PROTOTYPE REACH

RIVER REGULATING WORKS

MIDDLE MISSISSIPPI RIVER

MILE 140 TO 154

MAY 1971

U.S. ARMY ENGINEER DISTRICT, ST. LOUIS
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

FOREWORD

A prototype study, such as this one, is a necessary step toward the development of empirical design data which will enable the St. Louis District to obtain a dependable 9-foot navigation channel on the Mississippi River between the Ohio and Missouri Rivers.

The prototype reach, located between miles 140 and 154, was selected as the study site because most of the channel improvement problems encountered on the Middle Mississippi River are encompassed within this reach. It contains a straight reach, an S-type bend, deep water pools, shoal water crossings, and requires repetitive dredging to maintain the navigation channel.

The prototype reach consists of a series of stonefill dikes that contract the river to a width of 1,200 feet. Prototype construction was initiated in July 1967 and completed in March 1969. This is the first attempt at evaluating prototype reach performance and is based upon survey data obtained in June 1970.

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Colonel Carroll N. LeTellier, CE, was District Engineer and LTC George L. Pitre, Jr., was Deputy District Engineer during the preparation of this report.

SUMMARY

The conclusions contained in this report are based upon conditions which are still in a state of flux because the river has not fully adjusted itself to the 1200-foot contraction. Study data collected to date, however, does contain information which indicates the prototype reach may eventually bring about more improvements in the navigation channel than were originally contemplated at the time this study program was undertaken.

The original study program was based upon the premise that a 1200-foot contraction would most likely be required to develop a 9-foot navigation channel below a datum plane (i.e. low water reference plane) based upon a project flow (i.e. discharge) of 40,000 c.f.s. Study data contained in this report indicates the probability that the 1200-foot contraction may develop a deeper navigation channel than is required under the authorized 9-foot channel project for the Middle Mississippi River.

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PART I - INTRODUCTION

BACKGROUND INFORMATION

1. The existing Nine-Foot Channel Project was authorized by the River and Harbor Acts of 21 January 1927 and 3 July 1930. The improvement provides for obtaining and maintaining a 9-foot by 300-foot channel for navigation from Cairo, Illinois, to St. Louis, Missouri. An engineering determination indicated it was feasible to obtain a dependable 9-foot channel with dikes and revetments, and that some dredging would be required to maintain navigation depths across troublesome shoal-water areas.

2. Original design assumptions called for a 2,250-foot contraction from River Des Peres, mile 172, to Grays Point, mile 46.3; a 2,500-foot contraction from Commerce, mile 39.5, to Commercial Point, mile 32.1; and a 2,000-foot contraction from Commercial Point, mile 32.1, to the mouth of the Ohio River, mile 0. Timber pile dikes were designed to slope from the high-bank elevation at the landward end to the low-water reference plane elevation at the riverward end. The low-water reference plane elevation was equivalent to -2 feet on the St. Louis gage, based upon a low-water flow of 40,000 cubic feet per second.

3. Shortly after the 9-foot channel project was authorized, the original design assumptions were revised in order to obtain a

dependable 9-foot channel. The width of the contraction was changed to a uniform 1,800-foot width from the lower end of the St. Louis Harbor to the mouth of the Ohio River. The height of the contraction at the riverward end was also increased to an elevation equivalent to 20 feet on the St. Louis gage. The reason for increasing the height of the contraction was to encourage the growth of willow trees to stabilize accreted materials.

4. The project flow was changed from 40,000 c.f.s. to 54,000 c.f.s. about 1934 when it was assumed that advantage could be taken of planned releases from the newly constructed Ft. Peck Reservoir on the Missouri River. This action raised the low-water reference plane elevation from -2 feet on the St. Louis gage to 0.0 feet on the St. Louis gage.

5. When the 9-foot channel project was authorized, the navigation season extended only from 1 March to 1 December. Navigation was not practical during the winter months, due to the fact that the middle Mississippi River is subject to heavy ice floes and low river stages during the winter season. When towboats and barges constructed with steel hulls came into general use on the waterway, navigation interests found it was possible to move large tows through moderately heavy floes of ice. Due to the emergency which existed during the World War II period, the navigation season was extended to include the entire calendar year. Although much lower flows have been known to occur during the winter season, the project flow remained at 54,000 cubic feet per second.

6. From 1950 to 1958, pile dike structures were extensively damaged by floods, ice floes, and floating drift. While damages of this nature had occurred prior to 1950, the rate of damage losses increased sharply after 1950. This was due to the fact that the economic life of pile dike structures was less than the length of time required to construct the project. Consequently, by 1950, natural deterioration of pile dike structures had severely weakened those structures so that damages from floods, ice floes, and floating drift increased at a faster rate than funds were appropriated to make the necessary repairs.

7. Due to economic considerations, the use of timber piles for dike construction was discontinued about 1960. The initial cost of stone dike construction was higher than that for timber pile dike construction; however, the higher initial cost of construction was justified by the fact that stone dikes have a lower maintenance cost and longer economic life.

8. Prior to 1960, much of the difficulty experienced in maintaining a dependable 9-foot channel was attributed to the fact that the major portion of pile dike structures were in a state of disrepair. By 1965, approximately 25 percent of these pile dike structures had been converted to stonefill dikes. It was noted that considerable channel improvements were accomplished in those areas where the 1,800-foot contraction was essentially composed of stonefill dikes; however, dredging was still required when river stages fell below 5 feet on the St. Louis gage. To summarize the status of the channel

improvement program in 1965, experience gained from the construction of the 1,800-foot contraction, with the use of stonefill dikes, indicated a dependable channel could not be achieved at a project flow of 54,000 c.f.s. It is worthwhile to note at this point that degradation of the riverbed lowered the low-water reference plane for a flow of 54,000 c.f.s. from 0.0 feet on the St. Louis gage in 1926 to -3.5 feet on the St. Louis gage in 1956.

9. In the spring of 1965, the Corps of Engineers, Lower Mississippi Valley Division, expressed the opinion that the St. Louis District had an obligation to maintain a minimum 9-foot navigation channel throughout the entire navigation season. The entire 9-foot channel improvement project was reviewed to learn how this could best be accomplished. At the time this study was undertaken, some discharges occurred on the Middle Mississippi River which were less than 54,000 c.f.s. Accordingly, a decision was made to use a discharge of 40,000 c.f.s. in lieu of 54,000 c.f.s. Hydraulic computations indicated a 1200-foot contraction would be required to develop a dependable 9-foot channel at the lesser discharge.

10. Past experience gained from the design and construction of contractive works indicated the advisability of constructing a prototype reach to verify preliminary design assumptions. The St. Louis District made a recommendation to this effect which was subsequently approved by higher authority.

SCOPE AND PURPOSE

11. This report is concerned with the reach of Middle Mississippi River between miles 140.0 and 154.0 above the mouth of the Ohio River. Channel characteristics are compared for the period 1966 - 1970 to cover conditions before and after dike construction in this portion of the river.

12. The purpose of this report is to document all the data which has been accumulated to date, and to compare related factors before and after stone dike construction.

VARIOUS PLANS UNDER STUDY

13. When the prototype reach study was authorized the selection of the low-water datum plane was left to the discretion of the St. Louis District. The following four low-water datum planes are currently under consideration:

a. Average low-water for past 10 years.

b. Average low-water for past 20 years.

c. 54,000 c.f.s.

d. 40,000 c.f.s.

The average low-water for the past 10 and 20 year periods agrees very closely with the low-water datum plane for a discharge of 54,000 c.f.s. which is presently rated at -3.5-feet, St. Louis. The L.W.R.P. for a discharge of 40,000 c.f.s. is presently rated at -5.5-feet, St. Louis. The prototype reach was designed to develop a dependable 9-foot channel at the latter discharge. In addition, the data collected from this study program will be used to determine the feasibility of obtaining a 12-foot navigation channel.

DESCRIPTION OF DIKE SYSTEMS

14. Prior to prototype construction, the study site was contracted to an 1,800-foot width by 34 stonefill dikes and 53 pile dikes. All dikes were generally constructed to an elevation equivalent to 20 feet on the St. Louis gage. Operative revetment works (17,500 linear feet) were in service before and after prototype construction.

15. Contraction of the prototype reach was accomplished by converting 17 pile dikes to stonefill dikes, extending 19 existing stonefill dikes, and constructing 15 additional new stonefill dikes to form the 1,200-foot contraction. New dikes were constructed to slope from the high bankline down to an elevation equivalent to 5 feet on the St. Louis gage at the riverward end. Existing pile dikes, or stonefill dikes which were extended, were constructed to meet the original dike elevation at the 1,800-foot contraction line and were sloped to an elevation equivalent to 5 feet on the St. Louis gage at the 1,200-foot contraction line. Dikes were constructed normal to the flow and the 1,200-foot contraction line generally paralleled the existing banklines. After completion of the prototype reach, there were 66 stonefill dikes and 36 pile dikes between miles 140.0 and 154.0; however, the pile dikes are in a state of disrepair and no longer are effective as contractive works.

PART II: BASIC STUDY DATA

16. A field data collection program has been established for the study reach. The data being obtained include hydrographic surveys, channel cross sections, velocity measurements at 0.2 and 0.8 fractions of depth at four velocity ranges, discharge measurements, thalweg profiles, water surface profiles, rod float data, and riverbed samples. These data are discussed in the following paragraphs.

HYDROGRAPHIC SURVEYS

17. Hydrographic survey maps, plates numbered 56 through 62, show contours of the channel bottom at 10-foot intervals based on a project flow of 54,000 c.f.s., surface current directions as determined by floats, and current directions and magnitude at 0.2 and 0.8 of depth at selected velocity ranges.

COMPARATIVE CROSS SECTIONS

18. Comparative cross sections have not been plotted because the analysis of channel geometry has been based upon a series of computations made for each sounding run contained on hydrographic survey maps made before and after prototype construction. Changes in channel geometry due to prototype construction are fully discussed in Part III: Analysis of Channel Geometry.

DISTRIBUTION OF VELOCITIES AND DISCHARGE

19. Surface velocity direction and magnitude are indicated by rod float data shown on hydrographic survey maps, plates numbered 56

through 62, dated June 1970 about one year after completion of the prototype reach. Velocities taken at 0.2 and 0.8 depth along with discharge measurements are fully discussed in Part IV: Analysis of Hydraulic Data.

STUDY GAGES, WATER SURFACE AND ENERGY PROFILES

20. Slope gages are located upstream and downstream of the prototype reach. These gages were in existence prior to prototype construction and were utilized to obtain the water surface profiles shown on PLATE 7. To date, no study gages have been installed in the prototype reach proper; however, plans are underway to install four automatic recording gages during FY 72 for future studies. To date energy profiles have not been computed due to a lack of sufficient information to do so; however, this information will be obtained in future study programs. The water surface profile shown on PLATE 7 was obtained at high river stages and is more fully discussed in Part IV: Analysis of Hydraulic Data.

RIVERBED MATERIAL SAMPLING

21. Prior to prototype construction, 44 borings were taken at selected locations. The borings consisted of approximately three feet of core taken with a barge-mounted USGS bed material sampler. These cores were classified by the Waterways Experiment Station. Additional cores will be obtained during 1971 and a comparison will be made of the riverbed material sampling before and after prototype construction.

THALWEG PROFILES

22. PLATES 8 and 9 show the thalweg profile of the prototype navigation channel as of 13 July 1970. Thalweg sounding data were recorded by the MV Pathfinder during a normal channel sounding run. This particular sounding run indicates channel depths in excess of 9 feet below the L.W.R.P. (for a project flow of 54,000 c.f.s.) with the exception of a short reach located between miles 143 and 144. Numerous thalweg profiles will be plotted during the course of this study program.

PART III: ANALYSIS OF CHANNEL GEOMETRY

23. This part concerns the changes in channel geometry that have occurred within the prototype reach between 1966 and 1970.

DESCRIPTION OF HYDROGRAPHIC SURVEYS

24. The hydrographic survey made in 1966, prior to prototype construction, had 400-foot intervals between sounding runs and river-bottom elevations were recorded as sounding depths below the prevailing river stage on the date of survey. Due to personnel limitations and the increased demand for more surveys, the interval between sounding runs was increased from 400 to 500 feet on the 1970 hydrographic surveys. River-bottom elevations were recorded in m.s.l. in accordance with directives received from LMVD.

ANALYSIS OF COMPARATIVE CROSS SECTIONS

25. Due to the difference in survey procedures mentioned in paragraph 24 above, the analysis of comparative channel cross sections proved to be inconclusive because channel cross sections were not taken over the same sounding ranges. In addition, the 1966 survey was made at a low river stage, whereas the 1970 survey was made at a relatively high river stage, thus further complicating the analysis of comparative channel cross sections. Accordingly, another study plan was adopted wherein the average change in channel geometry was computed.

COMPUTATION OF CHANNEL GEOMETRY

26. Computations were based upon a low water reference plane for a flow of 54,000 c.f.s. (-3.5 feet, St. Louis). The reason for

selecting this reference plane was due to the fact that the former 1,800-foot contraction of this reach was also based upon a project flow of 54,000 c.f.s.; therefore, a direct correlation could be made for any improvements brought about by the 1,200-foot contraction. Computations were made to determine the average channel depth below the L.W.R.P. for each sounding run contained in the 1966 and 1970 surveys. The width of channel below the L.W.R.P. was scaled directly from hydrographic survey sheets. Average areas below the L.W.R.P. and Width/Depth ratios were also computed for each sounding run.

COMPARISON OF SEPARATE SEGMENTS

27. When all of the computations mentioned in paragraph 26 above were complete, it was noted that the average depth and area below the L.W.R.P. had increased after prototype construction, while the average width at the L.W.R.P. and average W/D ratio had decreased. This indicated a definite improvement in channel geometry. To further analyze the improvements brought about by prototype construction, the 14-mile reach was broken down into 39 separate segments.

AVERAGE DEPTH BELOW L.W.R.P.

28. PLATE 1 shows the average depth below the L.W.R.P. in 1966 and 1970 plus the change in depth for 39 separate segments of the prototype reach. The average depth below the L.W.R.P. increased in 35 segments while a decrease in average depth was noted in four segments.

AVERAGE WIDTH BELOW L.W.R.P.

29. PLATE 2 shows the average width at the L.W.R.P. in 1966 and 1970 plus the change in width. The average width at the L.W.R.P. decreased in 32 segments while an increase in average width was noted in seven segments.

AVERAGE AREA BELOW L.W.R.P.

30. PLATE 3 shows the average area below the L.W.R.P. in 1966 and 1970 plus the change in area. The average area below the L.W.R.P. increased in 29 segments while a decrease in area was noted in 10 segments.

AVERAGE W/D RATIO

31. PLATE 4 shows the average W/D ratio in 1966 and 1970 plus the change in the W/D ratio. The average W/D ratio decreased in 32 segments while an increase was noted in seven segments.

PERFORMANCE OF DIKE FIELDS

32. A composite of PLATES 1 through 4 was prepared to determine whether or not any general pattern could be detected from the changes which occurred in channel geometry. This composite clearly indicated that prototype construction had generally increased the depth and area, and decreased the width all measured with respect to the L.W.R.P. for a project flow of 54,000 c.f.s. The composite also revealed that individual contraction segments which did not show an improvement in

channel geometry generally had less depth, less area, more width, and were confined to localized areas within the prototype reach.

