	SM 80	I-28	8	07	158
Odenburg	SM 81	I-29	8	07	156
				06	073
Palmetto	SM 82	I-30	8	06	075
				07	077
Arnaudville	SM 83	I-30	8	06	077
Maringovin	SM 84	J-31	9	07	174, 176
				14	028
Loreanville	SM 85	J-32	9	14	024, 026
Lake Chicot	SM 86	K-32	10	06	023
Centerville	SM 87	K-33	10	06	025
Belle Isle	SM 88	K-34	10	06	027, 029
Morgan City	SM 89	L-34	11	14	009, 011, 013
Point Aufer	SM 90	K-35	10	06	031

Other reference photography was obtained from a variety of sources especially for the Morphology study. Key contacts for sources of aerial imagery are summarized as follows:

1. U.S. Army Corps of Engineers
   Office of the Chief Engineers
   Mr. Jack Jarman
   Mr. David Penick

2. U.S. Army Engineer Topo. Labs
   Mr. Robert Nichols, Chief Liaison

3. U.S. Army Corps of Engineers
   Lower Mississippi Valley Division
   Mr. Dusty Rhodes

4. Defense Mapping Agency
   Mr. Carmen Di Carlo, Headquarters

5. U.S. Air Force
   Lt. Col. John Dutton, Hq. USAF Operations
   Mr. Junior Hicks, Rome Air Dev. Center

6. Environmental Protection Agency
   Col. Vern Webb, Chief EPIC

7. U.S. Geological Survey
   Mr. Fred Doyle, Headquarters, Topo.: Reston, VA
   Mr. Don Orr, Sioux Falls, SD

2. Map-Making Methods

The surficial materials maps were prepared from small-scale color infrared photographs using accepted photo interpretation techniques.

Photo pattern elements were evaluated to yield a logical deduction as to the most probable landform-parent material existing throughout the study reach. Topographic form, drainage, vegetation and photo tones and textures, as well as boundary conditions and regional associations, were evaluated. Major landform-parent material units and those man-made features evident on the photography were delineated and marked as indicated on the key presented in fig. 5.1.

3. Significance of Map Units

The general surficial soil material descriptions and logic of interpretation of the landform units are summarized as follows:

a. Oxbow Lakes--Water-filled meander cutoffs and channels, now abandoned and removed from the active channel, were mapped as oxbow lakes. Arcuate swampy features with dark image tones indicative of high soil-water contents were also included when, in the opinion of the interpreter, they were more characteristic of oxbows than backswamp or channel fill.

b. Channel Fill--Filled arcuate meander sears with no apparent standing water were mapped as channel-fill deposits. Fine-grained sediments associated with the cutoff plugs and organics were inferred from the apparent poor drainage and dark image tones. Clay plugs would be expected to be located at ends of such filled channels or oxbows.

c. Backswamps--The low, swampy areas generally lying behind natural levee deposits were classified as backswamps when dark image tones indicated standing water, high soil moisture content and/or organic clayey soil materials.

d. Natural Levee--The topographically high, better-drained portions of natural levees were mapped as discrete landforms, whereas the

Fig. 5.1 - MAJOR LANDFORM-PARENT MATERIAL UNITS AND MAN-MADE FEATURES

KEY

*Note - Man-Made Feature symbols represent visually interpreted features only.

Bluff Line	
Levees	PRINCIPAL / OTHER
Dikes	
Revetments	REV
River Channel	
Oxbow Lakes	OL
Channel Fill	CF
Backswamp	BS
Natural Levee	NL
Ridge and Swale Deposits	RS
Sand Bar	SB
Natural Levee Deposits	NLD
Backswamp - Deltaic Deposits	BSD
Borrow Pits	BORROW

broad, gently-sloping deposits lying generally between the active channel and the backswamp were mapped as "natural levee deposits." In the case of the discrete natural levee, light image tones generally indicated relatively coarse-grained material intermediate in size between point bar (ridge and swale) and channel-fill deposits.

e. Ridge and Swale--This terminology was used to identify the characteristic high and low relief arcuate features associated with point bar deposits. The bars are indicated on the photography by pattern and light tone, whereas the swales are generally low dark toned. In general the bars contain relatively coarse-grained material. The swales are high in organics, clays and moisture content.

f. Sandbars--Channel deposits evident on low-water stage photography as light-toned features of an alluvial nature were mapped as sandbars. Although the particle size distribution of such landforms would vary with their position in the channel and their location downstream, such deposits should contain relatively coarse materials.

g. Natural Levee Deposits--These materials were inferred as a component of natural levee deposition. The broad expanses which generally slope away from the channel were characterized as being darker in color than the topographic levee and as having a more random image texture. It was inferred that these deposits have more variability of particle size and are generally finer grained.

h. Backswamp-Deltaic Deposits--In the lower Mississippi and Atchatalaya portion of the study reach, this symbol is used to delineate those features exhibiting Deltaic characteristics. Specific detailed Delta units were not interpreted.

The preceding units were chosen as being most suitable for interpretation and delineation from aerial photography without the benefit of field investigation. They are similar to those units used by R.T. Saucier in his report 3-659, "Geological Investigation of the St. Francis Basin", W.E.S., Sept., 1964. Inasmuch as no field investigations were made and no subsurface data used in compiling the surficial materials map, inferences from the maps alone as to subsurface geology should not be made. The mechanics of the surficial materials map-making process were simplified with the use of a Bausch and Lomb Zoom Transfer Scope. Color infrared transparencies were positioned on a lighted easel for projection on 15-minute topo. quad. sheets. By varying the light intensity and using scale variations the projected images were interpreted, landforms delineated, and resultant boundaries traced on overlays all in one operation. A surficial materials overlay was thus prepared for all imaged portions of those topo. quads. representing the study reach. Three photo interpreters were employed in making the surficial materials maps.

4. Accuracies and Precision

The surficial materials maps are reconnaisance maps. The small-scale color infrared photography was not rectified or otherwise corrected. Scale matching to the 15-minute topo. base sheets was accomplished with the Zoom Transfer Scope. The geometric quality of the surficial materials maps is good and is entirely consistent with the reconnaisance nature of the interpreted products. Many changes in the location of the river as well as physical features were observed and mapped. The overlays represent conditions as they existed in the fall of 1974. In those cases where the river position has changed since the date of preparation of the base map, the overlays indicate 1974 conditions.

C. River Bed Geologic Profile

1. Introduction

The primary objective of this portion of the study was to prepare a profile of the geologic materials that make up the various soil strata beneath the river bottom from existing data. The method of presentation consists of a series of boring logs plotted on large cross-section sheets where information is available. Each Corps of Engineers District Office, the U.S. Geological Survey, the State Highway Departments of States adjoining the river and the Waterways Experiment Station, Vicksburg were checked as possible sources of river bed boring data. The search indicated that a large amount of data are available adjacent to the river but a very limited amount is available in the channel.

2. Sources of Data

The specific sources of data used for preparing the cross sections are boring logs from the State Highway Departments of States adjacent to the river as indicated on the boring logs; the Corps of Engineers' Technical Report, "Geological Investigation of the Mississippi River Area, Artonish to Donaldsonville, La.", 5.69-4; "Geological Investigation of the Boeuf-Tensas Basin Lower Mississippi Valley", by R. T. Saucier, 3-757; and the Corps of Engineers Technical Report, "Investigation of Under-Seepage, Mississippi River Levees, Alton to Gale, Ill.", including the levee borings from Alton to Gale, Illinois.

3. Methods of Profile Preparation

Due to the small number of borings available in the channel, a profile of selected levee borings from Alton to Gale, Ill. is presented for subsurface information in the St. Louis District. Since the river is fairly restricted within the bluff lines, it was felt that the levee borings would be a fair indication of the material which probably exists below the river bed. However, this is still only a general indication of river bottom materials because of the great variability of soil configuration in an alluvial deposit. Attempts to use levee and revetment borings as a source of data for the preparation of river bed profiles and river cross sections proved to be unreliable. Available river channel borings from bridge crossings in the Memphis, Vicksburg, and New Orleans Districts were collected and presented in specific cross-sections along the river. The cross sections consist of:

a. Boring log profiles from Alton to Gale, Illinois with eight miles of the river shown on each sheet. The borings are spaced at a minimum of 1500-2000 ft. and are plotted on a vertical scale of 1 inch = 20 feet. The channel invert profile is shown as a dashed line for reference. Each sheet also displays a plan view of the eight-mile section of the river with the location of each boring noted on the plan view.

b. Bridge borings are presented as a cross section of the river bottom from levee to levee (or levee to bluff) with selected borings along the section. The river channel cross section at the time the borings were made is shown as a dashed line for reference. In addition to the cross-section borings, a location map for each district is presented, indicating the location of each cross section.

4. General Accuracy and Precision of Cross Sections and Profiles

The location of the boring log profiles are presented to the nearest 0.2 mile and the elevations in mean sea level are to the nearest 2.0 feet. The cross-section borings are presented to the nearest 50 feet and elevations are as accurate as the sources of information.

D. Conclusions and Recommendations for Surficial Soil and Riverbed Geology Studies

The amount of information available for a study of the river bed materials is very limited. A large amount of data exists from levee, dike and revetment borings but a very small amount is available in the river channel itself. Due to the high degree of variability of soil deposits in an alluvial environment, extrapolation of soil profiles from the river bank borings has proven to be unreliable. It is recommended that additional borings be secured in the river channel to provide a reliable profile of river bed materials. This would allow a better estimate of river bed stability as well as indicate stretches of river likely to be problem scour and fill areas during times of flood.

1. Conclusions

Small scale color infrared photography is an excellent data source from which to interpret and infer probable surficial soil types. When coupled with field investigation, it can provide for very efficient engineering soils data collection. The interpretation of surficial soils was accomplished with no major difficulties using established interpretative procedures. The products are necessarily only reconnaissance in nature. Thus, coarse and fine - grained material can be inferred from an analysis of landform type.

2. Recommendations

Inasmuch as small scale photography is relatively easy to procure, it is recommended that reconnaissance-type floodplain surficial materials maps be prepared at perhaps 5 to 10 year intervals. Such maps could easily be used to incorporate land-use change data. Channel shifts and deposits could be monitored at a much greater frequency to yield flood damage information. However, other than for monitoring flood damage and land use change, the surficial soils maps represent conditions that should remain stable for some time and as such should be used for planning any desired field investigations. It is further recommended that consideration be given to a study of interrelationship between surficial materials, stream morphology and land use change. Such a study could be facilitated by using the prepared geology, morphology and energy dissipater overlays for a mechanical comparison of the mapped parameters.