33. The overall contraction plan was reviewed in an effort to learn why some segments of the prototype reach did not react favorably to the 1,200-foot contraction. The length of each of the 39 segments in the prototype reach was determined along with the number of dikes in each segment to learn whether or not there was some correlation between dike spacing and the changes which occurred in channel geometry. The following observations were made:

a. From miles 140.0 to 140.5, the width of the channel increased but this did not cause a decrease in depth or area. Increase in width was attributed to exit velocities from lower end of prototype reach.

b. From miles 140.5 to 140.8, the area of the channel decreased due to a large reduction in channel width.

c. From miles 141.7 to 142.3, the width of the channel increased. No apparent reason could be found for the increase in width.

d. From miles 143.0 to 143.4, the area decreased slightly due to a reduction in width.

e. From miles 145.4 to 146.3, the depth and area decreased and the width increased. This was attributed to excessive dike spacing in this segment (i.e. more dikes required in this segment).

f. From miles 146.3 to 146.7, the width increased. Increase in width appears to be associated with excessive dike spacing in adjacent downstream segment.

g. From miles 148.5 to 148.85, the area decreased due to large reduction in width.

h. From miles 148.85 to 149.2, the width increased slightly. No apparent reason was noted for increase in width.

i. From miles 149.2 to 150.0, the depth and area decreased while the width increased. No apparent reason was noted for increase in width and associated decrease in depth and area.

j. From miles 150.0 to 150.2, the depth and area decreased even though there was a decrease in width. (A decrease in width generally results in more depth.) No apparent reason could be found for the fact that depth did not increase with a decrease in width.

k. From miles 150.2 to 151.3, the area decreased due to a large reduction in width. This appears to be associated with the poor channel geometry noted downstream.

34. Using the observations presented in paragraph 33 above, the June 1970 hydrographic survey was reviewed to learn what effect the changes in channel geometry had upon the navigation channel. PLATE 5 shows the results of this investigation. This plate shows the mileage of 39 separate segments along with the following information for each segment of the contraction:

a. Change in depth below the L.W.R.P.

b. Change in width at the L.W.R.P.

c. Change in area below the L.W.R.P.

d. Change in W/D ratio.

e. Whether or not a 9-foot channel had existed as of June 1970 for the following project flows:

(1) 54,000 c.f.s.

(2) 40,000 c.f.s.

f. Whether or not a 12-foot channel had existed as of June 1970 for the following project flows:

(1) 54,000 c.f.s.

(2) 40,000 c.f.s.

g. The number of dikes in each segment.

h. The length of each segment.

i. Comments.

35. The data contained on PLATE 5 show the following channel conditions existed as of June 1970:

a. Continuous 9-foot channel at 54,000 c.f.s.

b. 9-foot channel in 34 of 39 segments at 40,000 c.f.s.

c. 12-foot channel in 31 of 39 segments at 54,000 c.f.s.

d. A 12-foot channel at 40,000 c.f.s. had not developed.

(See paragraphs 42 and 58.)

36. No dredging has been required in the prototype reach since it was constructed; therefore, it was expected that the analysis of channel geometry would reveal a general improvement in channel dimensions throughout the prototype reach, but such was not the case. Accordingly, additional investigations were made to obtain more information about those segments of the prototype reach which did not react favorably to the 1,200-foot contraction. Aerial photographs were scrutinized and field inspection trips were conducted in an effort to

detect any condition which might conceivably have an adverse effect upon improvement of channel geometry. The results of this investigation are as follow:

a. The increase in channel width from miles 140.0 to 140.5 was attributed to divergent current patterns at the lower end of the prototype reach as previously mentioned in paragraph 33a.

b. The decrease in channel area from miles 140.5 to 140.8 was confirmed by making additional calculations. The decrease in channel width was proportionately greater than the increase in depth resulting in a net loss of channel area.

c. The unexplained increase in channel width from miles 141.7 to 142.3, previously mentioned in paragraph 33c, was resolved during this part of the investigation. Aerial photographs indicated that Dike No. 142.3R was flanked. This was subsequently confirmed by field inspection. This dike will be repaired during fiscal year 1972.

d. The decrease in channel area from miles 143.0 to 143.4 was confirmed in the same manner previously mentioned in subparagraph 36b, above.

e. The increase in width, decrease in depth, and decrease in area from miles 145.4 to 146.3 was confirmed by making additional calculations. A small shoal water area was detected in the middle of the channel at mile 146.0. The dike spacing in this segment is excessive. No remedial action is proposed at this time. Sounding runs indicate this sand bar has a tendency to move out at low river stages.

f. The increase in width from miles 146.3 to 146.7 was confirmed by making additional measurements. Rod floats show a tendency to spread apart as they approach to lower end of this segment. This is attributed to excessive dike spacing mentioned in subparagraph 36e, above.

g. All of the adverse changes in channel geometry for the eight segments located between miles 148.5 and 151.0 may be due to the fact that Dike No. 149.2L and Dike No. 150.0L have been breached. These dikes will be repaired during fiscal year 1972.

h. The channel geometry improved between miles 152.3 and 153.1, creating an adequate cross section to provide a 9-foot channel at 40,000 c.f.s.; however, the channel alinement was poor in June 1970. Subsequent sounding runs indicate that channel alinement improves at low river stages.

37. The analysis of prototype performance by the simple expediency of analyzing changes in channel geometry adequately pinpoints problem areas and gives a general indication where further channel improvement can be made. No additional improvements are contemplated at this time other than making repairs to Dike Nos. 142.3R, 149.2L, and 150.0L.

PART IV: ANALYSIS OF HYDRAULIC DATA

38. Sufficient discharge measurement data are not available at the present time to obtain any general relation of stage and discharge to the channel factor. An investigation of hydraulic factors will be undertaken when the required study data are available. Velocity and discharge measurements were obtained in 1967. Water surface elevations were obtained in conjunction with velocity and discharge measurements in 1970.

VELOCITY AND DISCHARGE MEASUREMENTS

39. The results of velocity and discharge measurements taken in 1967 and 1970 are shown on PLATE 6. Discharge measurements varied somewhat between study ranges. It is important to note that mean velocities obtained in the prototype reach during 1967 were slightly higher than normal. These mean velocities were obtained when river stages were approximately equivalent to 5 feet on the St. Louis gage and at a time when 19 stonefill dikes had already been constructed in the prototype reach. Thus it appears as though the 19 stonefill dikes constructed in the prototype reach were increasing current velocities at the time these velocity measurements were taken back in 1967.

40. Velocity measurements taken in 1970 were obtained when river stages were approximately equivalent to 20 feet on the St. Louis gage. Mean velocities within the prototype reach at that time were normal velocities for the aforementioned river stage. Thus it appears as though prototype construction has little effect on current velocities when river stages overtop the contraction works.

WATER SURFACE ELEVATIONS

41. PLATE 7 shows the water surface profile on 25 June 1970. The river stage in St. Louis on that date was 20 feet, and 21 feet on 24 June 1970. The water surface profile through the prototype reach agrees very closely with Mississippi River slope profiles based upon the 1956 - 1957 L.W.R.P. for a low water flow of 54,000 c.f.s.

PLANS FOR OBTAINING FUTURE HYDRAULIC DATA

42. During January of 1971, an attempt was made to obtain a low water hydrographic survey, velocity and discharge measurements, and water surface elevations after ice flows had diminished sufficiently so as not to interfere with this work or pose a safety hazard for survey crews. Approximately 6 miles of hydrographic survey work had been performed when river stages suddenly increased from 2 feet to 20 feet, St. Louis, within a few days. Survey efforts were cancelled due to the rise in river stage. When river stages permit, another low water survey will be initiated.

STUDY GAGES

43. Existing slope gages are located upstream and downstream of the prototype reach. These gages have been utilized in all surveys made to date. Plans are underway to install four automatic recording gages in the prototype reach so that changes in water surface elevations can be automatically recorded for future study programs.

EVALUATION OF HYDRAULIC DATA OBTAINED TO DATE

44. The most significant data obtained to date appear to be that current velocities have not been materially increased by prototype construction. Velocities did show a tendency to increase slightly during the initial phase of prototype construction; however, the overall increase in channel cross section area below the L.W.R.P. suggests that initial scouring velocities have probably decreased. Considerable attention will be given to this problem during future studies.

PART V: ANALYSIS OF DREDGING REQUIREMENTS

45. This section of the report concerns dredging requirements in the vicinity of the prototype reach for the period 1963 through 1969. Dredging records for the aforementioned period were analyzed to detect any changes in dredging requirements which might reasonably be attributed to the construction of the prototype reach. PLATE 10 shows the location and volume of dredging operations on the Middle Mississippi River for the period 1963 to 1969.

46. Since past experience indicates that dike construction affects the regimen of the river both upstream and downstream of the construction site, the analysis of dredging records was broken down into three separate parts. The first part deals with the reach of river between miles 169 and 154 which is immediately upstream of the prototype reach. The second part deals with the prototype reach proper, and the third part deals with a 10-mile reach below the prototype reach between miles 140 and 130.

UPPER REACH

47. From 1963 to 1968, a total of 19 separate dredge cuts were required between miles 169 and 154. PLATE 11 shows the location of dredge cuts during each of the aforementioned calendar years and the approximate river stage on the St. Louis gage at the time each dredging operation was performed. Sixteen dredge cuts were required at various locations at river stages in excess of a -3.5-foot reading on the St. Louis gage, while only three cuts were required at stages below -3.5 feet, St. Louis.

48. For reasons which are not known at this time, no dredging has been required between miles 169 and 154 since completion of prototype reach construction.

PROTOTYPE REACH

49. From 1963 to 1968, a total of 37 separate dredge cuts were required between miles 154 and 140. PLATE 12 shows the location of dredge cuts during each of the aforementioned calendar years and the approximate river stage on the St. Louis gage at the time each dredging operation was performed. Twenty-nine dredge cuts were required at various locations at river stages in excess of a -3.5-foot reading on the St. Louis gage, while only eight cuts were required at stages below -3.5 feet, St. Louis.

50. No dredging has been required between miles 154 and 140 since completion of the prototype reach. It appears reasonable to assume that this phenomenon can be directly attributed to the increased contraction through this reach (1,200 feet). Hydrographic surveys made in June 1970, about 1 year after completion of the prototype reach, indicate more depth, less width, and more area, all measured with respect to the elevation of the low water reference plane for a project flow of 54,000 c.f.s. (-3.5 feet, St. Louis).

51. It is well to note here that the increase in depth below the L.W.R.P. was sufficient to increase the total area below the L.W.R.P. even though the width at the L.W.R.P. was reduced. The original design assumptions were intended to obtain a deeper channel below the L.W.R.P.

but an increase in area was not anticipated. If the relationship Q = AV is valid for open channel flow, it follows that mean velocities are lower or the elevation of the L.W.R.P. is now lower as a result of channel degradation. Sufficient data have not been accumulated at this time to properly evaluate the significance of the increased area below the L.W.R.P., but it appears likely that some lowering of the L.W.R.P. has occurred within this reach.

LOWER REACH

52. From 1963 to 1969, a total of nine separate dredge cuts were required between miles 140 and 130. PLATE 13 shows the location of dredge cuts during each of the aforementioned calendar years and the approximate river stage on the St. Louis gage at the time each dredging operation was performed. Seven dredge cuts were required in the vicinity of Brickey's Landing, mile 136, at river stages in excess of -3.5 feet on the St. Louis gage, while two cuts were required at stages below -3.5 feet, St. Louis.

53. From 1968 to 1969, a total of five dredge cuts were made, two at mile 139 and three around mile 136. The two cuts made at mile 139 can be directly attributed to prototype reach construction because the increased bedload transport capability of the prototype reach was expected to result in increased deposition downstream of the reach. This also applies to the increased dredging requirements noted at mile 136.

REDUCTION IN DREDGING COSTS

54. Detailed information pertaining to dredge cut locations, dates, St. Louis gage readings, volumes of material dredged, dredging costs, and number of dredge cuts made at individual locations is all shown on PLATES 14, 15, and 16. The average annual dredging costs for the three separate reaches discussed above are as follow:

Years	Mile 169-154	Mile 154-140	Mile 140-130	Total
1963-1968	$76,177	$118,477	$ 22,031	$216,685
1968-1969	$ 0	$ 32,047	$ 59,192	$ 91,239
1969-1970	$ 0	$ 0	$108,490	$108,490
1970-1971	$98,774	$ 0	$ 43,424	$142,198

SUMMARY OF DREDGING REQUIREMENTS

55. From 1963 to 1968, prior to completion of prototype construction, 19 dredge cuts were made between miles 169 and 154; 37 cuts were made between miles 154 and 140; and 11 cuts were made between miles 140 and 130 for a total of 67 dredge cuts over a 6-year period. In 1969 and 1970, no dredging was required between miles 169 and 140 but dredging requirements increased as was expected between miles 140 and 130.

56. Of the 67 dredge cuts made between miles 169 and 130 for the period 1963 to 1968, 50 dredge cuts were required at river stages in excess of -2.6 feet on the St. Louis gage. Forty-one of the 50 aforementioned dredge cuts were required between miles 169 and 140;

however, no dredging has been performed in this reach since completion of the prototype reach in spite of the fact that the St. Louis gage was at -2.6 feet on 20 January 1970.

PART VI: CONCLUSIONS

INTERIM CONDITIONS AND DEVELOPMENTS

57. This report is basically an interim study since the prototype reach has not completely adjusted itself to the 1,200-foot contraction, particularly those portions of the river which are in the immediate vicinity of breached dikes. When these dikes are repaired, further channel improvements are expected to develop.

BASIC SURVEY DATA

58. Hydrographic surveys made in June 1970 show considerable improvement in the navigation channel. The partial hydrographic survey made in January 1971 between miles 148.5 and 154.0, previously mentioned in paragraph 42, indicated that the channel improves when the river stages fall completely within the 1,200-foot contraction (stages less than 5 feet, St. Louis). A cursory review of this survey indicated the existence of a 12-foot channel at a project flow of 40,000 c.f.s. As soon as low river stages prevail, another hydrographic survey will be made. It is expected that this low water survey will substantiate the fact that a 12-foot channel at a project flow of 40,000 c.f.s. develops when river stages fall completely within the 1,200-foot contraction.

59. In conjunction with the pending low water hydrographic survey, velocity and discharge measurements will be obtained along with water surface profiles. It is essential to obtain accurate field data to learn whether or not there has been any change in the elevation of

the L.W.R.P. Velocity readings taken to date do not indicate any material change in current velocities. The possibility exists that the elevation of the L.W.R.P. has lowered due to degradation of the river bottom.

ANALYSIS OF CHANNEL GEOMETRY

60. The analysis of channel geometry shows a general improvement in the navigation channel with the exception of those segments of the contraction where dikes have sustained damages and are not effective as contractive works. The general reaction of the river to the 1,200-foot contraction was to decrease its width at the L.W.R.P. and to increase its depth below the L.W.R.P. The increase in depth was generally proportionately greater than the decrease in width resulting in a net increase in cross-sectional area below the L.W.R.P.

ANALYSIS OF DREDGING REQUIREMENTS

61. The prototype reach required repetitive dredging prior to prototype construction but none has been required since completion of the prototype reach. Prior to 1966, there were six shoal water crossings in the reach. All shoal water crossings have been improved since completion of the prototype reach; no dredging has been required and no navigation problems have occurred.

EVALUATION OF DIKE SEGMENTS

62. Evaluation of each of the 39 separate segments which compose the overall 1,200-foot contraction is not yet complete. Each segment

in essence represents a separate and distinct contractive effort since the length of each segment varies, as well as the number of dikes contained in each segment. As this study progresses, more detailed study will be given to the contractive effort exercised by each segment of the contraction in an effort to correlate the improvement of channel geometry with a given amount of contractive effort.

63. As would be expected, there is some unknown relationship between the amount of contractive effort and the improvement of channel geometry. This can be noted by comparing the increase in average depth of each segment shown on PLATE 1 with the number of dikes and length of contractive segments shown on PLATE 5. In general, the depth of channel increases when dikes are spaced close together.

64. In some instances, dikes were spaced too close together, particularly between miles 144.1 and 145.4, and excess degradation of the river bottom occurred. The ultimate goal of this study program is to find ways and means to make needed channel improvements without over-designing the contraction. It appears that the most economical approach to this problem at the present time is to deliberately under-design the contraction and make needed adjustments to the works at some future date when sufficient data has been accumulated to determine what adjustments are needed.

65. Another general observation can be made by carefully scrutinizing the performance of all 39 segments which compose the overall 1,200-foot contraction. As previously mentioned in this report, deposition occurred wherever the dike spacing was too great or where the

contraction was impaired by damaged dikes. Both conditions are essentially the same and are analogous to omitting contractive works downstream of a contracted reach of river. This procedure has been tried several times in the St. Louis District where hydrographic surveys indicated the existence of a good navigation channel downstream of a reach which obviously needed contractive works to improve the channel. Contraction of the upper reach invariably caused deposition to occur in the lower reach which was left uncontracted so that the problem area merely moved downstream. In order to overcome the problem of downstream deposition, it appears logical that contractive works should be continuous and must be constructed in upstream to downstream order. The overall contraction plan must be continuous in order to improve bedload transport capabilities through stable reaches of river located downstream of a reach in need of contraction. There are exceptions to this recommended practice, notably in river bends. Contraction of river bends may cause excessive degradation such as that previously mentioned in paragraph 64.

66. The improvements brought about by prototype construction prove that the width of the contraction is far more important than the height of the contraction. This suggests the possibility that very low profile dikes may be effective as contractive works. The utilization of low profile dikes to maintain the navigation channel is preferred by conservationists who claim high profile dikes cause deposition to occur in the slack water areas which are best suited for fish habitat and propagation. The St. Louis District plans to investigate the performance of low profile dikes during the course of

a model testing program now being conducted at the Waterways Experiment Station in Vicksburg, Mississippi.

67. In essence, a 9-foot channel at 40,000 c.f.s. is practically the same as a 12-foot channel at 54,000 c.f.s. (see paragraph 13). Opponents of the Twelve-Foot Waterway Study are apparently unaware of this fact and fear the large volumes of material must be dredged to obtain a 12-foot channel; however, indications are quite favorable that a 9-foot channel can be obtained at a project flow of 40,000 c.f.s. or a 12-foot channel at a project flow of 54,000 c.f.s. with little or no dredging.

68. Prototype study data accumulated to date indicate that it is economically advisable to give serious consideration to another contraction plan other than those previously mentioned in this report in order to obtain a dependable 9-foot channel at the least cost. The 1,800-foot contraction plan has failed to achieve this objective whereas the 1,200-foot contraction plan shows considerable promise of being capable of achieving a 12-foot channel at a project flow of 54,000 c.f.s. Preliminary investigations relative to low water datum planes indicate a low water flow of 54,000 c.f.s. agrees very closely with the average low water flow for the past 10 to 20 years. Accordingly, it appears reasonable to assume that the authorized 9-foot channel project should continue to be based upon a project flow of 54,000 c.f.s. The project flow is, of course, subject to revision if future hydraulic computations indicate a definite need for this course of action.

69. Using the 54,000 c.f.s. project flow criteria it appears that a 1,500-foot contraction will most likely achieve a dependable 9-foot channel at the least project cost. Model tests conducted by the Waterways Experiment Station also indicate a 1,500-foot contraction will generally achieve project dimensions with some additional contractive effort being required only at troublesome channel crossings.

70. To summarize the results of this study program, to date, it appears that a 1,500-foot contraction will most likely provide a dependable 9-foot channel, and that future study data will provide empirical design data which will indicate that a 12-foot waterway on the Middle Mississippi River is feasible and can be obtained through the use of contraction works.

PART VII: FUTURE STUDIES

71. It is recommended that the following additional analyses, evaluations, and studies be accomplished as funds and personnel are available:

a. Determination of L.W.R.P. elevations for 10 year average low flows, 20 year average low flows, for discharges of 54,000 c.f.s. and 40,000 c.f.s., and make a determination which datum plane is most practical to achieve the objectives of the 9-foot channel project at the least cost.

b. Continue hydrographic survey program to study changes in channel geometry.

c. Initiate potamology studies to investigate area and area-depth relations, stage-discharge relations, energy profiles, sediment transport, etc.

d. Make construction improvements as necessary to develop a dependable 9-foot channel at a discharge of 40,000 c.f.s.

e. Develop empirical design criteria for obtaining a 12-foot navigation channel.

f. Initiate environmental studies to determine the impact of continued channel improvements upon fish and wildlife habitat.

g. Periodically compile all newly acquired study data and prepare additional reports on this study program.

PROTOTYPE REACH STUDY
DEPTH BELOW L.W.R.P. (54,000 c.f.s.)
1966-1970

From Mile	To Mile	Ave. D Below L.W.R.P. 1966	Ave. D Below L.W.R.P. 1970	Change in Depth More Depth	Change in Depth Less Depth
154.0	153.9	8.11	11.65	3.54	
153.9	153.7	7.66	13.12	5.46	
153.7	153.5	7.32	11.01	3.69	
153.5	153.1	6.64	9.57	2.93	
153.1	152.5	7.76	10.30	2.54	
152.5	152.0	9.46	13.11	3.65	
152.0	151.3	9.35	14.47	5.12	
151.3	151.0	8.89	14.00	5.11	
151.0	150.6	9.08	11.50	2.42	
150.6	150.4	9.64	9.93	0.29	
150.4	150.2	8.95	9.84	0.89	
150.2	150.0	10.87	8.81		2.06
150.0	149.7	13.11	11.42		1.69
149.7	149.2	13.89	10.35		3.54
149.2	148.85	9.55	11.34	1.79	
148.85	148.5	9.87	13.36	3.49	
148.5	148.3	8.65	10.43	1.78	
148.3	148.1	8.47	11.47	3.00	
148.1	147.7	7.73	11.29	3.56	
147.7	147.1	7.75	13.66	5.91	
147.1	146.7	10.08	13.78	3.70	
146.7	146.3	11.66	12.12	0.46	
146.3	145.4	13.85	10.99		2.86
145.4	145.0	10.11	16.86	6.75	
145.0	144.6	10.81	17.29	6.48	
144.6	144.3	10.80	19.23	8.43	
144.3	144.1	9.01	15.75	6.74	
144.1	144.0	7.09	11.54	4.45	
144.0	143.7	7.70	13.84	6.14	
143.7	143.6	7.46	14.90	7.44	
143.6	143.4	7.69	13.60	5.91	
143.4	143.0	8.56	13.14	4.58	
143.0	142.3	11.20	12.69	1.49	
142.3	141.7	12.54	13.44	0.90	
141.7	141.4	9.93	12.31	2.38	
141.4	141.1	8.46	12.40	3.94	
141.1	140.8	8.45	13.30	4.85	
140.8	140.5	8.09	10.47	2.38	
140.5	140.0	12.06	13.09	1.03	

Plate No. 1

PROTOTYPE REACH STUDY
WIDTH AT L.W.R.P. (54,000 c.f.s.)
1966-1970

From Mile	To Mile	Ave. W At L.W.R.P. in 1966	Ave. W At L.W.R.P. in 1970	Change in Width: Increase in Width	Change in Width: Decrease in Width
154.0	153.9	2075	1735		340
153.9	153.7	2125	1675		450
153.7	153.5	2133	1675		458
153.5	153.1	2190	1700		490
153.1	152.5	1963	1781		182
152.5	152.0	1851	1593		258
152.0	151.3	1987	1483		504
151.3	151.0	1960	1730		230
151.0	150.6	1875	1437		438
150.6	150.4	1900	1550		350
150.4	150.2	1966	1500		466
150.2	150.0	1833	1550		283
150.0	149.7	1538	1675	137	
149.7	149.2	1530	1570	40	
149.2	148.85	1760	1813	53	
148.85	148.5	2033	1383		650
148.5	148.3	1787	1550		237
148.3	148.1	1975	1500		475
148.1	147.7	1975	1358		617
147.7	147.1	1800	1394		406
147.1	146.7	1525	1456		69
146.7	146.3	1210	1428	218	
146.3	145.4	1159	1432	273	
145.4	145.0	1675	1405		270
145.0	144.6	1717	1183		534
144.6	144.3	1750	1200		550
144.3	144.1	1867	1170		697
144.1	144.0	2083	1433		650
144.0	143.7	2067	1550		517
143.7	143.6	1950	1725		225
143.6	143.4	2033	1485		548
143.4	143.0	1863	1200		663
143.0	142.3	1510	1407		103
142.3	141.7	1394	1588	194	
141.7	141.4	1830	1816		14
141.4	141.1	2125	1685		440
141.1	140.8	2066	1683		383
140.8	140.5	2150	1518		632
140.5	140.0	1366	1642	276	

Plate No. 2

PROTOTYPE REACH STUDY
AREA BELOW L.W.R.P. (54,000 c.f.s.)
1966-1970

From Mile	To Mile	Ave. Area Below L.W.R.P. 1966	Ave. Area Below L.W.R.P. 1970	Change in Area More Area	Change in Area Less Area
154.0	153.9	16828	20212	3384	
152.9	153.7	16277	21976	5699	
153.7	153.5	15614	18442	2828	
153.5	153.1	14542	16269	1727	
153.1	152.5	15233	18344	3111	
152.5	152.0	17510	20884	3374	
152.0	151.3	18578	21459	2881	
151.3	151.0	17424	24220	6796	
151.0	150.6	17025	16525		500
150.6	150.4	18316	15391		2925
150.4	150.2	17597	14760		2837
150.2	150.0	19924	13655		6269
150.0	149.7	20163	19128		1035
149.7	149.2	21251	16249		5002
149.2	148.85	16808	20559	3751	
148.85	148.5	20065	18476		1589
148.5	148.3	15457	16166	709	
148.3	148.1	16728	17205	477	
148.1	147.7	15266	15331	65	
147.7	147.1	13950	19042	5092	
147.1	146.7	15372	20063	4691	
146.7	146.3	14108	17307	3199	
146.3	145.4	16052	15737		315
145.4	145.0	16934	23688	6754	
145.0	144.6	18560	20454	1894	
144.6	144.3	18900	23076	4176	
144.3	144.1	16821	18427	1606	
144.1	144.0	14768	16536	1768	
144.0	143.7	15915	21452	5537	
143.7	143.6	14547	25702	11155	
143.6	143.4	15633	20196	4563	
143.4	143.0	15947	15768		179
143.0	142.3	16912	17854	942	
142.3	141.7	17480	21342	3862	
141.7	141.4	18171	22354	4183	
141.4	141.1	17977	20894	2917	
141.1	140.8	17457	22383	4926	
140.8	140.5	17393	15893		1500
140.5	140.0	16473	21493	5020	

PROTOTYPE REACH STUDY
W/D RATIO (54,000 c.f.s.)
1966-1970

From Mile	To Mile	W/D Ratio 1966	W/D Ratio 1970	Change in W/D Ratio: Increase in Ratio	Change in W/D Ratio: Decrease in Ratio
154.0	153.9	255	148		-107
153.9	153.7	277	127		-150
153.7	153.5	291	152		-139
153.5	153.1	330	177		-153
153.1	152.5	252	172		- 80
152.5	152.0	195	121		- 74
152.0	151.3	212	102		-110
151.3	151.0	220	123		- 97
151.0	150.6	206	124		- 82
150.6	150.4	197	156		- 41
150.4	150.2	219	152		- 67
150.2	150.0	168	175	+ 7	
150.0	149.7	117	146	+29	
149.7	149.2	110	151	+41	
149.2	148.85	184	159		- 25
148.85	148.5	205	103		-102
148.5	148.3	206	148		- 58
148.3	148.1	233	130		-103
148.1	147.7	255	120		-135
147.7	147.1	232	102		-130
147.1	146.7	151	105		- 46
146.7	146.3	103	117	+14	
146.3	145.4	83	130	+47	
145.4	145.0	165	83		- 82
145.0	144.6	159	68		- 91
144.6	144.3	162	62		-100
144.3	144.1	207	74		-133
144.1	144.0	293	124		-169
144.0	143.7	268	111		-157
143.7	143.6	261	115		-146
143.6	143.4	264	109		-155
143.4	143.0	217	91		-126
143.0	142.3	134	110		- 24
142.3	141.7	111	118	+ 7	
141.7	141.4	184	147		- 37
141.4	141.1	251	135		-116
141.1	140.8	244	126		-118
140.8	140.5	265	144		-121
140.5	140.0	113	125	+12	

Plate No. 4

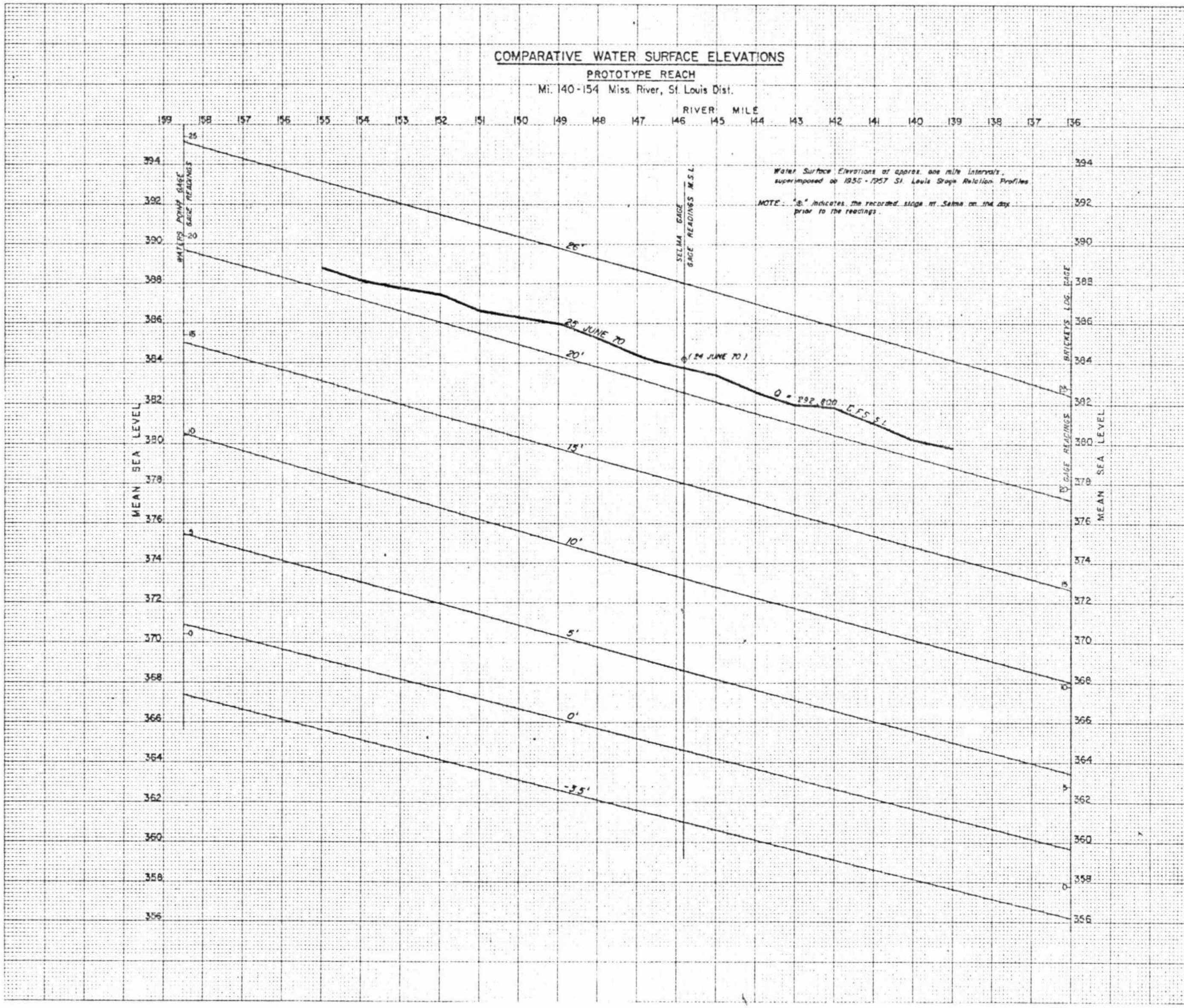
PROTOTYPE REACH STUDY (REPORT NO. 1)
ANALYSIS OF CHANNEL GEOMETRY (1966 - 1970)