E. The Bedrock Valley of the Mississippi--Alton Through Thebes Gorge

Thomas R. Beveridge

This study is divided into two phases, contour maps of the valley bedrock surface and a compilation of bluffline geologic mapping. A third phase, study of the sedimentary valley fill, was abandoned because of the lack of modern deep drilling data.

1. Bluffline Geology

No geologic mapping was done as part of this project. Mapping was transcribed from published and unpublished maps, the majority of them from the Missouri and Illinois Geological Survey files and publications. Mapping spans more than 50 years; therefore, standardization of the stratigraphic units and intervals used on the various maps were impractical. The composite rock columns and mapping symbols correlation shown on Plate G-1 were designed with practicality having a higher priority than the niceties of stratigraphic nomenclature. Areas left blank are highly faulted with no detailed mapping available. An example is on the Missouri side of the Thebes Gorge where spot mapping has indicated faulting comparable to that on the Illinois side.

2. Valley Bedrock Surface

The lowest available elevations of the bedrock surface are 277 feet above sea level near Alton and 154 feet on the Alto Pass Quadrangle. These figures exemplify the need for more data, as the Alton figure is in the northern part of the quadrangle where more concentrated borehole data are available from Locks and Dam No. 27, whereas less closely spaced data downstream do not give as low a figure on the same quadrangle. The Alto Pass Quadrangle figure of 154 is lower than available figures downstream in the Cape Girardeau area where 159 feet above sea level is the lowest. Data on the Chester Quadrangle are insufficient to show whether the rock thalweg is on the east or west side of the valley and the location of the thalweg on the Jonesboro Quadrangle is shown very approximately. Countouring does show that figures of what appeared to be unusually high or low bedrock are in most cases reliable; the thalweg is so narrow that the probability of encountering it in random drilling is not great. Modern "rock islands" such as Tower Rock and Fountain Bluff on the Altenburg and Alto Pass Quadrangles give credence to the existence of a varied locally high rock. Time did not permit obtaining all of the boring data that are probably available, especially those from construction activities and water wells not on public record. Because of the lack of data on depth to rock in major tributaries, no consistent attempt was made to assure fidelity in plotting main valley contours as related to alluvial fill in tributaries. Data are sufficient to show that Fisk (28) working with less data in the 1940's does not have the valley as deeply entrenched as do the maps of this report. His lowest contour, using a 25-foot interval, is the 200-foot in the Cape Girardeau area, whereas the lowest contour on the present report is the 140-foot in the same area (projected from the 154-foot figure on the Jonesboro Quadrangle). More detailed data will probably show more complex channel shiftings and possibly superposition of channels which crossed older buried channels in response to glacial activity.

3. Studies Needed

The present study has impressed the writer with the lack of modern data as contrasted with much of the area farther downstream where extensive and intensive borings and studies have been made. Boring data were so sparse in the stretch between Thebes Gorge and Cairo that no attempt was made to contour the bedrock surface. Borings showing detailed sediment lithology between the bottom range of levee borings and bedrock were so scarce that no meaningful study could be made of the deeper part of the fill. The Cairo-Alton stretch of the Mississippi is somewhat of a data orphan as contrasted with the downstream stretch to the Gulf. The bedrock valley, nature of the fill, and geologic history cannot be the object of much further study until further data are available. The highest priority for data would include boreholes across the valley to delineate the thalweg more accurately and to determine the nature of the sedimentary fill. Seismic and/or resistivity geophysical studies would be very useful tools, and, if used in conjunction with existing or future borings, could be relatively low-cost data sources. The Alton-Cairo stretch of the Mississippi poses a number of unanswered questions of an academic nature. Is the original valley preglacial, or Pleistocene in origin? The writer, from buried valley studies in Iowa, suspects it is preglacial. How much influence does geologic structure and lithology have on the present and past locations of the thalweg? A geologic map of bedrock between the blufflines would be a necessary part of such a study. How much influence did glaciation have in forcing the river out of the older channels? The Mississippi, above Cairo, is a fruitful area for classic studies like those of Fisk and Saucier, but such studies cannot be made without a great amount of new subsurface data.

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VI. MORPHOLOGY

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Morphology is defined in part as "the scientific study of form and structure". In order to study the form and structure of so vast an area as the Mississippi River, one must become familiar with a few basic morphological features which may appear throughout the area under consideration. A brief description and summary of the more common forms and features is included.

A. Stages of Stream Development

All streams may be classified geomorphically in the following stages: young, mature, and old. The young or youth stage of a stream is characterized by the ability of the system to dissect its own channel--river deepening. Stream gradients are high with consequently high velocities which transport the load. The drainage system is coarse in texture. Floodplains and meanders are not found. Valleys are steep-sided and V-shaped; rapids and waterfalls are common. When erosive action from river deepening to river widening occurs, the stream is said to be mature. A mature stream has a reduced gradient with velocities sufficient only to transport the load within the system. Lateral migration of the stream (meandering) occurs. Also occurring are planation (widening of the valley floor), cut-bank erosion (sculpturing of the valley sides), and floodplain accretion (deposition on the widened valley floor). Old age streams are either completely graded, or in equilibrium where erosion equals deposition. Their floodplains are extensive. Low gradients and meandering are characteristic of the rivers. Topography is flat or gently undulating.

B. Floodplains

A floodplain is that portion of a river valley adjacent to the river channel which is built of sediments during the present regime of the stream and which is covered with water when the river overflows its banks at flood stages. All floodplains are level, or almost level, plains of low topographic situation existing at the level of (or slightly above or below) an adjacent parent stream. They are characterized by distinctive remnants of erosion and deposition. The type of floodplain is dependent upon the dominant type of flood which the stream experiences and on whether the stream has predominantly single- or multiple-channel flow. Floodplains associated with streams of single-channel flow are known as meander floodplains, covered floodplains, or composite floodplains. Those associated with streams of multiple-channel flow are bar meander or bar plains.

Meander floodplains are created as a result of "bankfull" floods, where there is lateral erosion and lateral deposition of coarse materials. Characteristics of the meander floodplain include well-developed and intricate patterns composed of closely-spaced, often overlapping, series of channel scars, meander scars, oxbow lakes, etc. The surface is at or slightly higher than the present channel.

Vertical deposition of fine materials by "over-the-bank" floods create covered floodplains. Finer sediments (silts and clays) are carried over the plains and dropped only when the stream velocity becomes very low. Considerable thicknesses of fine-grained alluvium may be built up in this way. Natural levees are formed by sudden decrease of stream velocity in the vicinity of the natural banks and resulting deposition of medium (silty) to coarse-grained sediments.

Composite floodplains are the result of both bankfull and over-the-bank floods, and features of both are present.

When multiple-channel flow exists in a stream valley, bar meander plains are formed. These consist of level surfaces scarred with evidences of past irregular bar deposition adjacent to a slightly lower stream channel which is partially braided with the greatest amount of braiding occurring at the bends. Valley alluvium is largely sand and gravel from the surface to the floor of the plain.

C. Terraces

Terraces are relatively flat, horizontal or gently-inclined surfaces that usually represent former levels of the valley floor or floodplain. They may be located at more or less constant heights above the present floodplain and are usually separated by low bluffs, rises, or scarps. Their origin may be alluvial, marine, or rock.

There are two fundamental categories of fluvial terraces: erosional and depositional. Erosional terraces are formed in bedrock or former sedimentary valley fill when a river meanders from one side of its floodplain to the other, eroding laterally into the bedrock valley slopes. Depositional terraces are the result of the accumulation of stream deposits on the valley floor.

Drainage characteristics are variable. In granular materials, there may be no surface drainage developed. Dendritic patterns are common in fine-textured soil. Infiltration basins, meander scrolls, and other evidences of past currents may also be present. Erosion occurs mainly on the bluffs or scarps which separate the terraces. In granular materials, V-shaped gullies with short, steep gradients are found along the terrace face. In fine-grained materials, severe gully erosion may develop, forming broad saucer-shaped gullies with long uniform gradients.

D. Deltas

Deltas are alluvial deposits that have been built outward from the shoreline of a large body of water by deposition of sediments carried by streams. Three basic types of deltas have been identified. They are the arcuate, estuarine, and bird's foot deltas.

Arcuate deltas are built by streams carrying and depositing a load of coarse sediments. Their characteristic fan shape is convex toward the sea. The delta itself is a flat, gently-sloping plain. The outlet of the major stream is through many shallow channels with considerable braiding. There is also considerable internal drainage through the granular material.

When the mouth of a stream is submerged beneath the main body of water, estuarine deltas are formed. The delta is parallel to the stream gradient. The surface is highly irregular, forming many islands and inlets. The deltas are comparatively narrow with long boundaries parallel to the water flow.

Bird's foot deltas (also called lobate deltas) occur in association with streams which are carrying and depositing considerable amounts of fine-textured soils in a large body of quiet or relatively protected water. Water flow is confined to one or two main channels or distributaries. The channels may have sharp bends or meanders, and numerous lakes and lagoons are usually present. Deposition occurs at levees along the banks and at the mouth of the distributaries. The delta forms a broad, flat surface with a low ground slope. The Mississippi River Delta is an example of this type.

Many other small landform features may develop in the fluvial system.

These are described in the following section.

E. Abandoned Courses and Channels

Abandoned courses are the stream courses left in disuse with the diversion of the stream to a new course. The abandoned course becomes plugged at the point where the flow was diverted by coarse-grained sediment, and the rest of the course gradually fills with clay and silt deposited in the flood stage of the river.

The abandoned course can be recognized by its long, meandering pattern. The topography is low relief, marked by natural levees to either side of the stream bed and the ridge and swale topography of point bar scars. The size of the stream bed can vary from a few feet in width to a mile or more, depending on the size of the original stream. The soils of an abandoned course are relatively impermeable clays and silts. Because the soil is difficult to work, the land is usually left in timber or used for grazing in the areas near oxbow lakes where there may be extensive areas of grass or reeds. Drainage usually consists of a small stream following the original course of the stream. Cross section is gently undulating. Roads and railroads are usually aligned at right angles to the course if a crossing is necessary. Abandoned courses contain remnants of all the landforms which characterize fluvial, including meander scars, point bar scars, oxbow lakes, and natural levees.

Abandoned channels are longer segments of a stream that have been abandoned by the stream in the diversion of the flow through a cutoff. Two main types of cutoff can occur: the neck cutoff and the chute cutoff. In a neck cutoff, the stream breaches the neck of a meander loop, usually during flood stage. The chute is formed when the stream flows through a large swale between two point bar deposits. The points where the abandoned channel meets the cutoff becomes silted up with coarse-grained sediment. When the abandoned channel has been completely blocked at the cutoff, further sedimentation occurs only during over-the-bank floods, and only the finer materials are deposited.