FROM MILE	TO MILE	CHANGE IN DEPTH BELOW L.W.R.P.		CHANGE IN WIDTH AT L.W.R.P.		CHANGE IN AREA BELOW L.W.R.P.		CHANGE IN W/D RATIO		9 FOOT CHANNEL AT				12 FOOT CHANNEL AT				NO. OF DIKES IN SEGMENT	LENGTH OF SEGMENT IN FEET	COMMENTS
		MORE DEPTH	LESS DEPTH	MORE WIDTH	LESS WIDTH	MORE AREA	LESS AREA	W/D RATIO MORE	W/D RATIO MORE	54,000 c.f.s.		40,000 c.f.s.		54,000 c.f.s.		40,000 c.f.s.				
										Yes	No	Yes	No	Yes	No	Yes	No			
154.0	153.9	✓			✓	✓			✓	✓		✓		✓			✓	2	600	
153.9	153.7	✓			✓	✓			✓	✓		✓		✓			✓	2	450	
153.7	153.5	✓			✓	✓			✓	✓		✓		✓			✓	3	1000	
153.5	153.1	✓			✓	✓			✓	✓		✓		✓			✓	4	2100	
153.1	152.5	✓			✓	✓			✓	✓			✓		✓		✓	3	3200	INCREASED DIKE SPACING
152.5	152.0	✓			✓	✓			✓	✓		✓		✓			✓	2	3000	
152.0	151.3	✓			✓	✓			✓	✓		✓		✓			✓	2	3100	
151.3	151.0	✓			✓	✓			✓	✓		✓		✓			✓	2	1000	
151.0	150.6	✓			✓		✓		✓	✓		✓			✓		✓	3	1400	
150.6	150.4	✓			✓		✓		✓	✓		✓			✓		✓	3	1000	DIKE NO. 150.0L AND
150.4	150.2	✓			✓		✓		✓	✓			✓		✓		✓	2	1150	
150.2	150.0		✓		✓		✓	✓		✓			✓		✓		✓	2	1150	DIKE NO. 149.2L WERE
150.0	149.7		✓	✓			✓	✓		✓			✓		✓		✓	3	1700	
149.7	149.2		✓	✓			✓	✓		✓		✓			✓		✓	3	2200	BREACHED AT THE TIME
149.2	148.85	✓		✓		✓			✓	✓		✓		✓			✓	3	2050	
148.85	148.5	✓			✓		✓		✓	✓		✓		✓			✓	2	1450	OF JUNE 1970 SURVEY
148.5	148.3	✓			✓	✓			✓	✓		✓		✓			✓	2	1100	
148.3	148.1	✓			✓	✓			✓	✓		✓		✓			✓	2	1150	
148.1	147.7	✓			✓	✓			✓	✓		✓		✓			✓	2	2200	
147.7	147.1	✓			✓	✓			✓	✓		✓		✓			✓	2	2700	
147.1	146.7	✓			✓	✓			✓	✓		✓		✓			✓	2	3550	
146.7	146.3	✓		✓		✓		✓		✓		✓		✓			✓	3	1800	
146.3	145.4		✓	✓			✓	✓		✓			✓		✓		✓	3	2500	INCREASED DIKE SPACING
145.4	145.0	✓			✓	✓			✓	✓		✓		✓			✓	5	1400	
145.0	144.6	✓			✓	✓			✓	✓		✓		✓			✓	3	1600	
144.6	144.3	✓			✓	✓			✓	✓		✓		✓			✓	3	1400	
144.3	144.1	✓			✓	✓			✓	✓		✓		✓			✓	4	1200	
144.1	144.0	✓			✓	✓			✓	✓		✓		✓			✓	4	1000	
144.0	143.7	✓			✓	✓			✓	✓		✓		✓			✓	4	1050	
143.7	143.6	✓			✓	✓			✓	✓		✓		✓			✓	3	800	
143.6	143.4	✓			✓	✓			✓	✓		✓		✓			✓	3	900	
143.4	143.0	✓			✓		✓		✓	✓		✓		✓			✓	2	1600	INCREASED DIKE SPACING
143.0	142.3	✓			✓	✓			✓	✓		✓		✓			✓	2	4100	AND DIKE NO. 142.3R BREACHED
142.3	141.7	✓		✓		✓		✓		✓		✓		✓			✓	2	2650	
141.7	141.4	✓			✓	✓			✓	✓		✓		✓			✓	3	2300	
141.4	141.1	✓			✓	✓			✓	✓		✓		✓			✓	3	1300	
141.1	140.8	✓			✓	✓			✓	✓		✓		✓			✓	2	1450	
140.8	140.5	✓			✓		✓		✓	✓		✓		✓			✓	2	2250	INCREASED DIKE SPACING
140.5	140.0	✓		✓		✓		✓		✓		✓		✓			✓	2	2300	

PROTOTYPE REACH

VELOCITY AND DISCHARGE MEASUREMENTS

DATE	RIVER MILE	MEAN DEPTH	MEAN VELOCITY	MAX. VELOCITY	W.S. M.S.L.	Q.	MEAN VEL. ST. LOUIS
6-25-70	154.9	30.5	4.2	5.7	388.7	292,800	5.2
6-24-70	149.8	29.0	4.4	6.0	386.6	297,600	5.2
5-28-70	145.5	32.0	4.9	6.5	382.8	275,500	5.0
5-26-70	139.9	37.1	5.0	6.7	379.7	280,000	5.1
3-9-67	154.9	23.2	3.7	4.8	371.3	92,000	2.8
3-10-67	149.8	19.2	3.2	4.6	368.3	87,500	2.8
3-10-67	145.4	17.4	3.3	4.7	366.1	87,500	2.8
3-13-67	140.0	15.8	3.1	5.6	364.5	102,200	3.0
10-31-67	150.0	18.3	3.5	4.3	373.1	129,000	3.4
10-31-67	140.0	18.9	3.7	5.1	367.3	129,000	3.4



U. S. ARMY ENGINEER DISTRICT, ST. LOUIS
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

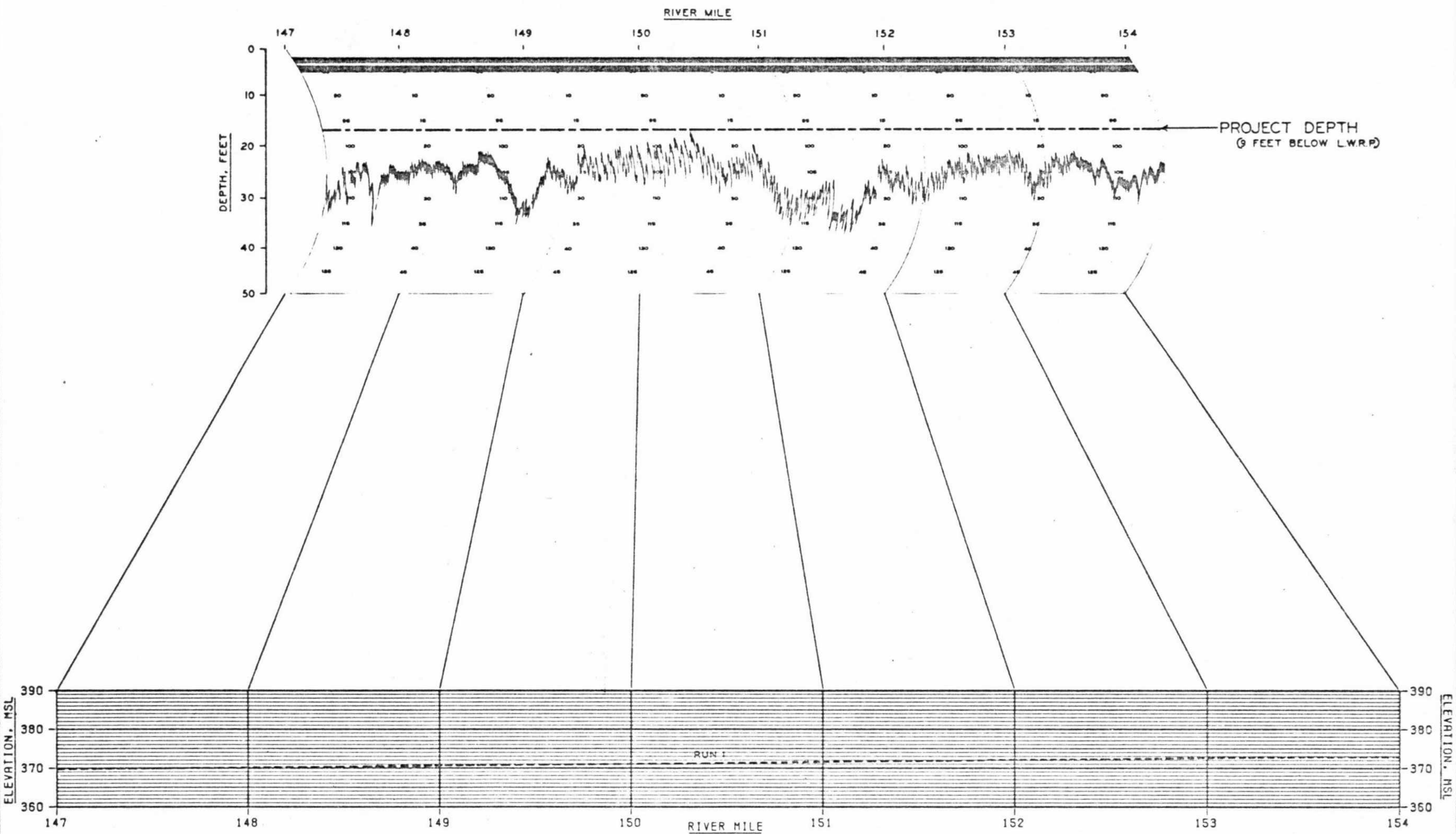
COMPARATIVE WATER SURFACE ELEVATIONS

PROTOTYPE STUDY REACH

MISSISSIPPI RIVER MILE 140 TO 154
(CONTRACTED TO 1200)

F DACW 43

SHEET OF



WATER SURFACE ELEVATIONS

	GAGE RECORD			
	ST. LOUIS	WATERS POINT	SELMA	BRICKEYS LANDING
RIVER MILE	179.6	158.5	145.8	136.0
GAGE ZERO, MSL	379.94	370.39	0.00	357.78
L.W.R.P., MSL	376.44	367.43	361.00	356.23

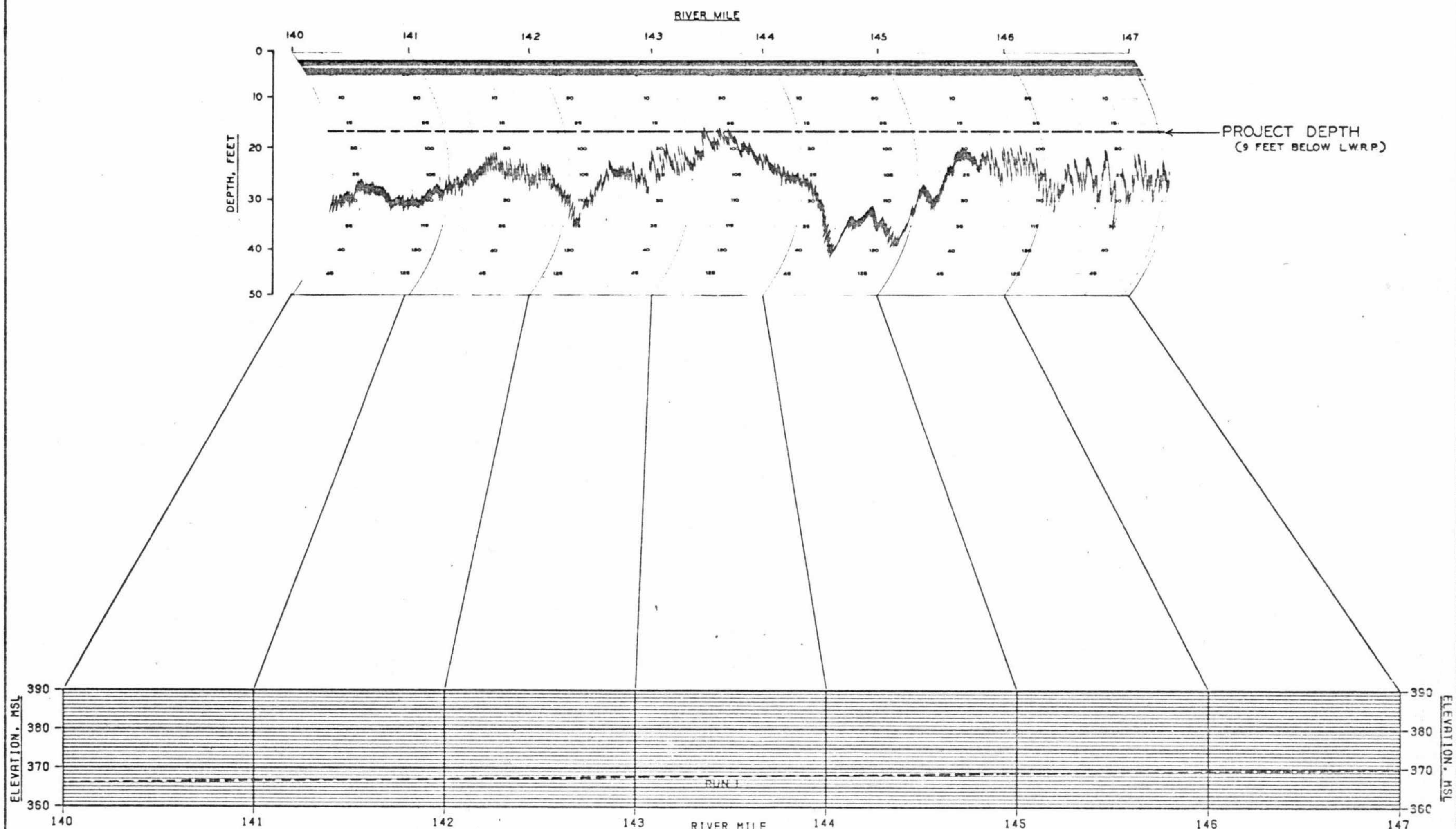
RUN NUMBER	DATE SOUNDED	GAGE READING FOR DATE OF SOUNDING			
1	7-13-70	5.4	4.7	369.0	6.0

MISSISSIPPI RIVER - POTAMOLOGY STUDIES
DETAILED STUDY REACHES
LONGITUDINAL BED PROFILES

PROTOTYPE REACH
MILE 154 TO 140

U. S. ARMY ENGINEER DISTRICT, ST. LOUIS
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

PLATE NO. 8



WATER SURFACE ELEVATIONS

	GAGE RECORD			
	ST. LOUIS	WATERS POINT	SELMA	BRICKEYS LANDING
RIVER MILE	179.6	158.5	145.8	136.0
GAGE ZERO, MSL	379.94	370.39	0.00	357.78
L.W.R.P., MSL	376.44	367.43	361.00	356.23