F. Oxbow Lakes

Oxbow lakes are the result of the neck cutoff of the meander loop of a river. These lakes are recognized by their arcuate shape and their location in the meander belt of the flood plain. Meander scrolls and natural levees may be evident, marking the progress of the river course.

G. Clay Plugs

When an oxbow lake has been filled by sediment deposited by the flood waters of the adjacent river, it becomes a clay plug. Only the finer-grained particles are left to settle after the sands and silts were deposited with the decrease in velocity that occurs when the river overflows its banks. These clays are relatively impermeable and resist erosion. When a stream bank is eroding a clay plug, the underlying coarser materials are scoured out first, causing the bank to slump due to undercutting. This produces a scalloped pattern along the bank. The general land use of clay plugs is cultivation or natural timber cover.

H. Point Bar Deposits

Point bars are formed by the lateral migration of a meandering river. They begin as sandbars following the curvature of the convex bank. As the sandbar receives additional sediments, it grows in length, forming a small channel or slough between it and the river bank. Eventually, blockage of the slough is caused by lateral migration of the stream and further sand deposition. The slough then becomes a water-filled swale which is eventually filled with fine sediments carried into it by floodwaters. Meander scrolls are the products of the cycle being repeated as the stream continues to migrate, leaving behind a series of ridges and swales. The contract between the ridges and swales is due to two causes. First is soil moisture, the swales being wettest. Secondly, the overall dark tone of the swales, even when dry, is due also to an accumulation of organic material. Even though relief between ridges is small, particularly those areas used for agriculture, the swales are lower and surface water carries the organic debris into the swales. Low-order drainage is generally collinear, with the drainage ways following arcuate swales. Some swales may not exhibit developed scour channels; some may be basins, which form shallow elongate lakes or ponds after rain.

Vegetation increases in size and age with the age of the point bar deposits. Newly-formed ridges and swales may be barren, but these surfaces are then colonized by small herbs and grasses, then shrubs, and finally by dense forest. However, some swales remain water-logged, and will support only dense growths of marsh grass and reeds.

Although newly-formed meander scrolls are rarely cultivated, older surfaces of this type are commonly cultivated. The normally sharp distinction between drainage conditions and soil types from ridge to swale commonly results in a field pattern consisting of elongate rectangles oriented parallel to the trend of the topography. The parent materials of the point bar's surface are generally sandy or gravelly on the ridges, with finer-grained materials forming the swales. There is considerable variation from region to region, or even along different segments of the same floodplain. In some cases (e.g., where the parent stream has a steep gradient and swift current), ridges may be composed of silty sand.

The surface soils of this landscape chiefly are relatively impermeable silty sands, clay silts and silty clays. Soils tend to be slightly coarser on the ridges and finer in the swales. Highly organic silts and clays occur in relatively infrequent, exceptionally poorly-drained swales.

I. Natural Levees

Natural levees are low, alluvial ridges of varying widths and elevations that normally flank both sides of a stream channel. They are caused by overbank flooding. As the stream overflows its banks, a loss in velocity allows the coarsest and greatest quantity of suspended sediment to drop out in areas nearest the stream bank. Successive flooding over a period of time adds additional materials forming low alluvial ridges which slope gradually away from the channel into the floodplain back of the levee.

The levees are low-relief, sinuous features which are relatively well drained. The larger levees are normally cultivated and the fields are aligned with their long dimensions perpendicular to the adjacent stream, forming a distinctive pattern. The borders of the narrow and broad rectangular fields appear as thin dark lines criss-crossing the levee surface. When not cleared for agriculture, the levees support stands of hardwood trees.

The height and lateral extent of natural levee deposits are an indication of the stream size and maturity. Cross-sectional shape is undulating or blocky. The levees consist of asymmetric ridges of very low relief parallel to a stream channel. The steep slope faces the water, and the very gentle reverse slope faces away from the stream. Relief may be from a few inches to as much as 15 or 20 feet, although these extremes are rare. The ridges range from a few yards to a mile or more in width. Changes in river courses may leave natural levees abandoned and far from the present course. Old levees may be intercepted or truncated by newer ones. Backswamps frequently occur on the landward side of a levee.

The soils are usually well drained, encouraging diversified agriculture. Roads parallel the trend of the ridge where these features are fairly large. Natural levees often are used as the basis for artificial levee systems. Borrow pits for construction of road, railroad, and levee embankments are common.

Low-order drainage of the natural levees is usually of the parallel type, with the channels draining the gentle reverse slope of the ridge, and thus oriented roughly at right angles to the trend of the ridge and river. Such drainage is usually straightened and deepened by Man to improve drainage.

Erosion in levees on the active course is negligible, but in abandoned levees the steep face of the ridge may develop gully systems. In general, these are of the "v" type with steep gradients. When floodwaters overtop the natural levees, they tend to scour the reverse slope; the marks left are indefinite, consisting of poorly-defined streaks of light and dark photo tones produced by minor differences in vegetation cover and soil type.

Crevasses are short channels which are formed initially as breakthroughs in the natural levee during flood stage with flow through the crevasses increasing with successive floods. Crevasse channels are characterized by thin, dark sinuous lines, many of them branching, crossing the levee surface from these river surfaces to the backswamps.

J. Backswamps

Backswamps are low, flat basins that occur between natural levee systems, or between natural levees and higher ground. Backswamps are distinguished from marshes by the extensive growth of trees. Under natural conditions, these low tracts are periodically inundated by overbank flow during stream flooding. Fine-grained sediments carried by the floodwater eventually settle out, forming extensive deposits of silty clays and clays. Organic matter in the backswamp deposits is high because debris from the trees builds up; locally, peat deposits may form.

The gross drainage pattern is dendritic, but also may exhibit some of the features of the reticulate type and deranged types. There may be no obvious trend to the drainage as a whole. Channels are commonly contorted. Lakes with exceedingly irregular outlines are not unusual. Where cultivated, the patterns are usually either (or both) ditched or tiled.

The cross-sectional shape is undulating, and is often very nearly plane; relief is normally only a few inches or at most a few feet. Areas of backswamp are extremely variable in size. They may range from a few hundred square yards to several square miles. They are normally bounded on at least one side, and frequently on all, by natural levees. Usually there is at least one drainage exit. The surfaces rarely exhibit evidence of local erosion. However, in some cases where local relief for some reason exceeds a few feet, gullies may develop.

Backswamps are usually forested, although in some places extensive areas of marsh grass and reeds occur, especially in and near the lakes, similar to those occurring in deltaic plains.

The soils of backswamps are normally poorly drained and difficult to work. As a result, this environment is commonly left in timber; where cleared, it is frequently used for grazing. However, in many places backswamps have been either naturally or artificially drained, in which case the field patterns are rectangular and tend to be independent of topography. Roads and railroads avoid backswamps where possible. Where it is necessary to cross them, both cut across without regard to topography. Where backswamps are used for agriculture, ditching is usually required. The surface soils are generally thin and relatively poorly developed. They are dense, highly organic, impermeable clays and silty clays.

K. Marshes

Marshes occupy a large portion of the land area in the deltaic plain and are low tracts of periodically inundated land supporting grasses, reeds, and rushes. The marsh surface is generally featureless and seldom more than two feet above mean sea level.

The marshes are drained by bayous which are influenced by tides near the coast. Where changes in water salinity occur, the vegetation will reflect that change. The vegetation patterns are broken by areas of open water and lakes which often have a characteristic circular shape. The marshes are uninhabited by humans and are utilized primarily as game preserves. Man's activity in the marsh is evidenced by numerous canals which comprise the major transportation network and by the tracks of swamp buggies and the traces of oil pipelines.

The marsh soils are primarily organic clays and silts with high moisture content. Organic sedimentation is interrupted periodically by the introduction of fine sand during flooding.

L. River Bars and Islands

River bars are short, oval-shaped deposits of sand located within the confines of stream channels and along the banks of channels. They exhibit some relief but are rarely more than one meter above low water level and are barren of vegetation. Islands tend to be long and narrow and pointed at the downstream end when formed from river bars. Islands may be colonized by vegetation, but neither river bars nor islands are cultivated or otherwise occupied by Man in the Mississippi Delta due to the large fluctuations in water level. River bars and islands consist of fine and silty sands with some occurrence of clays. The coarse materials usually will be found at the upstream nose of these features.

M. Objectives of Study

The objectives of the morphology study are as follows:

1. To the extent possible with existing data, document and map significant changes in meander pattern, and bar and chute development through the reach.
2. Document and map significant changes in vegetation and other energy dissipaters.
3. Document and map significant changes in river thalweg, cross section and channel invert with time.
4. To the extent possible with existing data, analyze the changes in river morphology with respect to causal factors.

Each of the above listed objectives requires that significant changes in the river's morphology be delineated in order to accomplish these objectives. The first requirement was to outline periods when significant changes in the morphology of the river might have occurred. The time periods which were chosen were the early 1930's, middle 1940's, early 1960's, 1973 (prior to the flood in 1973) and 1974 (post flood). This span of years (approximately 40) is very small in comparison to the length of time the river has required for significant changes. However, this period was chosen for two reasons: (1) The study was accomplished primarily with aerial photography which began to be widely used in the early 1930's, and (2) The times selected represent periods of definite changes in the river. The early 1930's was selected as a period when much of the levee construction had been completed along the river. The period of 1944 and later was selected as the time at which all the cut-offs in the river had been completed. The early 1960's represents a period when the dike construction began to be primarily of rock type rather than pile dikes. The final two periods were selected in order to delineate any significant changes which might have occurred as a result of the 1973 flood.

Various means of outlining the changes in the river's morphology are available: topographic maps, navigation charts, hydrographic surveys and aerial photography.

Aerial photography and hydrographic surveys were the two sources chosen to provide the main portion of information in this study. Both the aerial photography and hydrographic surveys covered a relatively brief span of time. In many cases, the photography was not controlled; however, sufficient landmarks (i.e. roads, levees, structures, etc.) were distinguishable for marking the outline of the river channel on a topographic map.

1. Documentation of Bar and Chute Development and Meander Pattern. The method of presenting changes in meanders and bar and chute development was accomplished through graphical means. Appendix

C consists of a series of overlays at a scale ratio of 1:62,500 which will match the 15-minute United States Geological Survey topographic quadrangle sheet for each segment of the Mississippi and Atchafalaya Rivers. These sheets were developed from overlays which have been traced on frosted acetate from the aerial photography for each of the selected year periods. The river channel, vegetated bars, sand bars, chutes, dikes and islands were transferred from the photography to the frosted acetate. The photographs were at various scales ranging from 1:10,000 to 1:62,500. Some of the photography was available in controlled mosaics while in many cases with the older photography, individual pictures were fastened on large fiber boards to produce a mosaic for tracing. The tracings were then reduced to a 1:62,500-scale photographically. The reduced tracings were placed on the 15' USGS topographic quadrangle sheet and aligned with existing land features. A final tracing was then produced for the report, and a copy of each tracing bearing the year and title of the topographic quadrangle was enclosed in the appendix. The overlays provide a graphic chronological summary of changes in the river's morphology with time and are keyed to the USGS topographic quadrangles with a scale of 1:62,500. This means of portraying the river's outline provides a basis for investigating the influence of the river's morphology on the flow regime of the river.

2. Changes in Vegetation and Other Energy Dissipaters.

The changes in energy dissipaters within the confines of the channel are displayed on the morphological overlays in Appendix

C. The time periods over which the changes are displayed are noted on each overlay sheet. The sheets note all the dikes and man-made features which were visible from the photography. In many cases, a dike which was active during one period of time has subsequently been buried and would be no longer visible on the later photography. All the vegetation within the channel is noted, as well as islands, towheads etc. The vegetation on the islands is represented either as low undergrowth or high, topped-out vegetation, primarily trees. The distinction between low undergrowth and higher vegetation was interpreted from the aerial photography and in some cases, especially with the older photography, required careful interpretation. The low-water features such as sandbars are also noted on the over-lays. The energy dissipaters outside the channel and in the adjacent floodplain were evaluated for the Fall of 1974. The overlays contained in Appendix E were prepared from the color infrared photography supplied by the Corps of Engineers. This overlay provides an up-to-date presentation of the vegetation in the area adjacent to the channel. This series of overlays would have direct application for the revision of the energy dissipaters in the large scale model of the Mississippi River operated by the Corps of Engineers.

Microfilm copies of photographic mosaics prepared by the U.S. Soil Conservation Service covering the entire river from St. Louis to New Orleans for two time periods, the 1940's to early 1950's, and the 1960's were purchased and catalogued. These copies were used to prepare overlays of the vegetative cover for the time period of the late 1940's and 1950's. The 1974 & 1940-50's overlays are prepared at identical scale ratios and a direct comparison of the two provides a graphic portrayal of significant changes in energy dissipater for the time period. A significant reduction in the vegetative cover was noted in the upper reaches of the river. The forested areas adjacent to the river in the Memphis District and the upper part of the Vicksburg District have been largely removed during the period of the 1940's to the present time. This reduction in the vegetative cover may have accounted for some of the erosion and scour problems during the 1973 flood.

3. Changes in River Thalweg, Cross Section and Channel Invert. The significant changes in the thalweg are shown on the overlays of the river channel. The 1973 thalweg is shown as a dashed line, and where significant changes have occurred in the past are indicated on the overlays for the particular year period in which the change occurred. The changes in river cross section are shown on the cross-section sheets in the appendix. The cross sections are shown at approximately thirty-mile intervals down the river. A listing of problem reaches by river mile was requested from each district and the cross sections were located in those areas of the river. Each sheet contains the river cross section for the same general time periods as the overlay sheets. The cross sections were prepared from the hydrographic surveys supplied by each district. In most cases, the cross sections are not at exactly the same location on the river since the hydrographic surveys were not taken at the same location over the forty-year time span under consideration. A small section of the river plan is shown, indicating the location of each cross section. The elevations

have all been corrected to mean sea level and the average low-water plane elevation is also shown. All the cross sections have been taken from hydrographic surveys at lower than bankfull river stages. The invert profiles were also prepared from the hydrographic surveys at approximately the same time periods as the overlay sheets. Each sheet displays approximately thirty miles of the river with the time periods as indicated. The invert profiles are all based on mean sea level elevation with the average low-water plane plotted for reference. The datum points plotted are the lowest elevation in the navigable channel of the river. Thus, the invert profile portrays the lowest elevation in the main channel, although a lower elevation may exist outside the main channel due to scour, etc. A combined study of the invert profiles, cross sections and morphology overlays certainly provides considerable insight into the river's behavior. However, insufficient time was available to attack the problem of selecting specific reaches wherein a series of closely spaced cross sections might be studied in detail. The selection of the spacing presented was quite large due to the constraints of time. A further study of selected reaches utilizing detailed cross sections, invert profiles and the morphology overlays would certainly provide useful information and is recommended for further study.

4. Documentation of Morphology in the Reach of the Mississippi River from Cairo, Illinois to Alton, Illinois.

   a. Significant changes in minimum, maximum, and average top bank width of channel for the reach above Cairo, Illinois. Aerial photography from the following years was used to meet this requirement:

10/29-30/35
12/14/47 - 2/9/48
8/2-3/65
1/30/70
9/5/74

Measurements were taken at every second river mile at the narrowest dimension of the channel through each river mile. Top bank was defined as the line of permanent vegetation.

b. Significant changes in minimum, maximum, and average radius of curvature, meander length, and meander width for the reach above Cairo, Illinois. Hydrographic surveys and aerial photographs were used to meet this requirement for the one meander (mile 11.0 - mile 26.0) in river reach above Cairo, Illinois. Measurements were taken for the following years:

1876-1881	(Survey)
1919	(Survey)
1929	(Survey)
1931	(Photography)
1937	(Survey)
1942	(Survey)
1948	(Photography)
1965	(Photography)
1968	(Survey)

Meander parameters were defined as in Fluvial Processes in Geomorphology by Leopold, Wolman, and Miller. Meander axis was drawn from mile 11.0 through mile 26.0. Meander width was measured from bend to bend from lines through channel invert and parallel to axis. Radius of curvature was measured from best fit of curve through channel invert of the bends.

c. Documentation, to the greatest extent possible, of annual bank caving volumes for the reach above Cairo, Illinois. Bank caving volumes were taken from hydrographic surveys for the following intervals:

1937-1944	$45,458.0 \times 10^3$ yd^3	
1944-1956	$42,180.6 \times 10^3$ yd^3	Trend of decreasing bank caving w/years
1956-1965	$30,374.7 \times 10^3$ yd^3	

River plan views were traced on frosted acetate for each year from the hydrographic surveys. These were then overlayed to indicate progressive recession or inundations of bank lines in the main channel and chutes. Changes in bank lines correlated well with areas marked on the surveys as subject to caving banks. Areas on the overlay changes were computed by planimetry. Height of caving banks was computed by taking the mean of the interpolated "average low-water reference plane" river elevations for the upstream and downstream gages for the year intervals, then subtracting these ALWP means from the average bank elevations; bank caving volumes were computed by multiplying bank areas times computer heights.

N. Conclusions

1. The information on morphology in the form of maps, charts and aerial photographs on file in each District Office of the Corps of Engineers can provide valuable insight into the behavior of the Mississippi River. This project has just begun to uncover and relate this material from each district to provide an overall view of the river's behavior. The information on morphology from each district should be kept current and available for use in evaluating changes in the river.
2. The study of energy dissipaters in the channel and floodplain can provide useful information on the flow regime of the

Mississippi River. Additional study in this area, including a land use study, would be useful for predicting the river's behavior.

O. Recommendations

As a logical extension of this study, a detailed analysis of selected reaches of the river, wherein the information presented on the morphology overlays, invert profiles, cross section and vegetative cover overlays is recommended. The study would certainly provide useful information on the river's behavior with time and the influence of physical changes such as channel configuration, vegetative cover, etc.

P. Bibliography*

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2. Von Bandat, Horst F., Ph.D., "Aerogeology," Gulf Publishing Company, 1962.

3. Fairbridge, Rhodes W., (Editor), "Encyclopedia of Geomorphology," Reinhold Book Corporation, 1968.

*Note: These entries are additional to those listed in the general bibliography section at the end of the report.

VII. INVENTORY OF DIKES, REVETMENTS AND LEVEES

Clifford D. Muir

A. Introduction

The development and control of a river system is a large and complex engineering problem requiring resources not available to private or local groups. Responding to the need for large-scale efforts in connection with the Mississippi River system, the United States Government created the Mississippi River Commission in 1879. The River and Harbor Act of 1890 charged the U.S. Army Corps of Engineers with maintaining navigable streams. This charge was extended to flood control by the Flood Control Act of 1928. The response to these charges by the U.S. Corps of Engineers and Mississippi River Commission on the Mississippi River has been a significant engineering achievement.

In order to assess the effect of human activities on this major inland waterway, an accurate record of what has been done is needed. To provide this record of engineering activities on the Mississippi River, an inventory of dikes, revetment, and levee construction based on available data was tabulated. Data were collected to show their location, apparent characteristics, and current status. These data were collected considering their possible use in hydraulic calculations. A shortage of records in some areas hampered completion of the inventory.

B. Channel Regulation Structures

1. Dikes: A dike may be defined as a structure used for channel

regulation or bank protection purposes. Dikes may be classified as either permeable or impermeable. Permeable dikes are built of materials which readily allow passage of flow. Their success depends on reduction of velocity to facilitate deposition of sediment. Impermeable dikes are built of material, such as sand and rock, which will not readily allow passage of flow. Some basic functions performed by dikes as training works are:

a. providing protection against bank erosion
b. guiding or deflecting flow
c. controlling channel widths at low stages
d. promoting sediment deposition or scour
e. creating storage areas for dredged material
f. promoting chute closures

Dike construction began before federal involvement on the river; for example, private dikes were used in the St. Louis area beginning in the 1830's. These dikes were built basically of stone.

After formation of the Mississippi River Commission in 1879, federal dike construction began to appear along the river. The early federal dikes were permeable types. However, by 1962 in the St. Louis District and by 1964 in the Memphis District, impermeable or stone-filled dikes had gained favor.

2. Revetments: A revetment is a bank protection structure which serves as a shield against erosion and as a training structure to maintain channel alignment. Materials used in revetments include rock, woven-willow mats, asphalt mats, and articulated concrete mats. Other materials such as concrete tetrahedrons, lap slabs, and reinforced asphalt have also been used, but on a much smaller scale. At present

the most popular material in the St. Louis District is rock while downstream articulated concrete mats are preferred.

Major federal activities in revetment construction had initial emphasis in the early 1880's as part of the program of the Mississippi River Commission. Another period of emphasis began in 1928 as a consequence of the Flood Control Act.