RUN NUMBER	DATE SOUNDED	GAGE READING FOR DATE OF SOUNDING			
1	7-13-70	5.4	4.7	369.0	6.0

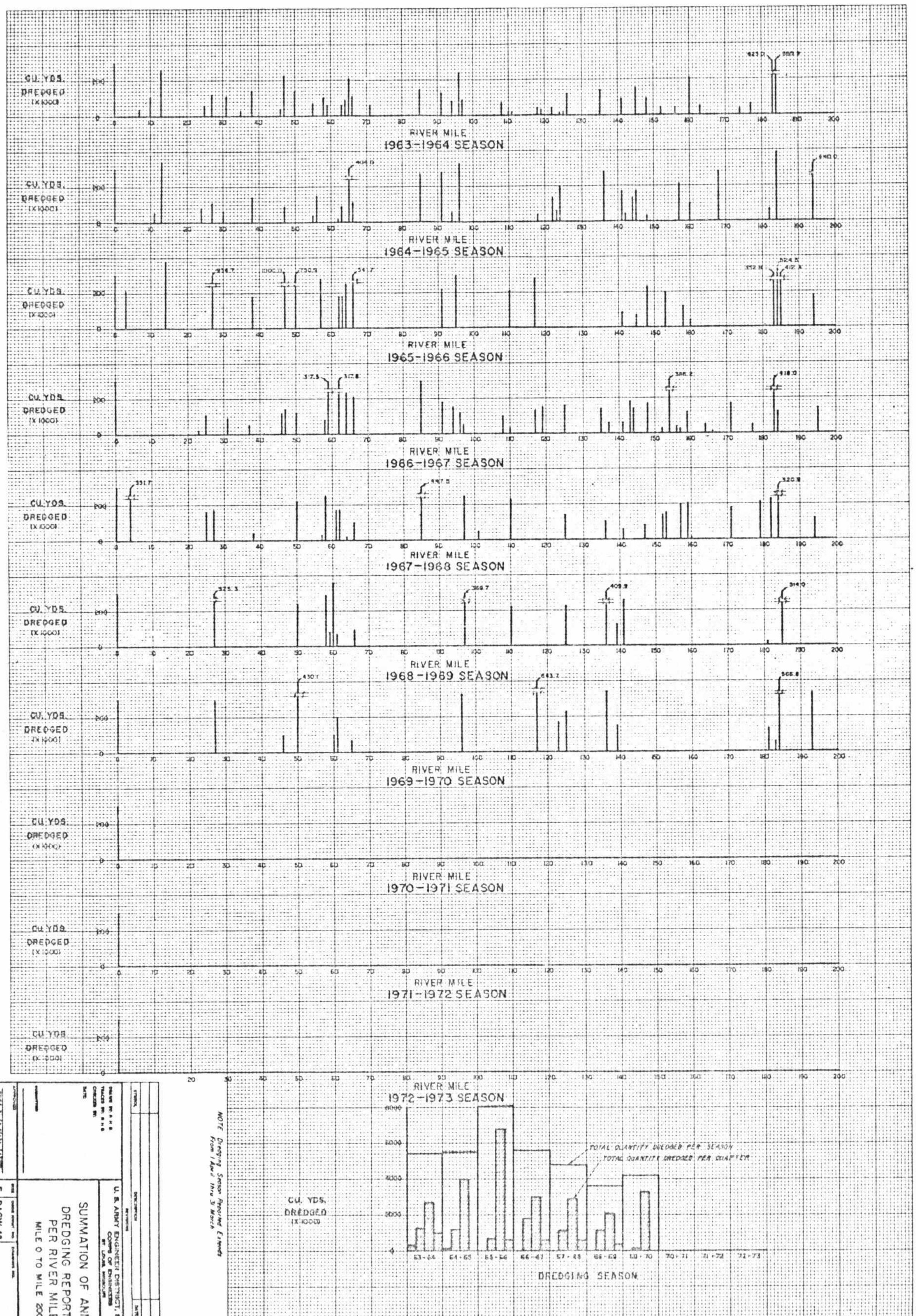
MISSISSIPPI RIVER - POTAMOLOGY STUDIES
DETAILED STUDY REACHES

LONGITUDINAL BED PROFILES

PROTOTYPE REACH
MILE 154 TO 140

U. S. ARMY ENGINEER DISTRICT, ST. LOUIS
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

PLATE NO 9



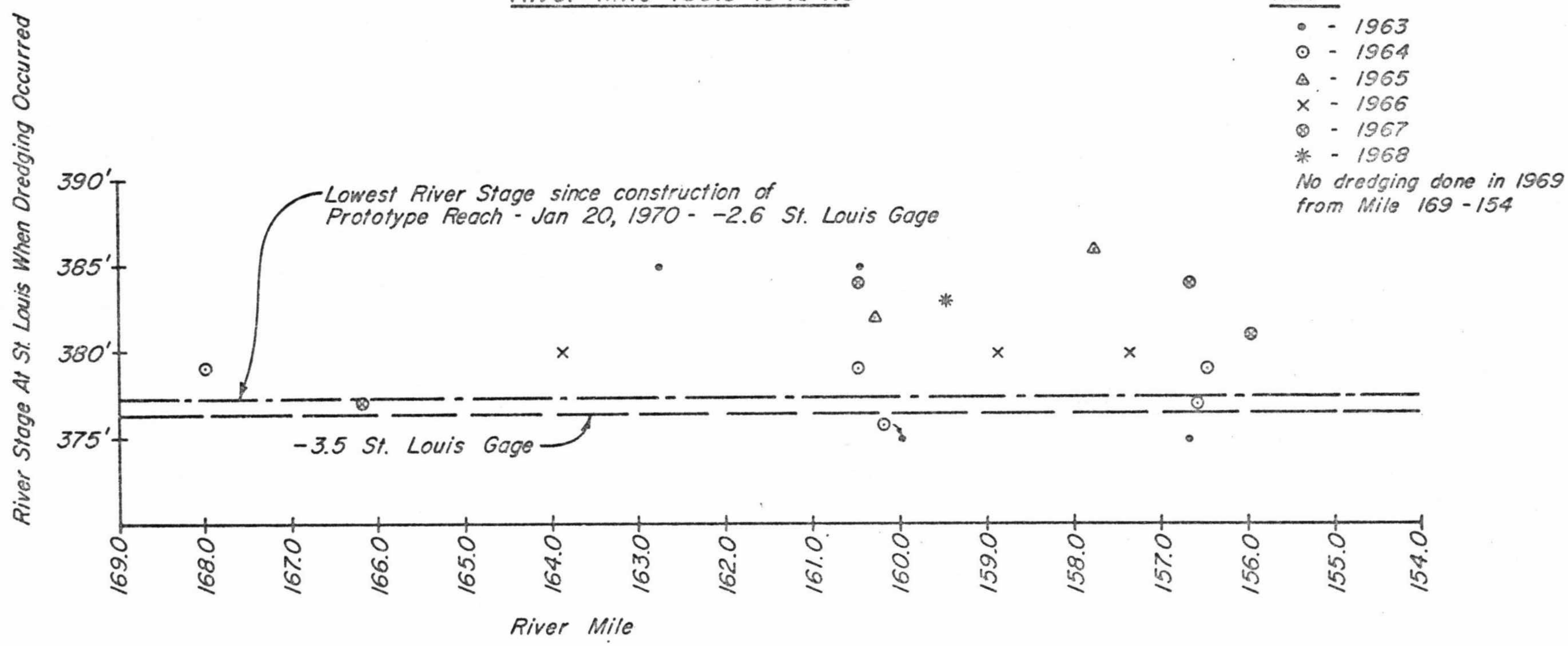
U. S. ARMY ENGINEER DISTRICT, ST. LOUIS
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

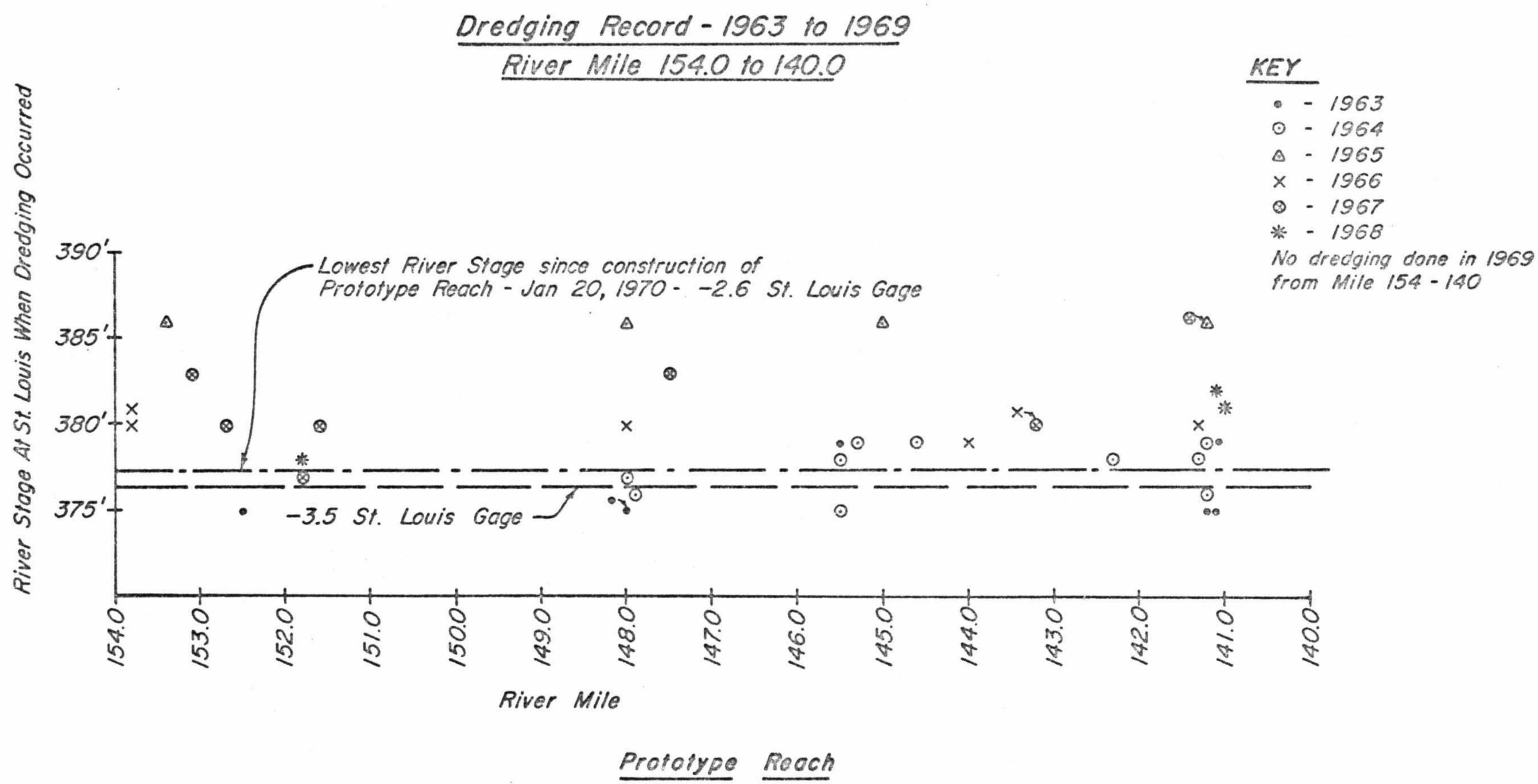
SUMMATION OF ANNUAL DREDGING REPORTS PER RIVER MILE
MILE 0 TO MILE 200

F DACW 43

PLATE NO 10

Dredging Record - 1963 to 1969
River Mile 169.0 to 154.0





Dredging Record - 1963 to 1969
River Mile 154.0 to 140.0
KEY
• - 1963
⊙ - 1964
△ - 1965
× - 1966
⊗ - 1967
✳ - 1968
No dredging done in 1969
from Mile 154 - 140
Lowest River Stage since construction of
Prototype Reach - Jan 20, 1970 - -2.6 St. Louis Gage
-3.5 St. Louis Gage
River Stage At St. Louis When Dredging Occurred
390'
385'
380'
375'
154.0
153.0
152.0
151.0
150.0
149.0
148.0
147.0
146.0
145.0
144.0
143.0
142.0
141.0
140.0
River Mile
Prototype Reach

PLATE NO. 12

Dredging Record - 1963 to 1969
River Mile 140.0 to 130.0

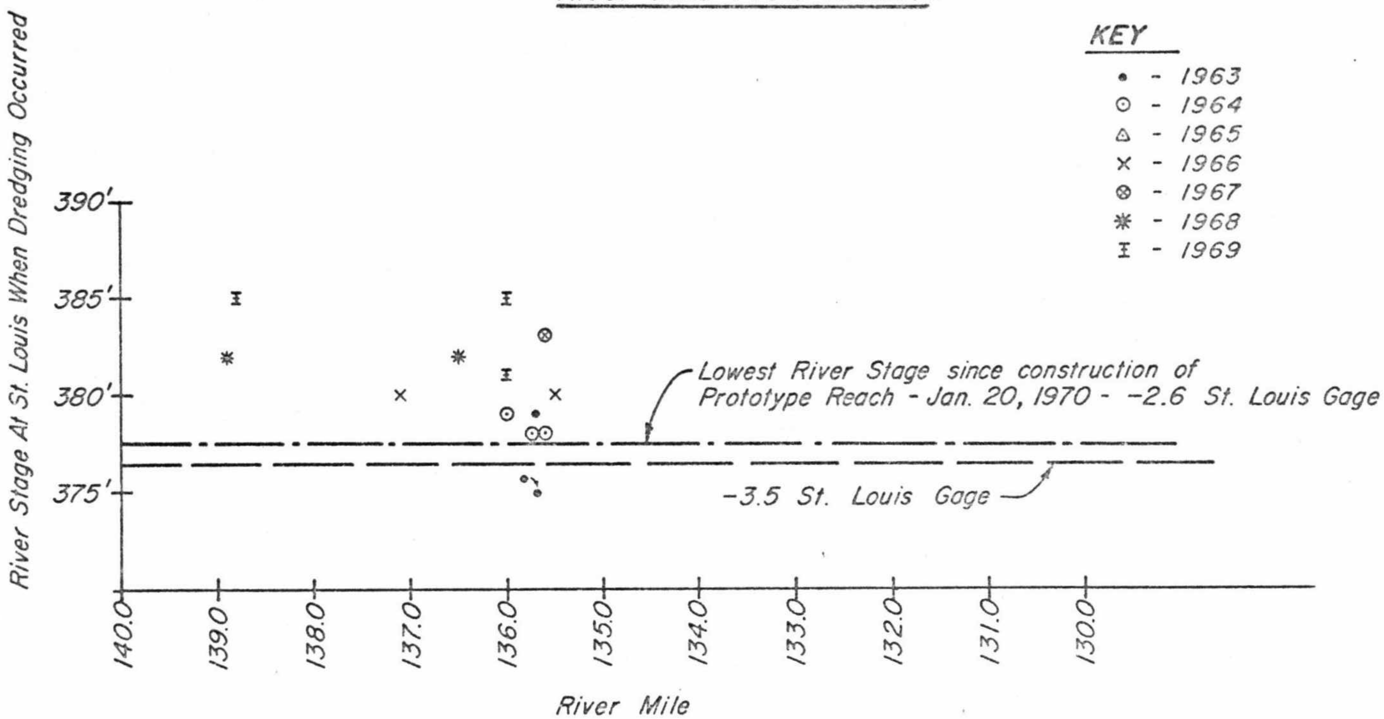


PLATE No. 13

DREDGING RECORD - 1963 to 1969
River Miles 169 to 154

Mile	Date	River Stage (St. Louis Gage)	Vol. Dredged (100 cu yds.)	Cost ($)	No. of Dredge Cuts
168.0	10/64	379	2770	40,876	1
166.2	1/67	377	105	5,767	1
163.9	12/66	380	506	18,126	1
162.8	6/63	385	505	17,881	1
160.5	6/63	385	1262	28,578	3
	10/64	379	1054	17,211	
	10/67	384	155	2,043	
160.3	8/65	382	402	12,572	1
160.0	12/63	375	198	4,423	2
	1/64	375	595	10,958	
159.5	2/68	383	1070	74,651	1
158.9	12/66	380	1234	19,948	1
157.8	11/65	386	1205	21,150	1
157.4	12/66	380	289	19,948	1
156.7	12/63	375	400	4,723	2
	10/67	384	2023	24,518	
156.6	12/64	377	1783	39,739	1
156.5	10/64	379	322	4,302	1
156.0	2/67	381	429	13,471	1

DREDGING RECORD - 1963 to 1969
River Miles 154 to 140

Mile	Date	River Stage (St. Louis Gage)	Vol. Dredged (100 cu yds.)	Cost ($)	No. of Dredge Cuts
153.8	9/66	380	1404	30,007	2
	11/66	381	2058	50,445	
153.4	11/65	386	2036	36,247	1
153.1	10/67	383	633	8,173	1
152.7	9/67	380	692	9,419	1
152.5	12/63	375	373	4,723	1
151.8	1/67	377	341	18,069	2
	1/68	378	253	6,708	
151.6	9/67	380	1207	32,966	1
148.0	12/63	375	268	4,723	5
	12/63	375	271	6,400	
	12/64	377	329	5,007	
	11/65	386	2363	36,257	
	9/66	380	1701	27,349	
147.9	2/64	376	423	10,092	1
147.5	11/67	383	868	11,525	1
145.5	10/63	379	1094	11,804	3
	1/64	375	453	9,550	
	8/64	378	528	8,372	
145.3	11/64	379	1159	23,964	1
145.0	11/65	386	734	12,085	1
144.6	1/64	379	1324	14,747	1
144.0	10/66	379	1416	26,093	1
143.2	2/67	380	1075	38,881	2
	12/66	380	737	15,152	
142.3	8/64	378	393	10,465	1

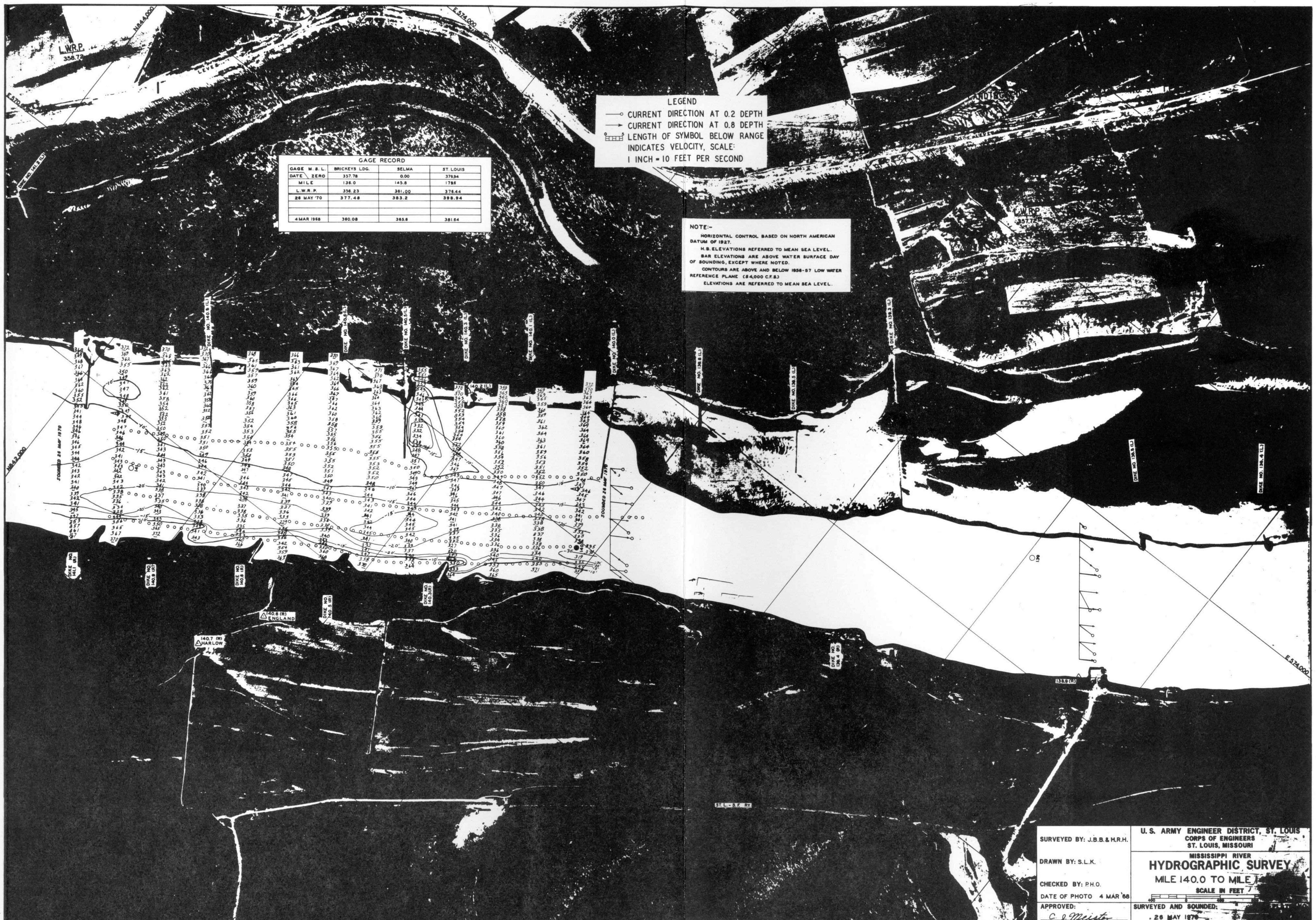
PLATE NO. 15

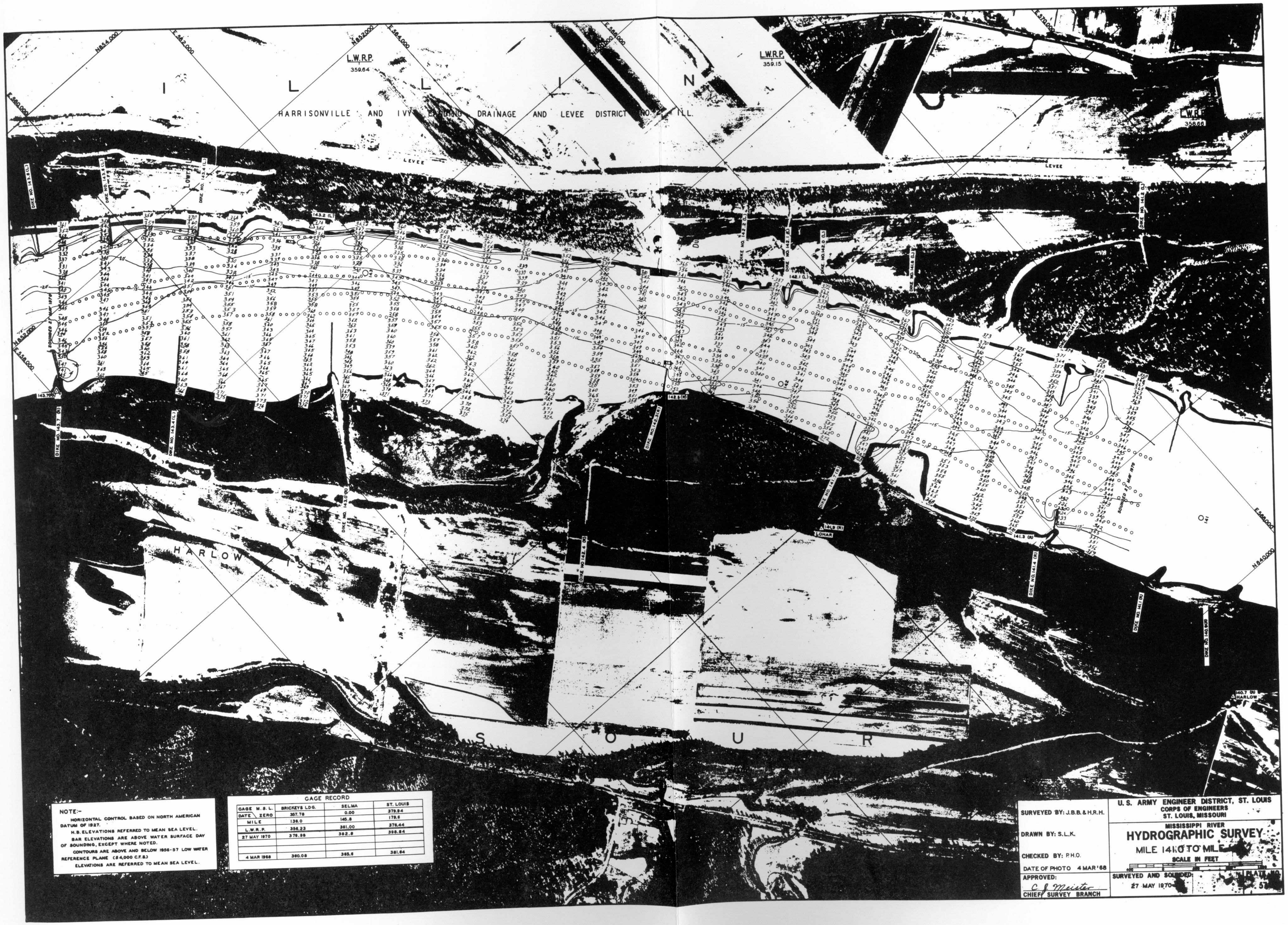
Mile	Date	River Stage (St. Louis Gage)	Vol. Dredged (100 cu yds.)	Cost ($)	No. of Dredge Cuts
141.3	8/64	378	252	6,279	2
	9/66	380	587	16,716	
141.2	12/63	375	301	16,533	5
	2/64	376	246	8,363	
	11/64	379	1429	23,964	
	11/65	386	850	15,107	
	12/67	386	625	24,505	
141.1	12/63	375	127	3,200	3
	9/63	379	276	8,516	
	9/68	382	1900	15,576	
141.0	12/68	381	740	16,471	1

PLATE NO. 15 (Continued)

DREDGING RECORD - 1963 to 1970
River Miles 140 to 130

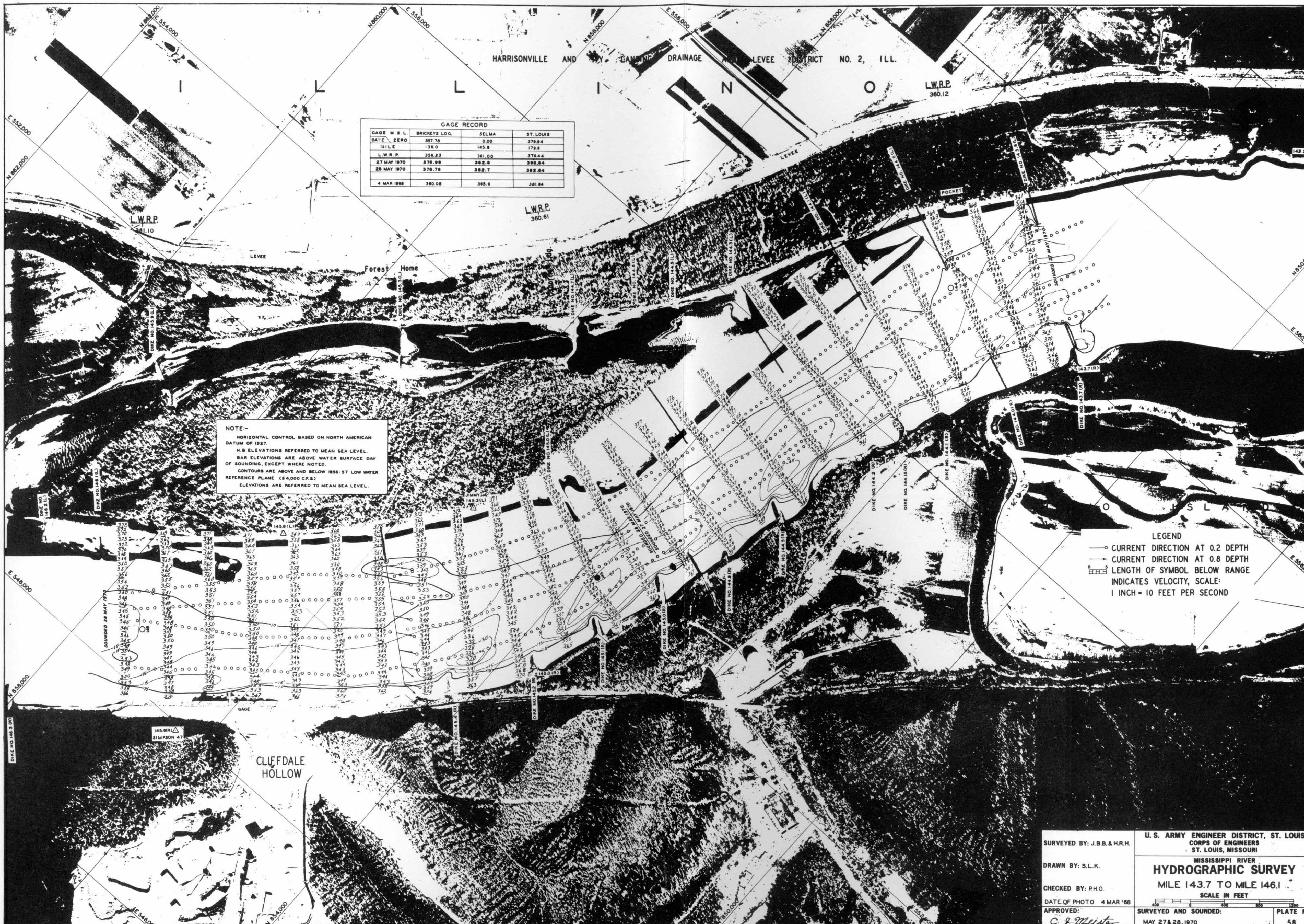
Mile	Date	River Stage (St. Louis Gage)	Vol. Dredged (100 cu yds.)	Cost ($)	No. of Dredge Cuts
138.9	9/68	382	1265	15,577	1
138.8	10/69	385	1473	32,547	1
137.1	12/66	380	587	16,716	1
136.5	9/68	382	4099	43,615	1
136.0	11/64	379	1957	23,212	3
	10/69	385	2922	65,094	
	12/69	381	494	10,849	
135.7	10/63	379	652	11,804	4
	12/63	375	442	6,400	
	12/63	375	58	3,200	
	8/64	378	497	8,372	
135.6	8/64	378	390	4,186	2
	11/67	383	1057	11,525	
135.5	9/66	380	604	24,743	1