C. Levees

An inventory of levee construction would be incomplete without commentary relative to the natural levee system which exists solely by virtue of processes in nature. The early non-federal levee construction accompanying agrarian settlement along the river must also be recognized. Existence of these early levees, in many respects, affected subsequent levee construction activities. Section F of this chapter is a synopsis of the history and development of the program of river control.

D. Levee Crevasses

There are annual failures of small farm levees for which documentation is unavailable. Therefore, this study has been restricted to tabulation of significant crevasses of federally-owned levees within the Lower Mississippi Valley Division. This tabulation includes date of breach, location, type of breach, flood stage, size and type of area flooded, estimated damage and physical features of levee and breach. Much of the historical information is not documented. Recent breaches are well documented but their occurrences are rare. The most recent breach in the study limits was at Kaskaskia Island in the St. Louis District (1973). This failure was due to overtopping because the levee was not constructed to the authorized grade. In the St. Louis district between 1940 and 1950, several failures which occurred by overtopping during construction were not listed as crevasses. In general, most crevasses occur as a result of overtopping and subsequent erosion rather than as a direct structural failure.

E. Data Procurement and Compilation

1. Procurement: The procurement of inventory data was in accordance with specifications of the study contract. Special data forms were developed to facilitate the orderly compilation of the available data. The information on these forms which pertains to structures included physical location, date of construction or modification, materials used, elevations and profiles referenced to a low-water reference plane, and a summary of the current operational status of the structure. Information on forms pertaining to crevasses included date of breach, identification number and name, location, type of breach, and other information relating to the size of the breach. The prime sources for data were:

   a. Original plans
   b. OCE reports
   c. Congressional documents
   d. U.S. Corps of Engineers special reports
   e. U.S. Corps District channel improvement reports
   f. Project maps

2. Dike, revetment, levee, and crevasse data were placed in individual files by river-mile location and each file was partitioned according to Corps District. These were then coded, keypunched, and stored on the computer. Computer programs were written to sort each file and to produce the inventories of dikes, revetments, levees, and

crevasses presented in Appendices 7.1, 7.2, 7.4, and 7.5, respectively. Map locations of federal levees in the St. Louis District and dikes and revetments for the entire study area are shown in Appendix H as an incidental consequence of surficial soils mapping.

F. History of River Control - John B. Heagler, Jr.

The natural condition of the Lower Mississippi River is that of a meandering sedimentary stream which deposits its alluvium over the floodplain during high water. The pattern of alluvium distribution has determined the development of the river and has had important consequences for later levee construction. The geological history of the river is well treated by Fisk in his various reports. In discussing alluvial deposits (1947), he states:

> "Under natural conditions the river channel was unable to accommodate all of its high-stage flow and overtopped its banks periodically. Great quantities of silty and clayey sediments were laid down by these floodwaters, forming natural levees along the banks of the stream. The natural levee is typically best developed on the outside of river bends as a low sloping wedgelike ridge of sediments, over a mile in average width, tapering into the adjacent lowlands. These levees are being constructed above the general level of the floodplain basins and are the topographic forms which cause the meander belt to stand up as an alluvial ridge...Because of the fertility of the soil and the comparative ease with which it drains, the natural levee is the site of most of the agricultural land in the lower Mississippi Alluvial Valley."

Fisk also reports that these natural levees, while lower than 15 feet in the northern part of the Valley, are generally greater than 25 feet above the surrounding floodplain in the southern section. Humphreys and Abbot, in a study published almost a hundred years earlier, also noted the height of the natural levees near the river and included the following table of slopes in their report.

TABLE 7.1
Slope of the natural banks of the Mississippi.

Locality.	Bank.	Fall in first mile from river.	Authority.
		Feet.	
Near Cairo	Right.	4	Cairo and Fulton railroad company.
Near Memphis (measured from bank of Mill-seat lake)	Right.	6	Military road—Memphis to Little Rock.
Near Prentiss	Left.	7	Delta Survey (party of Mr. Pattison).
Near Gaines' landing	Right.	5	Gaines' landing and Fulton railroad company.
Northern boundary of Louisiana	Right.	8	Professor C. G. Forshey.
Near Lake Providence	Right.	8	Providence and Fulton railroad company.
Near Natchez; measured from bank of lake Concordia	Right.	8	Delta Survey (party of Mr. Pattison).
6.6 miles above Williamsport	Right.	7	Delta Survey (party of Mr. Ford).
1.3 miles above Williamsport	Right.	5	Delta Survey (party of Mr. Ford).
Below Williamsport, near Morgan's	Right.	9	Delta Survey (party of Mr. Ford).
New Texas road	Right.	10	Swamp-land commissioner's office, La.
11 miles above Point Coupée church	Right.	3	Delta Survey (party of Mr. Ford).
3 miles above Waterloo	Right.	12	Delta Survey (party of Mr. Ford).
4 miles below Port Hudson	Right.	9	Delta Survey (party of Mr. Ford).
7 miles below Lobdell's store	Right.	5	Delta Survey (party of Mr. Ford).
5 miles above Baton Rouge	Right.	3	Delta Survey (party of Mr. Ford).
Grosse Tête railroad	Right.	10	Dr. William Sidney Smith.
6 miles below Baton Rouge	Right.	13	Delta Survey (party of Mr. Ford).
7.5 miles below Baton Rouge	Right.	12	Delta Survey (party of Mr. Ford).
1.5 miles above bayou Manchac	Left.	6	Delta Survey (party of Mr. Ford).
Opposite bayou Manchac	Right.	11	Delta Survey (party of Mr. Ford).
4 miles above Bayou Goula	Right.	10	Delta Survey (party of Mr. Ford).
1.5 miles above Bayou Goula	Right.	6	Delta Survey (party of Mr. Ford).
8 miles below Bayou Goula	Right.	5	Delta Survey (party of Mr. Ford).
1 mile below Domenique's landing	Right.	6	Delta Survey (party of Mr. Ford).
3.5 miles above Donaldsonville	Right.	3	Delta Survey (party of Mr. Ford).
5 miles below Donaldsonville	Left.	5	Delta Survey (party of Mr. Ford).
10 miles below Donaldsonville	Left.	9	Delta Survey (party of Mr. Ford).
10 miles below Donaldsonville	Right.	6	Delta Survey (party of Mr. Ford).
20 miles below Donaldsonville	Left.	8	Delta Survey (party of Mr. Ford).
4 miles above Bonnet Carré church	Right.	7	Delta Survey (party of Mr. Ford).
Upper end Bonnet Carré crevasse	Left.	10	Delta Survey (party of Lieutenant Warren).
Lower end Bonnet Carré crevasse	Left.	3	Delta Survey (party of Lieutenant Warren).
Barataria canal	Right.	7	Surveys of canal company.
1 mile below Barataria canal	Right.	4	Delta Survey (party of Mr. Ford).
Near New Orleans	Right.	10	New Orleans and Opelousas railroad company.
Near New Orleans	Left.	10	Mr. G. W. R. Bailey.
11 miles below New Orleans	Left.	8	Delta Survey (party of Mr. G. C. Smith).

The general composition of these natural levees, as reported by Fisk is given in the following figure.

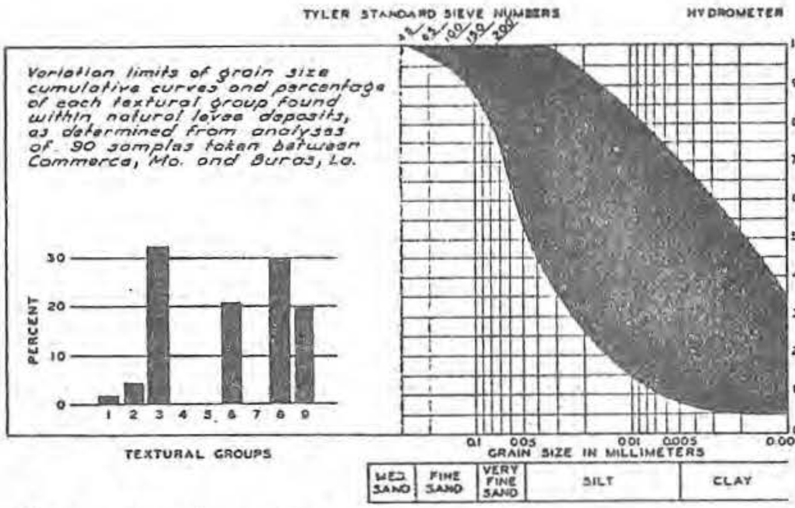

Figure 7.1 NATURAL LEVEE DEPOSITS

TEXTURAL GROUPS: COMPOSITION VARIES FROM SAND TO CLAY. CHARACTERISTIC TEXTURAL GROUPS ARE SANDY SILT, CLAY SILT, SILTY CLAY AND CLAY. THERE IS A GRADUAL DECREASE IN GRAIN SIZE SOUTHWARD FROM CAIRO, ILL. THE PERCENTAGE OF SANDY AND SILTY MATERIALS ALSO DECREASES AWAY FROM THE CREST OF THE NATURAL LEVEES.

SORTING: SANDY AND SILTY SEDIMENTS OF THE COARSER TEXTURAL GROUPS ARE USUALLY WELL SORTED; THE CLAYS ARE REPRESENTED BY THE COARSER HALF OF THEIR GROUP AND ARE GENERALLY POORLY SORTED.

WATER CONTENT: GENERALLY VERY LOW. LENSES OF CLAYEY SEDIMENTS OCCASIONALLY HAVE HIGH WATER CONTENT.

ORGANIC CONTENT: EXTREMELY LOW. SMALL LAYERS OCCUR LOCALLY.

COLOR: USUALLY LIGHT IN COLOR, VARYING FROM TAN, BROWNISH GRAY TO LIGHT GRAY. COLOR IS INFLUENCED BY SOURCE OF SEDIMENTS; RED AND ARKANSAS RIVERS CONTRIBUTE BROWN AND RED SEDIMENTS.

THICKNESS AND DISTRIBUTION: OCCURRENCE LIMITED TO NARROW ZONES ALONG PRESENT AND ABANDONED RIVER COURSES. THICKNESS OF THESE DEPOSITS VARIES WITH LATITUDE AND POSITION ALONG STREAM. DEPOSITS ATTAIN THEIR MAXIMUM THICKNESS AND DISTRIBUTION ON THE OUTSIDE OF BENDS. DEPOSITS ARE SELDOM OVER 15 FEET THICK IN THE NORTHERN PART OF THE VALLEY AND INCREASE TO A MAXIMUM OF ABOUT 25 FEET IN THE DELTAIC PLAIN REGION.

STRATIFICATION: GENERALLY MASSIVE, WELL-BEDDED EXTENSIVE LAYERS.

The natural levees form the highest aggradational floodplain feature and, as such, exhibit a significant influence on the river and the development of the floodplain. The surface drainage away from the river has turned the adjacent lowlands into backswamps into which the finest clays and silts carried by floodwaters, are deposited. Also, since the natural levees are higher than the surrounding floodplain they tend to block drainage from the floodplain back into the main channel and force it into secondary tributaries that ultimately enter the main channel at a lower elevation. Because of this, the backswamp areas are rather poorly drained. "When the natural levee deposits become too high, the river confined by them often breaks away during flood times and forms a new channel through the interstream depression." The natural levee is also subject to destruction by bank caving which may occur during low water. As the river's current impinges on the banks, strata underlying the natural levee may be eroded until the overburden load collapses into the stream and is carried away as sediment. Natural levees formed by river deposition have obviously beem important agents in determining the course of the river and the morphology of the river's floodplain. The natural levees also had and still have an important influence on the settlement patterns and land use of the floodplain. It is obvious that the landforms established by deposition during flood stages are susceptible to inundation from later high water. If the natural levees are submerged, the lowlands behind them are covered even more deeply. In discussing this fact J.A. Ockerson (1903) states that while people saw flood depths of three or four feet over the natural levees, "They did not appreciate the fact that perhaps five miles farther back the water was 10 ft., or more, in depth." The first Mississippi flood on record occurred in 1543 (Elliott, 1932). It began in early March and was not back within the banks until the end of May, about eighty days after it had begun. Although water was again confined by the natural levees, the lower lands behind them must have taken longer to clear because of the poor drainage of the backswamps. With floods of such depth and duration, it is apparent that no permanent settlement or cultivation could be established along the river without making provisions for floods. The use of artificial levees for the protection of man, his properties, and his endeavors began with the very first settlement of white men on the Mississippi floodplain. When Bienville chose a site in 1717 for the City of New Orleans, his engineer, de Latour, objected on the basis that it would be easily inundated by high water. Upon being overruled, de Latour constructed an earthen embankment, modeled after the European levees, to protect the city. It was only four feet high, 5400 feet long, and 18 feet wide, but it proved to be sufficient for protection. As settlement progressed along the river, the levee line was extended by individual landowners at their own expense both above and below the city to prevent flooding of the farmlands. To allow the greatest area for cultivation, to utilize the best agricultural soil, and to keep construction expenses low, these levees were set close to the river along the top of the natural levees. This meant that the levees often failed due to caving banks. Apparently this did not discourage construction, for by 1735 the levee line extended about thirty miles above New Orleans on both sides of the river. No specifications for levee grade and section for this period are known, but some minimum criteria must have existed, since levee construction did become the official policy of the French government. Riparian landowners were required to complete their levees by January 1, 1744, or forfeit their lands to the Crown. The required levees were small by today's standards and crevassed often, but they provided enough protection to be put into general use. What effect the leveeing of this portion of the river had on the Mississippi itself cannot be assessed. The river was still free to flood above this section and outlets such as the Atchafalaya were still unobstructed. Furthermore, according to Fisk, the alluvial deposits below Baton Rouge are mainly clays, as opposed to sandier alluvia above this point. Clay deposits resist erosion much better than sand, so any change in the channel due to levees would be slow and, in the absence of precise observations at the time, impossible to determine. The use of levees by individuals for flood protection continued even after the transfer of Louisiana to the United States and by 1812, the east bank had levees up to Baton Rouge and the west bank forty miles beyond that. By 1844, the west bank levee line was almost continuous up to the Arkansas River, while only a few levees protected the Yazoo Basin on the east side. During most of this period, it appears that there was very little planning done as to the location, dimensions, etc., of the levee system. Some of the largest levees were indeed built with engineering considerations, but this was generally not the case. The levees from the French period and after were constructed by the riparian landowners and supervised by local authorities to ensure adequate strength. What constituted adequate strength seems to have been based on experience rather than on any engineering criteria. As settlement continued, the task of flood control increased and slowly the engineering of levee construction became more important. For example, in 1833 Louisiana created a post for a civil engineer to be a supervisor of public works, including levees, and in 1835 legislatively specified the dimensions of the Concordia Levee. Larger engineering questions of flood control were also discussed. According to Harrison,

> "The long debate on the best plan for protection of the Alluvial Valley bagan in the 1840's. The need for outlets for Mississippi River floodwaters was discussed with attention to their possible location. Reservoirs were mentioned

> occasionally as a possible protection, but immediate efforts were directed towards levees as the only practical means of flood control."

Such attention to levees was given that by 1858 William Hewson was able to publish a detailed study of the various engineering aspects of levee construction and could recommend specifications for dimensions, materials, etc. With the gradual accumulation of knowledge about levees by landowners, engineers, and the States, over six hundred miles were erected before the Federal government became involved, to any major degree, in levee construction in 1850. Previous Federal involvement consisted simply of granting land for particular levees when these levees were being built. Under the prompting of Louisiana and several other states, Congress eventually passed a series of bills, the Swamp Acts, in 1849 and 1850. These granted all swamps and overflowed lands to the States, provided that the States would construct levees to protect the areas and open the swamps to cultivation by draining them. These laws are loosely worded and the actual intent of the Congress is unclear. Elliott feels that they were intended to be flood control legislation, while other writers, citing grants to States outside the frequently inundated Mississippi Valley such as Oregon, Michigan, and Florida, stress that the reclamation of wetlands was the basic intent. In much of the literature on the Lower Mississippi Valley "reclamation" and "flood control" appear to be almost synonymous. Thus, it cannot be claimed that the Swamp Acts are a clear statement of a Federal desire for flood control by an extensive levee system. It must also be stressed that the Federal government merely granted the lands for reclamation but expended no funds to aid this project. For example, even the surveys to determine what swamplands actually existed were done at the States' expense.

The major effect of the Swamp Acts in the Mississippi Valley was to organize levee construction much more than it had been. Responsibility for the levees had been slowly passing from the landowners to the States, but now the States assumed an even greater role as they began to specify grades and sections, and set up administrative systems for construction and maintenance. The expense of the levees were now assumed, through bonds and taxes on reclaimed land, by people other than the riverside landowners. Unfortunately, the levees built under this system were not large enough, poorly located and poorly constructed, while the administrative systems were defectively organized, and coordination between states was difficult. In spite of these failings, much practical experience with levee construction was gained by engineers and the levee system built was the best yet achieved. One contemporary evaluation of the system, while admitting its deficiencies, states:

> "Great practical good, however, has resulted even from the imperfect application of the system; for without it the greater part of the alluvial region below the mouth of the Ohio would be an uninhabitable swamp in the high-water months of the year."

In 1850, Congress also authorized a detailed survey of the river with a view to determining "the most practical plan for securing it from inundation." Captain A.A. Humphreys and Lieutenant H.L. Abbot made detailed observations of the river in 1851 and 1858 and considered a variety of proposed methods for flood control. The importance of the Delta Survey's report cannot be underestimated, for its conclusion that levees alone could control the river was accepted by later studies and eventually became the basis of flood control on the river, despite many other proposals. Until this point, levees had been built as necessities and little consideration was made of their potential effect on the river. Humphreys and Abbot, on the other hand, were required to make such an evaluation and much of their work included obtaining the precise data needed for such a task. Some interested people had kept stage records for a few cities, but a general collection of data did not exist. Thus, a major effort of the Delta Survey was the establishment of gages at various points along the river, and making a detailed study of the topography and characteristics of the Mississippi and its tributaries' basins. Utilizing these data, Humphreys and Abbot considered a series of flood control measures. The proposals generally followed one of two philosophies, later characterized by Corthell (1882) as a "Dispersion Theory" and a "Concentration Theory". The first is based on the principle that if one could get the water to the Gulf more quickly, either by shortening the river or by providing more outlets, floods would be lowered. The second functions on the basis that confining the water to the main channel would force the river to conduct all of its floodwater to the Gulf without spreading over the floodplain. Artificial cutoffs, designed to shorten the river, were decided to be impractical if they must be constructed from the mouth to the point where flood reduction is needed, as proponents desired. A cutoff of a single bend, while it would certainly depress flood stages above it, would merely raise stages below because the river could not handle the increased amount of water. Cutoffs, whether natural or artificial, were thus to be prevented. Artificial outlets, designed to remove the extra amount of water needed to create a flood, were considered in great detail. These were to be constructed either by creating new outlets or by enlarging already existing bayous which run parallel to the Mississippi. It was concluded that crevasses, and therefore outlets, do not induce sediment deposition immediately below their openings, a conclusion still contested years later, but the disposal of water after intake was the proposal's main defect. Some bayous were too long to be enlarged practically, while other might enlarge too much and divert too much of the river. In the case of a Bonnet Carre or Lake Borgne outlet, sediment deposition at the mouth would cause many problems. In general, outlets were seen as impractical, but it must be remembered that Humphreys and Abbot were considering all-season outlets, not spillways. Diversion of tributaries such as the Missouri, Arkansas, and Red Rivers, to reduce the total amount of water needed to be conducted by the Mississippi, was rejected. Humphreys and Abbot did not have all the data they felt they needed to make an absolute conclusion, but from what they had it appeared either that the diversions would create more injury once they were made or that they would have little effect on the Lower River. The final alternative to levees considered was the use of reservoirs. Humphreys and Abbot admitted that retention of water during floods and subsequent release during low water would have a neglible effect on the Lower River, because much of the rainfall causing floods falls directly over the Valley. On the other hand, reservoirs in the Lower Valley would be impossible because there are no suitable locations for them on the floodplain. After the discussion of the alternatives, the Delta Survey report contains a long analysis of levees and their effects. The main objection to levees with which Humphreys and Abbot dealt was that levees cause an elevation of river beds. Based on the European experience with the Po, it was argued that the sediment ordinarily spread over the floodplain would now be dumped on the river bed, raising the river surface, and thereby requiring a further heightening of the levees. This idea was dismissed based on further observations of the Po by Chevalier Lombardini. Following discussion of their observations, Humphreys and Abbot concluded that a fully-leveed river with no crevasses would have floods up to ten feet higher than that of 1858. Because of the increased head and the resultant velocity increase, these floods would be of shorter duration. It was therefore recommended that a levee system be built below Cape Girardeau, Mo. of sufficient height to contain the increased flood stages. A single outlet near Lake Providence connected to Bayou Tensas was also suggested as a possible way to reduce the stages in this reach of the river. Much of the Delta Survey's conclusions rest on the assumption that the bed of the Mississippi consists of hard, virtually non-erodible blue clay. Thus, Humphreys and Abbot did not claim, as later proponents did, that levees would deepen the channel, for they felt any increase must be made at the expense of the banks, producing a wider but not deeper channel. They must have felt this deterioration of the natural levees by the artificial levees was already taking place. In considering the use of bank heights in leveed sections as indicative of previous flood heights, they state that:

> "...crevasses may reduce the surface of the river as low as, if not lower than, it would have been if the natural banks existed in their original, unleveed condition, for the mean level of the natural bank, where the levee system has been in operation for many years must, from constant caving, be lower than it was originally."