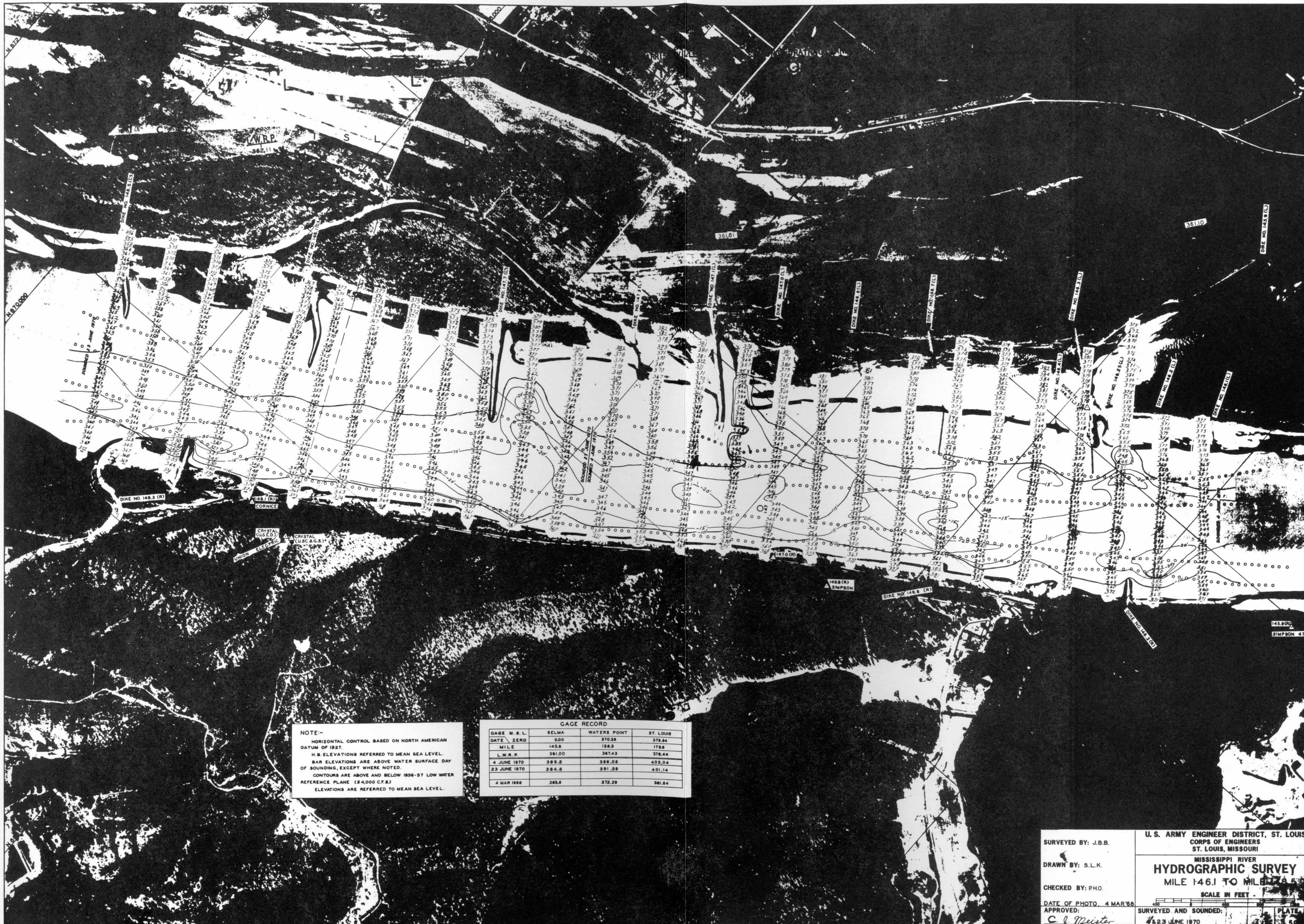

LEGEND
CURRENT DIRECTION AT 0.2 DEPTH
CURRENT DIRECTION AT 0.8 DEPTH
LENGTH OF SYMBOL BELOW RANGE INDICATES VELOCITY, SCALE:
1 INCH = 10 FEET PER SECOND
GAGE RECORD
GAGE M.S.L. | BRICKEYS LDG. | SELMA | ST. LOUIS
DATE ZERO | 357.78 | 0.00 | 379.94
MILE | 136.0 | 145.8 | 179.6
L.W.R.P. | 356.23 | 361.00 | 376.44
26 MAY '70 | 377.48 | 383.2 | 398.94
4 MAR 1968 | 380.08 | 365.6 | 381.64
NOTE:-
HORIZONTAL CONTROL BASED ON NORTH AMERICAN DATUM OF 1927.
H.B. ELEVATIONS REFERRED TO MEAN SEA LEVEL.
BAR ELEVATIONS ARE ABOVE WATER SURFACE DAY OF SOUNDING, EXCEPT WHERE NOTED.
CONTOURS ARE ABOVE AND BELOW 1956-57 LOW WATER REFERENCE PLANE (54,000 C.F.S.)
ELEVATIONS ARE REFERRED TO MEAN SEA LEVEL.
L.W.R.P. 358.72
L.W.R.P. 357.77
SOUNDED 26 MAY 1970
140.7 (R) HARLOW
140.6 (R) ENGLAND
SURVEYED BY: J.B.B. & H.R.H.
DRAWN BY: S.L.K.
CHECKED BY: P.H.O.
DATE OF PHOTO 4 MAR '68
APPROVED:
C. J. Meister
CHIEF SURVEY BRANCH
U.S. ARMY ENGINEER DISTRICT, ST. LOUIS
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI
MISSISSIPPI RIVER
HYDROGRAPHIC SURVEY
MILE 140.0 TO MILE
SCALE IN FEET
400 0 400
SURVEYED AND SOUNDED:
26 MAY 1970



GAGE RECORD

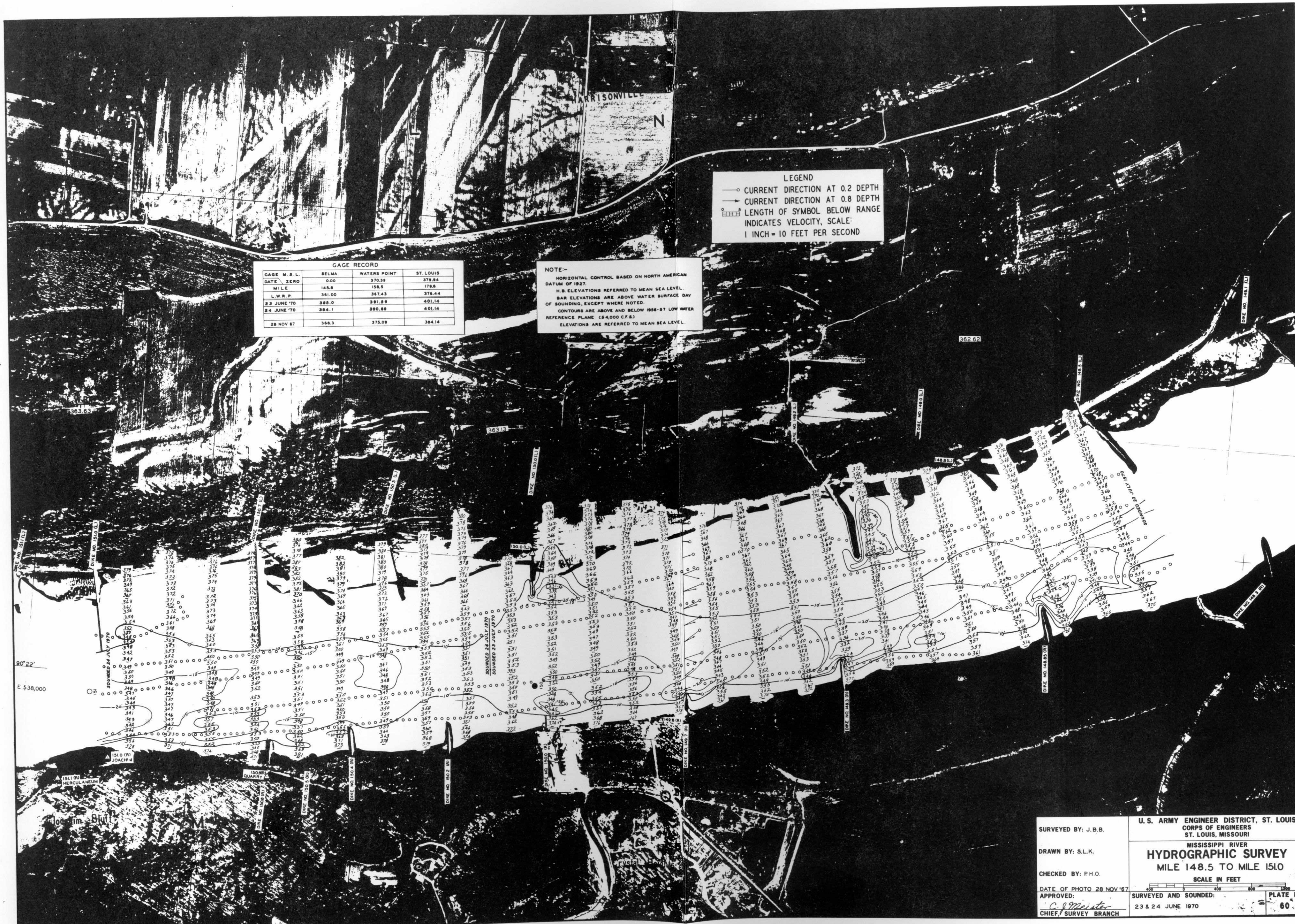
GAGE M.S.L.	BRICKEYS LDG.	SELMA	ST. LOUIS
DATE \ ZERO	357.78	0.00	379.94
MILE	136.0	145.8	179.6
L.W.R.P.	356.23	361.00	376.44
27 MAY 1970	378.98	382.8	398.84
4 MAR 1968	360.08	365.6	381.64


HARRISONVILLE AND ... DRAINAGE ... LEVEE DISTRICT NO. 2, ILL.
I L L I N O
GAGE RECORD
GAGE M.S.L. DATE ZERO | BRICKEYS LDG. 357.78 | SELMA 0.00 | ST. LOUIS 379.94
MILE | 136.0 | 145.8 | 179.6
L.W.R.P. | 356.23 | 361.00 | 376.44
27 MAY 1970 | 376.98 | 382.8 | 392.84
28 MAY 1970 | 376.76 | 382.7 | 392.64
4 MAR 1968 | 360.08 | 365.6 | 381.64
L.W.R.P. 361.10
L.W.R.P. 360.61
L.W.R.P. 360.12
LEVEE
Forest Home
POCKET
NOTE:-
HORIZONTAL CONTROL BASED ON NORTH AMERICAN DATUM OF 1927.
H.B. ELEVATIONS REFERRED TO MEAN SEA LEVEL.
BAR ELEVATIONS ARE ABOVE WATER SURFACE DAY OF SOUNDING, EXCEPT WHERE NOTED.
CONTOURS ARE ABOVE AND BELOW 1956-57 LOW WATER REFERENCE PLANE (54,000 C.F.S.)
ELEVATIONS ARE REFERRED TO MEAN SEA LEVEL.
LEGEND
CURRENT DIRECTION AT 0.2 DEPTH
CURRENT DIRECTION AT 0.8 DEPTH
LENGTH OF SYMBOL BELOW RANGE INDICATES VELOCITY, SCALE: 1 INCH = 10 FEET PER SECOND
SOUNDED 28 MAY 1970
SOUNDED 27 MAY 1970
CLIFFDALE HOLLOW
GAGE
SIMPSON 47
U.S. ARMY ENGINEER DISTRICT, ST. LOUIS
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI
MISSISSIPPI RIVER
HYDROGRAPHIC SURVEY
MILE 143.7 TO MILE 146.1
SCALE IN FEET
400 0 400 800 1200
SURVEYED BY: J.B.B. & H.R.H.
DRAWN BY: S.L.K.
CHECKED BY: P.H.O.
DATE OF PHOTO 4 MAR '68
APPROVED: C. J. Meister
CHIEF SURVEY BRANCH
SURVEYED AND SOUNDED: MAY 27 & 28, 1970
PLATE NO. 58



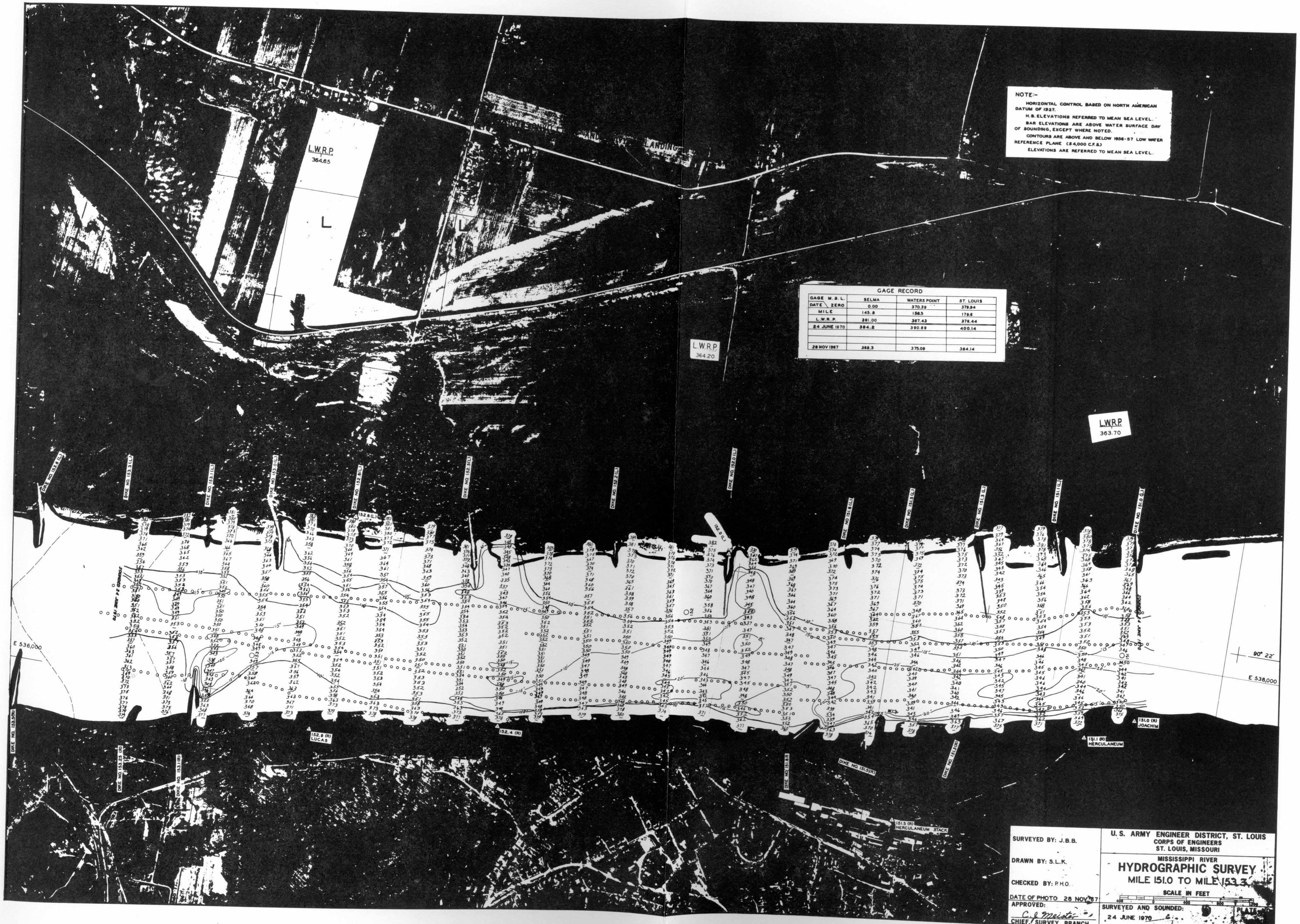
GAGE RECORD

GAGE M.S.L.	SELMA	WATERS POINT	ST. LOUIS
DATE \ ZERO	0.00	370.39	379.94
MILE	145.8	158.5	179.8
L.W.R.P.	361.00	367.43	376.44
4 JUNE 1970	389.2	396.09	405.04
23 JUNE 1970	384.8	391.59	401.14
4 MAR 1968	365.6	372.29	381.64



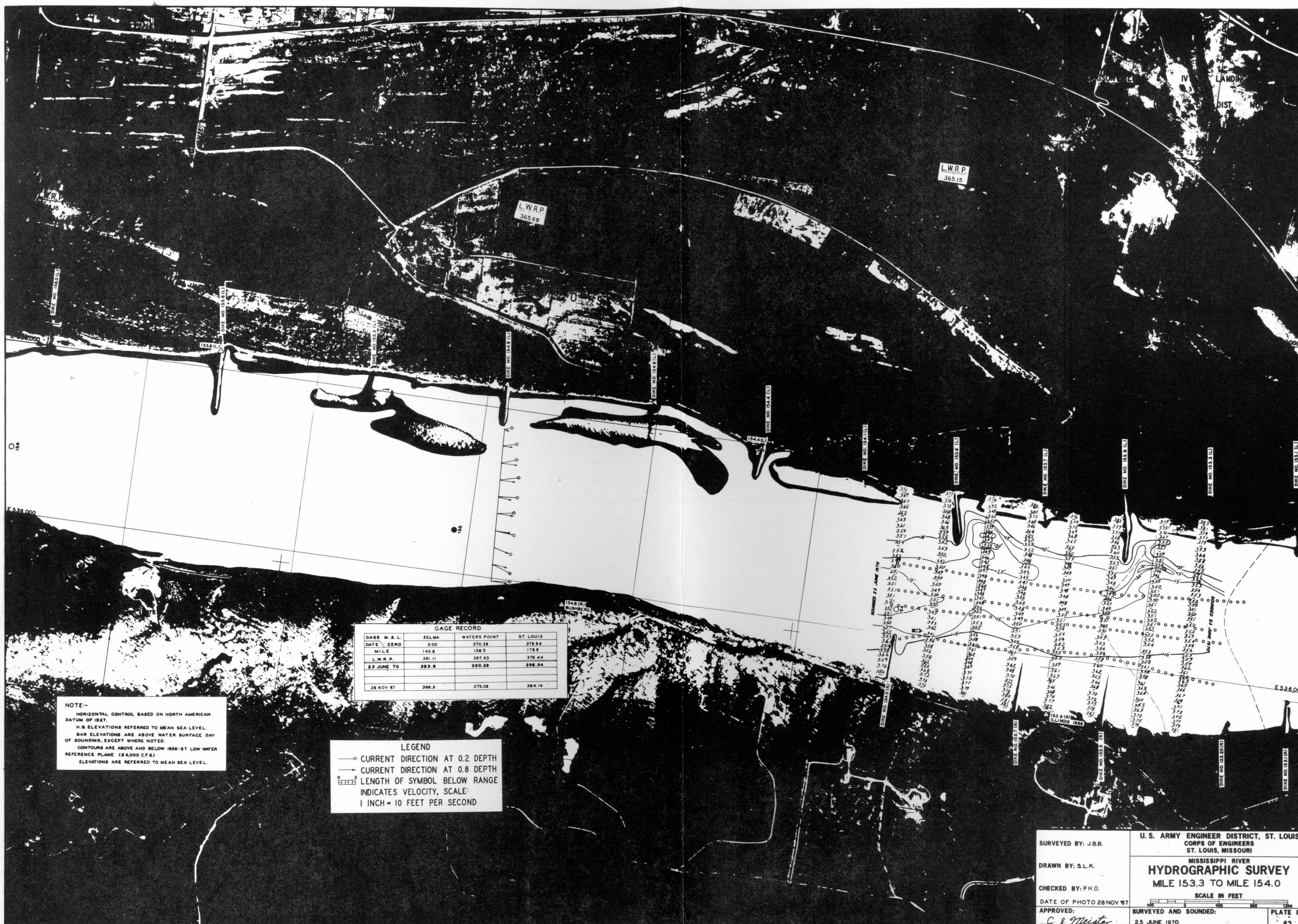
GAGE RECORD

GAGE M.S.L. / DATE ZERO	SELMA	WATERS POINT	ST. LOUIS
	0.00	370.39	379.94
MILE	145.8	158.5	179.6
L.W.R.P.	361.00	367.43	376.44
23 JUNE '70	385.0	391.59	401.14
24 JUNE '70	384.1	390.69	401.14
28 NOV 67	368.3	375.09	384.14