Before any action was taken on further flood control, the Civil War intervened and with the States' energies focused elsewhere, the existing levees were crevassed and many washed away. After the war the States were too impoverished to maintain the levees to any great extent, and the main Federal effort on the river was aimed at navigation improvement, not flood control. Although little construction was taking place, engineers continued to discuss the issue of levees and their effects. Some rejected the Delta Survey's conclusion about the permanence of the river bed, claiming considerable deepening would or had occurred and thus there would be no increase in flood heights. Hewson, in his Principles and Practices of Leveeing, was not concerned with the bed, but suggested that a slow increase in flood heights would begin as the delta was extended by the increased amount of sediment carried into it. Others stood by the conclusion that the bed would remain at the same level, while still others continued to believe in the elevation of the bed. Obviously, the Delta Survey had not settled the question of flood control, but it did provide necessary data for subsequent discussion. While levee construction and flood control continued under the old system, the Federal government became more involved in the navigational aspects of the river. Since 1824, the Corps of Engineers had been charged with the removal of snags from the stream and other channel improvements. The first dredging occurred in 1856 and was attempted again in 1867; river gages were constructed in 1875. With this emphasis on navigation improvement, little investigation was made into flood control, but the studies which were made reached important conclusions. A commission studying the impact of the 1874 flood on the levees clearly defined the grave deficiencies in the system for levee construction and administration. Elliott reports as follows:

> "In its report, submitted in 1875 and based largely on the work of Humphreys and Abbot, the Commission found the existing system defective as the result of five principal causes, to-wit: vicious levee organization; insufficient levee height; injudicious cross section and construction; inadequate inspection and guarding; and faulty location. The Commission expressed

> its opinion that no practicable aid could derive from any diversion of tributaries or by artificial reservoirs; that cut-offs were pernicious in their effects; and that outlets, although correct in theory, would find no useful application on this river. A general system of levees from the head of the Alluvial Valley to the Gulf, including the valleys of the tributaries, was advocated, and it was recommended that this project be executed under the general supervision and control of a board of commissioners which would report to the supreme authority from which it would derive its legal existence. The board further stated that little could be accomplished under the existing conditions without Federal aid."

Another report in 1879 by a board of engineers considering low water navigation combined the theories of levees and navigation improvement in a manner foreshadowing the future Federal stance on levees. Elliott again reports:

> "(The Board) advanced the conclusion that a complete levee system would aid commerce during periods of high water but would have little or no influence upon low-water navigation. The Board stated that the greatest obstacle to navigation improvement and levee maintenance was the instability of the river due to bank caving. The Board concluded that the levee system, if undertaken, should be developed in connection with navigation improvement."

With the establishment of the Mississippi River Commission in 1879, the entire Federal program on the river entered a new phase. The Commission consisted of four government and three civilian engineers appointed by the President and reporting directly to the Secretary of War. The jurisdiction of the MRC was confined strictly to the Mississippi from Cairo to Head of Passes, but within this area there were now two engineering bodies, the MRC and the Corps of Engineers. To insure cooperation, the president of the MRC and two commissioners were to be from the Corps. The MRC was charged with improving the river channel to aid navigation, protecting the banks, preventing destructive floods, and aiding commerce and the mails. Harrison correctly notes the debate in Congress over the true reasons for this legislation. Was it for navigation or for flood control? Opponents to the new arrangement argued that while navigation was definitely a national concern, flood control should be handled strictly by local concerns. They feared that this step would eventually result in large expenditures by the Federal government for flood control. Proponents solved the dilemma by considering both concerns as part of the same problem. They stressed that navigation improvement was their primary aim, but if some relief from floods resulted from this work, so much the better. Illuminating, perhaps, are the opinions of one supporter, Rep. Gibson, which demonstrate this emphasis:

> "In the first place, official reports show that during several months in every year immense sandbars and snags close the navigation of the river as effectually as if artificial dams were constructed across its channel. In the second place, official reports show that at other seasons the river rises over its banks throughout the alluvial region and spreads over the country for forty to sixty miles--becomes a mighty roaring torrent--destructive not only to human life and property upon its borders, but destructive to the commerce upon its waters......... In such seasons the largest boats propelled by steam are sometimes destroyed and often detained several days by the extraordinary obstacles they encounter, but that countless fleets of smaller boats, barges, and flatboats, propelled by the current of the river itself, are absolutely at its mercy and are sometimes borne into the adjacent forests and wrecked or whelmed and destroyed in the furious eddies and cross-currents........ This commission is created with the hope that they may devise some plan, economical, feasible, and complete, that shall give us deep water at all seasons of the year and prevent these destructive floods so ruinous not only to the country through which it flows, but to the mighty commerce that carried the production of the teeming millions who inhabit the great valley to the markets of the world and brings back in exchange the wealth of other countries."

The plan submitted by the MRC in 1880 followed closely the suggestions of the Delta Survey and the 1879 Board. Although levees were not absolutely necessary adjuncts to navigation improvement, they were desirable for they were thought to deepen and enlarge the channel.

Bank revetment, permeable contraction works, and the closure of chutes and alternate channels were also among the recommendations accepted and funded by Congress. In order to administer the construction of levees, the MRC simply adopted the existing system of levee districts which had been set up earlier under the States' jurisdiction. At the time, the levee districts had ample funds, while the MRC was dependent on Congressional appropriations, so the new levees were mainly built with district funds. The MRC acted as a coordinator between the districts and States. The Commissioners were not all agreed as to the true value of levees in relation to navigation, but since they were under Congressional instructions to build levees only as aids to navigation, they had to justify any construction in these terms. It was decided in 1882 that levees would be built to grade sufficient to hold the most frequent floods, but the cost of restraining abnormally high floods could not be justified. To accomplish this, gaps and crevasses were to be closed and the levee line was to be extended upstream. The history of the MRC until 1917 was a repetitious cycle of new high-water stages followed by new levee grades. These grades were set in reference to local high water with correction for water lost through crevasses and new upstream levee construction, rather than designing them for a projected flood, the present practice. This meant a new levee at one place occasioned higher levees elsewhere, and the levees were raised in see-saw fashion. For example, during every flood the low levees guarding the St. Francis basin crevassed, providing relief to the much higher levees on the east bank. The controversial closure of the front raised the 1897 flood heights at Memphis by 2.5 feet, causing great strain on the eastern levees.

The Commission recognized that levees would increase flood heights, but with each new flood the crevasses always occurred at points where the levees were still below Commission grades. The belief in the ultimate deepening of the channel and in the impracticality or injurious effects on navigation of other flood control measures encouraged the Commission to stand by its "levees only" policy, despite the continuing opposition by some engineers to it. The debate over the effectiveness of levees was quite extensive, and many other types of flood control were discussed. The Transactions of the American Society of Civil Engineers contain many debates and discussions of levees and alternatives to them. Some writers, such as Robert McMath (1884), attempted to demonstrate that the very theory behind levees was inherently faulty and the levees thus destined to failure. Others merely argued the feasibility of supplementing levees with other devices, such as outlets and reservoirs. One writer even advocates constructing a secondary stream on the western edge of the alluvium to decrease the total volume of water to be carried by the Mississippi. This may be a rather unusual suggestion, but it indicates the range of alternatives being actively considered. Any reader interested in the general feeling of these debates would be well-advised to read "The Levee Theory on the Mississippi: An Informal Discussion", Transactions of the ASCE (1903). These alternatives to levees were not accepted by the MRC and levee proponents at that time, but many points raised in the debate were ultimately utilized for flood control. For example, as early as 1882 emergency outlets to decrease dangerous flood heights were suggested. The Bonnet Carre spillway presently operates on this principle. As the years progressed the focus of the MRC expanded from primarily navigation improvement to include flood control as a major part of its work. It was eventually conceded that the levees' influences on the navigation channel were only slight, but the passage of the first flood control act in 1917 finally permitted the MRC to build levees just for flood control. The act also made changes in the financing of the levees by stating that Federal funds would pay two-thirds while local interest would pay one-third of construction costs, as well as provide the right-of-ways and assume maintenance after completion. Levees constructed entirely by local interests were not prohibited. Although retarded a bit by World War I, the levee building progressed until almost the entire line met MRC standards and the remaining gaps were closed. The successful high-water fight of 1922 brought increased optimism to the Valley about flood control. This optimism was not totally shared by the people intimately involved in flood control. Those constructing levees recognized the great danger still posed by caving banks and pressed for more bank protection. They also realized that floods greater than 1922 could occur and that another raising of levee elevations was required. Others, such as the City Engineer of New Orleans, felt that levees alone were inadequate and should be supplemented with spillways. Throughout this period, the MRC continued its "levees only" policy, but other flood control agencies were considering alternatives. In 1924 the Chief of Engineers, Gen. Lansing Beach, stated:

> "It is to be expected that in the future, as in the past, various alternative plans will be urged for achieving the results desired... All these proposals have been investigated and reported on time and again. However, with the growth of the art of engineering, plans which were not practicable in the past may become feasible in the future,

> and the Engineer Corps will maintain an open mind in the investigation of any reasonable means for river control that are presented by responsible organizations or able engineers."

The MRC claimed no less a willingness to listen. In the words of its president:

> "The Commission is often criticized because it does not hasten to adopt suggestions made to it. People think it so committed to archaic ideas that it will not accept suggestions from the outside--is unwilling to admit that anyone from the outside can tell it anything. On the contrary, it is glad to hear any suggestion. But when a man comes in with the same old thing that has been considered, possibly tried and discarded-nothing new about it except a name-the Commission cannot go all over the ground again. The public is loath to give credit for the amount of thought the Commission has put on river problems--thinks it obstinate when it adheres to principles that have been proven by forty-five years of careful study and observation."

The MRC showed its continuing faith in these proven principles when it considered a proposal for a spillway below New Orleans leading to Lake Borgne. With the aid of Gen. Beach, a group of New Orleans businessmen and professionals had submitted a detailed plan, but after considering it, the MRC replied that, with only the slight reduction in stage, the lengthening of levee lines, and the negative effects on the river by the spillway, "it would be wise first to make the city safe by tried methods which are wholly feasible and much cheaper. The confidence of the MRC in "levees only" and the security felt by the valley inhabitants were shattered by the extraordinary flood of 1927. For the first time, completed levees built to the existing MRC grades were overtopped and crevassed. It was called "the greatest disaster of peace times in our history," by Secretary of Commerce, Herbert Hoover. It killed at least 246 people and left 700,000 homeless while creating over $400,000,000 in losses and damages. The magnitude of the flood and the resulting national attention forced a total review of the existing system of flood control. Congressmen were beseeched to act with passionate appeals, such as that of Rep. Gregory of Kentucky:

> "Mr. Chairman and gentlemen of the Committee, those of you who just a year ago witnessed the mad rush of the mighty Father of Waters, sweeping like a destroying angel over hundreds of proud cities, thousands of happy and contented homes, and millions of fertile fields, or who later visited the stricken area to view the scenes of the greatest peace-time disaster this country has ever experienced, know how futile would be the effort of the most gifted tongue or the most facile pen to describe the wreckage and the ruin, the horror and the agony which were left in the wake of the 1927 flood."

Long Congressional hearings were held and detailed plans for flood control were submitted by both the MRC and the Chief of Engineers, General Jadwin. What is striking about the new proposals is the universal agreement that levees alone were incapable of providing the necessary protection. The MRC was strongly criticized by the House Committee on Flood Control for its strict adherence to the "levees only" policy, and in its own new plan, levees were to be supplemented by floodways, including a spillway to Lake Borgne. A similar system was proposed by Jadwin, but while both plans urged the raising and strengthening of the levees, they included different floodways. Jadwin recommended building a levee about five miles back from the river running from Bird's Point, Missouri, opposite Cairo, Illinois, to New Madrid, Mo. The area between the levees would be flooded during great floods, dropping flood stages at Cairo. Similar floodways were proposed to conduct extra water down the Boeuf Basin and the Atchafalaya. These floodways would be activated by an untried device, a fuse-plug levee, which raised great controversy. The principle involved the construction of a section of the riverside levee, deliberately smaller in grade and section. This section would crevasse naturally at a certain stage, allowing water into or out of the floodway. The final feature of the Jadwin plan was a spillway at Bonnet Carre to let flood waters into Lake Pontchartain. The MRC plan extended the levees up to Rock Island, Ill., and also provided for the Boeuf and Atchafalaya floodways, but none in Missouri. Instead of fuse-plug levees, entrance to these areas would be controlled by concrete spillways. Two spillways would also be built to protect New Orleans, one above at Bonnet Carre and one below at Caernarvon. The most hotly debated issue in Congress was not which engineering plan to accept, but whether local concerns should help pay for the chosen program. The economic devastation of the area raised the question of how much the people in the Valley, who already helped raise the former levees, could now pay. Some, like the President, felt that it would be wrong for the Government to pay the full expense of improvements which would make the protected lands more valuable. Others, like Congressman Reid, head of the House Committee on Flood Control, viewed the situation as follows:

> "Under the present law the United States says to the threatened ones, 'No pay, no protection'....Is our civilization so little removed from barbarism that it will permit hundreds to be drowned and thousands to be made homeless and destitute while, like Shylock, it demands its pound of flesh from those who cannot pay?"

Finally, in 1928 Congress responded to the disaster of 1927 by making the control of the Mississippi a national project. The MRC was reorganized to be a consulting and advisory board under the Chief of Engineers and the Corps of Engineers took over the actual construction work. A board was appointed to examine the two proposed plans and to recommend a comprehensive project; the Jadwin plan ultimately was accepted. Perhaps the most important aspect of the new project was the assumption of the whole cost of construction by the Federal Government. The local interests were still to provide the right-of-ways for the levees free of charge and to maintain them, but, while Congress reaffirmed the principle of those protected helping to pay, it declared that the "approximately $292,000,000 heretofore made by the local interests" fulfilled the requirement. The direct descendant of the 1928 plan is the present system for flood control. What is interesting is that the old controversy over "Dispersion Theory" and "Concentration Theory" was superseded by the use of both principles in controlling the river. It was no longer a case of levee proponents on one side, with supporters of everything else on the other, but a situation where each suggestion was discussed on its own merits. In such an atmosphere the present system came to include outlets and reservoirs. Ironically, even the river itself suggested the adoption of what earlier writers saw as the greatest evil--artificial cutoffs. In 1929, despite all preventive efforts, the Mississippi eroded its banks until it intersected the Big Black River tributary, two miles above the latter's mouth. Over a period of years, the Mississippi's current transferred to the new channel without causing the drastic regime changes attributed to cutoffs. This prompted the making of a series of artificial cutoffs in the middle section of the river by the Corps of Engineers. These cutoffs substantially reduced the floods heights at Memphis and Natchez and permitted the elimination of the Boeuf Floodway from the flood control plan. In reaching the present situation, there has been a gradual assumption by higher authorities of the responsibility for the river, forced by the magnitude of the task of controlling the floods. Finally, the Federal government assumed partial interest, and ultimately total responsibility, for levee construction. Each shift of responsibility came as the existing authority could no longer build levees that were sufficient to protect the lands. It was this last consideration that underlines the entire history of the levees, for, regardless of who had responsibility for them, the basic premise for their construction remained unchanged: levees are absolutely necessary if cultivated and inhabited land is to be protected. The early French believed this and each succeeding generation has continued the use of levees despite disastrous crevasses and floods and great expense. Levees do keep the river from naturally depositing its sediment on the floodplain, rejuvenating the land, but such extensive flooding and inhabitation of the floodplain are two incompatible states. A choice has been made, not only by the present generation, but by the first settlers and each succeeding generation. The increase in flood heights, although not always anticipated, has been accepted as a consequence of being able to live and utilize the Mississippi floodplain.

G. Conclusions

The inventories presented as appendices will aid in evaluation of the effectiveness of past engineering activities related to development and control of the Mississippi River. Such inventories may aid in anticipation of the effects of future engineering activities. Several problems encountered in preparing this inventory should be considered in light of the possibility that continued interest on this subject will prevail. First, the volume of data to be processed required considerable effort. Second, the variation in records or consistency of data between Districts caused problems in tabulation. For example, revetment data in the St. Louis District had to be tabulated with a different format. Third, loss and destruction of records was a problem.

VIII. COMPUTER DATA BASE AND PROCESSING

Frank J. Kern

A. Introduction

The computer-generated plots and tables in the appendices are derived from two major data files which were compiled as one of the tasks completed by the project teams. One major file contains all stage-discharge data for all eighteen stations covered in the study and the other file contains dike, revetment and levee data. Since the organization of, and methods used, in processing these major files are quite different, they will be discussed in separate sections.

B. Stage-Discharge Data File

1. Organization

The stage-discharge data file contains numeric stage and discharge data for each of eighteen stations. Data for each station are arranged sequentially by month and year, each year block being separated from the next year by a header card. All stations are arranged in a partitioned, sequential data set with the first eight characters of the station name being used as an identifier. The station names contained in this file are:

> St. Louis, Vicksburg, Red River, Memphis, Keokuk, Arkansas City, Meredosia, Paducah (Flow data only), Little Rock, Simmesport, Alexandria, Helena, Hermann, Metropolis, Thebes, Clarendon, Chester, and Alton.

The data contained in these files are FORTRAN compatible. A complete description of the card format is contained in Appendix 3.1.

2. Debugging

The data cards were punched from written lists. After each station file was completely punched, a listing of the card images was checked by hand against the lists used to punch the data. After corrections were made, the data file was loaded onto disk and a series of debugging programs were run. The first program (called MXMN in Appendix 3.1) was used to check for obvious punch errors, misplaced cards, and order-of-magnitude data errors which result from having entire cards shifted left or right one or more columns. A second program (called BUGPACK in Appendix 3.1) was used to determine if the data were "reasonable", i.e., if successive data points are likely to be on the stage-discharge curves. "Questionable" data points indicated by this program were checked by hand thus enabling some correction of errors which occurred in the original data lists.

3. Processing

All debugging and processing programs for this file are written in FORTRAN IV (G) (IBM 360/50). A complete, documented, listing of each is contained in Appendix 3.1 and will not be discussed in further detail here. All machine-generated plots contained in other appendices were made in a standard 7.5" x 15" format on a Calcomp 565 Plotter using a felt tip pen and then photo reduced for report purposes. With slight modifications, the plotting programs also are fully FORTRAN compatible and can be used in other Calcomp plotter installations.

C. Dike, Levee, and Revetment Files

1. Organization

The dike, levee, and revetment files contain alphanumeric code which is a distillation of information collected on data forms by the project team. Data cards containing this information were punched from coding forms which were in turn prepared by copying data from questionnaire forms which were filled out in the various districts. Since the type of information obtained on dikes, levees, and revetments is slightly different, the main file is organized into dike, levee, and revetment subfiles. Each subfile is further subdivided into blocks of approximately 1000 card images, each block containing data pertaining to a particular district and (variable) span of river miles. The card images in each block are loaded in random order with the information on each card keyed to an identifier number which may be used for sorting purposes.

2. Debugging

After punching, each file block was checked by hand against the coding form using a listing of the card images. No further preliminary debugging was attempted.

3. Processing

Since the generation of the reports pertaining to those data involves primarily character-string manipulation, all programs used in processing have been written in PL-I (IBM 360/50). This language was chosen because of the flexibility it offers in character-string manipulation and also because of local availability. A complete, documented listing of these programs is contained in Appendix 3.1 along with a detailed description of the card format for each file. It was necessary to develop a standard format for displaying all dikes, all levees, and all revetment data in report form which included all information which could, but did not necessarily, appear in a given file. Therefore, blank entries in the report format are usually interpreted to mean that data are not available from current files.

D. Obtaining Copies of Data Files

The two major files consist of approximately 100 boxes of cards. Copies of these cards, or card images on user supplied tape, are available from University of Missouri-Rolla. There will be some duplication fee, depending on the user's requirements.

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5-2	June 1948	Field Investigation of Reid Bedford Bend Revetment, Mississippi River, Vol. 1 Text, Vol. 2 Plate, Vol. 3 Appendix A-Soils Investigation.
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IV. UMR LIBRARY

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Subject - Geological Investigation of the Alluvial Valley - 1944
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Part VII - Summary and Conclusions
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