GAGE RECORD

GAGE M.S.L. / DATE ZERO	SELMA	WATERS POINT	ST. LOUIS
	0.00	370.39	379.94
MILE	145.8	158.5	179.6
L.W.R.P.	361.00	367.43	376.44
24 JUNE 1970	384.2	390.69	400.14
28 NOV 1967	368.3	375.09	384.14



GAGE RECORD

GAGE M.S.L. DATE ZERO	SELMA	WATERS POINT	ST. LOUIS
	0.00	370.39	379.94
MILE	145.8	158.5	179.8
L.W.R.P.	361.11	367.43	376.44
25 JUNE 70	383.8	390.39	398.94
28 NOV 67	368.3	375.09	384.14

TC 425 D

D3940

PROTOTYPE POTAMOGRAPHY MIDDLE MISSISSIPPI RIVER MILE 154 TO 140

SLD POTAMOLOGY STUDY (S-2) RIVER STABILIZATION BRANCH

PROPERTY OF THE UNITED STATES GOVERNMENT
US-CE-C

U. S. ARMY ENGINEER DISTRICT, ST. LOUIS
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

March 1976

IIa

PROTOTYPE POTAMOGRAPHY

MIDDLE MISSISSIPPI RIVER

MILE 154 TO 140

SLD POTAMOLOGY STUDY (S-2)

RIVER STABILIZATION BRANCH

U. S. ARMY ENGINEER DISTRICT, ST. LOUIS

CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

MARCH 1976

FOREWORD

This report was prepared by Mr. Claude N. Strauser, Potamologist and Mr. Gary W. Schwartz, Assistant Potamologist, River Stabilization Branch, Engineering Division.

Assistance was provided by Mrs. Joann M. Hutchinson, Chief Librarian, Mr. Lester Arms, Chief, Mapping Section, Survey Branch; Mrs. J. Bernice Thornton, Survey Branch; Mr. Harold Williams, Mapping Section, Survey Branch; Mrs. Helen Schleipman, Service Section; and Mrs. Lois J. King, Project Planning Branch.

This report was prepared under the direction of Mr. Norbert C. Long, Chief, River Stabilization Branch, and Mr. Jack R. Niemi, Chief, Engineering Division, St. Louis District.

Colonel Thorwald R. Peterson, CE, was District Engineer and LTC Richard W. Gell was Deputy District Engineer during the preparation of this report.

Authors' Preface

In dealing with the many parameters that affect the river, it is best to keep in mind that a permanent improvement should be designed in harmony with the natural laws of the river. This policy was established by Colonel J. H. Simpson in 1875.

"Nature overlooks nothing, and we may confidently assume that the position and direction of the river, at any time, is the resultant of all the forces, and consequently, is a concrete expression of the law of the stream, which we may modify and preserve, but may not safely destroy or radically change. To accept and follow nature is, in this case, the beginning and end of science."

Between 1846 and 1848, Mr. Henry Lewis traveled to many places along the Mississippi River. As a result of his journeys he published a book in 1850 that was entitled, "Das illustrirte Mississippi." A portion of the Prototype Reach is briefly described in his book and it is reproduced here. The pictures that accompany this description were taken by Mr. Charles X Stricker on 12 October 1975 while he and the authors were traveling through the Prototype Reach aboard the Corps of Engineer M/V Mississippi.

THE CORNICE ROCKS

"These are really a kind of curiosity. The perpendicular sides of these limestone walls have been worn into irregular shapes by the water, and in some places one sees a continuous formation resembling a handsome cornice overhanging the cliffs, whose sides represent columns and other architectural devices."

THE CORNICE ROCKS

"These are really a kind of curiosity. The perpendicular sides of these limestone walls have been worn into irregular shapes by the water, and in some places one sees a continuous formation resembling a handsome cornice overhanging the cliffs, whose sides represent columns and other architectural devices."

TABLE OF CONTENTS

Appendixes

LIST OF TABLES

Middle Mississippi River

Miles 154.0 to 140.0

Report No. 3

PART I - INTRODUCTION

This is the third in a continuing series of reports pertaining to the reach of river now referred to as the "Prototype Reach." The first report was prepared by Norbert C. Long, Chief of the River Stabilization Branch, St. Louis District, Corps of Engineers (May 1971). The second report was prepared by Eugene A. Degenhardt, Potamologist, St. Louis District, Corps of Engineers (20 September 1972).

The first report compared various hydraulic parameters derived from the 1966 hydrographic survey and the 1970 hydrographic survey. The second report compared various hydraulic parameters derived from the 1966, 1970, winter 1971 and summer 1971 hydrographic surveys. This report will compare the 1959, 1966, 1967, 1970, winter 1971, summer 1971, 1972, winter 1975 and spring 1975 hydrographic surveys. (Due to various adverse field conditions and survey limitations, there were no hydrographic surveys made in this reach of river during 1973 and 1974.)

PART II - NAVIGATION PROJECT AUTHORIZATIONS (1910-1927-1930)

R&H Act of 26 June 1910	Provide a channel 8 feet deep and 200 feet wide between the Ohio and Missouri Rivers.

R&H Act of 21 Jan 1927	Provide a channel 9 feet deep and 300 feet wide from Ohio River to northern boundary of City of St. Louis.
R&H Act of 3 Jul 1930	Project between northern boundary of City of St. Louis and Grafton (mouth of Illinois River) modified to provide a channel 9 feet deep and generally 200 feet wide with additional width around bends.

The River & Harbor Act of 30 August 1935 extended the lower limits of the Mississippi River between the Missouri River and Minneapolis, Minnesota, project to the mouth of the Missouri River and authorized improvement by a system of locks and dams supplemented by dredging in accordance with plans recommended in House Document No. 137, 72d Congress, 1st Session. This, in essence, eliminated the reach of the Mississippi River from the mouth of the Illinois River to the mouth of the Missouri River from the Regulating Works project.

PART III - BACKGROUND INFORMATION

This 14-mile reach of the Mississippi River, called the Prototype Reach, contains the channel improvement problems most frequently encountered along the entire length of the Middle Mississippi River. Prior to the construction of improvements, extensive dredging was required to maintain the authorized navigation channel dimensions.

Dredging costs amounted to $624,000 between 1963 and 1968 to make a total of 37 dredge cuts. Since the completion of the river regulating improvements (March 1969), no dredging has been required to maintain the navigation channel.

The regulating structures in this reach include existing bank revetment and 51 newly constructed stone-fill dikes (includes dike extension constructed on existing dikes). These new structures contracted the low-water width of the river to 1200 feet. To reduce the cost of construction, dike elevations were built to slope downward from the high bank (or the ends of previously constructed dikes) so that the riverward ends of the new dikes were at an elevation equivalent to 5-foot on the St. Louis gage.

The Middle Mississippi River meanders within its banklines from one deep water pool on one side of the river to another deep water pool on the other side of the river. The areas located between successive deep water pools are called channel crossings. The critical depth of water available at any given channel crossing can, and often does, control the amount of depth available for navigation along the entire length of the Middle Mississippi River. There are six channel crossings in the reach of river from miles 154 to 140 which formerly required repetitive dredging to maintain minimum project dimensions.

The design and construction of regulating structures has been the subject of considerable research and development studies in recent years. Many model studies have been conducted at the Waterways

Experiment Station in Vicksburg, Mississippi. The studies have been conducted in an effort to improve design criteria and reduce construction costs. The construction of regulating works between miles 154 and 140 is part of special prototype study program to learn what effect a 1,200-foot low water contraction would have upon navigation depths for the authorized 9-foot channel project.

While there are no reliable engineering formulas which can be used to determine the amount of contractive effort required to develop a navigation channel possessing a specified minimum depth and width, the construction of regulating structures between miles 154 and 140 has proven that the desired channel improvement objectives can be obtained provided available research and development data, existing dike field performance data, and engineering judgement are properly utilized during the planning stage. The reach of river between miles 154 and 140 now possesses an excellent 9-foot navigation channel.

This reach of the Middle Mississippi River has been converted through a period of approximately 100 years from a shallow, wild, meandering stream, unpredictable and hazardous to navigation, into a controlled channel of adequate depth and national importance over which millions of tons of bulk freight are handled annually.

The middle Mississippi was not, nor is now, a lazy stream. Its steep slope and the erodible character of the post-glacial deposit make it agressive in its attempt to change its course and cut off bends. It accomplished its purpose by caving banks ruthlessly and flowing over farmland in a highly destructive manner. On the authority of Mark Twain (the novelist, humorist and river pilot), the unlighted and uncharted river channel was never the same on any two successive trips. He also said the Mississippi River was remarkable for its ability to cut through narrow necks thereby shortening its overall length by as much as 30 miles with a single cutoff. His early observations concerning the ability of the Mississippi River to create new channels via cutoffs is borne out by the fact that three segments of the state of Illinois are located on the Missouri side of the river while two segments of Missouri are located on the Illinois side. Now, due to the construction of regulating structures similar to those constructed between miles 154 and 140, the banklines have been stabilized and a dependable navigation channel has been developed.

On 30 September 1971, it was announced that the Chief of Engineers had selected the Prototype Reach for an Award of Merit. This award is given for efficient, economical and sound engineering designs. See Plates 1 thru 3.

III - CHANNEL ANALYSIS (1959-1975)

The methods used, in this report, to analyze data obtained from hydrographic surveys of the Prototype Reach are essentially the same as were used in the two previous reports.

It has been the opinion of the River Stabilization Branch that an analysis of the hydrographic surveys should be associated with the Low-Water Reference Plane (LWRP). This theoretical plane is based upon a discharge of 54,000 cfs. There are advantages in making comparisons with regard to the LWRP, one of which is the elimination of the problem associated with deposition and the related "masking" of the channel geometry. Although this approach was thought to be original, a search of old records revealed that this idea was formulated before the turn of the century. The following quotation was taken from the Annual Report of the Chief of Engineers, in the year 1880:

"In examining (river cross sections), it is to be borne in mind that the works are built to a height (several feet) above the low water, and that the portion of the river bed lying below that level is mainly to be considered as to their effect."

Some reports recently published by private individuals and universities have taken river data and attempted to make a comparative analysis of river conditions, at various times, without considering the changes in stage, discharge, etc. that were present when the surveys were taken. This common error has led to many conclusions that can not, upon closer examination, be substantiated. For instance, one report compared river bed elevations in different years and did not make any attempt to explain that the river conditions were not similar. Comparisons should be made only when similar conditions exist. Even though this was realized by experienced river engineers many years ago, there are still individuals that are unaware of this basic rule. In Senate Document No. 204, 63d Congress, 1st Session, dated 16 May 1913, it is simply stated as follows:

"... the only way to determine whether the river bed is rising or being scoured out is by comparing corresponding low waters with each other, or corresponding high waters."

Even in 1880 this problem was realized and was addressed as follows:

"It is no easy matter in the case of a silt-bearing stream to show definitely upon paper the effect of the works of improvement upon the channel. A statement that a certain depth existed before the execution of the works and another depth existed afterwards might be strictly true, but at the same time might be misleading and unfair. The channel is constantly shifting its position and the bottom fills or scours with the rise or fall of the water surface."

There are three hydrographic surveys used in this report which were made before the Prototype Reach was constructed and six hydrographic surveys which were made after the Prototype Reach was constructed. These are the surveys that will be used in this report for the comparative analysis. See Table No. 1.

Table No. 1

Listing of Hydrographic Surveys Used in This Report

Date	Average Stage Above LWRP	Miles Covered	
1959 Feb. - Mar.	15.2	140 to 154	
1966 Oct. - Nov.	3.9	140 to 154	
1967 Oct.	9.8	140 to 154	Before Prototype Const.
1970 May - Jun.	23.3	140 to 154	After Prototype Const.
1971 Jan. - Feb.	5.1	146 to 154	
1971 Aug.	5.6	140 to 154	
1972 Jul, Aug, Sep.	15.6	141 to 154	
1975 Feb.	20.9	148 to 154	
1975 May	26.5	148 to 154	

*Note: Similar stages are not always accompanied by similar discharges

The only significant construction activity that has taken place in the Prototype Reach since its completion has been the rehabilitation of three breached dikes. These dikes were mentioned in the previous prototype report. The rehabilitated dikes are:

Mile	Bank	Date of Repair
150.0 L	left	28 November 1973
149.2 L	left	6 December 1973
148.1 L	left	10 December 1973

The dike at river mile 142.3 R has not been repaired and is therefore, still inoperative.

a. Navigation Channel Width

Width is one of the channel dimensions that can be most easily influenced by the works of man. The topic of river width has been discussed by river engineers for years. One of the earliest published discussions is found in the Annual Report to the Chief of Engineers, in the year 1880. The following account is reproduced here because of the importance of this early discussion.

"One of the most important developments of this survey is the evidence which the present position of the shore line affords, that the stability of the banks has decreased with the settlement of the country and the clearing away of the forests. Weakened banks permit more rapid erosions, give the river greater width, and therefore less depth, and the navigation is injured. The fact that the river has materially widened within the last 60 years (since 1820) is generally acknowledged by those best informed, but all evidence that can be procured in support of it is useful in resisting claims for damages, by establishing the position that our works of improvement are works of conservancy. And if this widening process is still going on it is evident that the navigation is still further deteriorating. An examination of the shore line shows that in every case where cleared fields along a caving bank are interrupted by a patch of woods, the latter projects out into the river. It is easy to believe that the binding quality of the roots, and the protection formed by the fallen trees at the foot of the bank should have this effect. Wooded banks yield finally, of course, but the rate of erosion is so slow that the river has time to build up on the opposite side, and there is no increase in width.

"The facts lead to the belief not only that the navigation has been deteriorating in the past, but that the process is still going on, and will increase in rapidity as further clearings are made, and that, unless energetic measures are adopted to replace the guards established by nature and removed by man, the day will come when the navigability of the river for vessels that now use it will be destroyed."

This widening of the river from the 1820's to the 1880's was recently reported in a study sponsored by the U.S. Army Engineer District in St. Louis, Missouri (July 1974). This report, "Geomorphology of the Middle Mississippi River", states that the average river width in 1821 was 3600 ft., in 1888 it was 5300 ft. and in 1968, the average river width was 3200 ft.

Since the river widths of 1821 and 1968 are approximately the same, it shows that much of the work performed on the river during the last 100 years has been a work of conservancy.

With the above background information on the total river width in mind, an examination of the change in the average navigation widths throughout the Prototype Reach may be better understood.

To determine the change in navigation width, it was first necessary to define the term. Navigation width will be used in this report as the distance between the contour lines on the hydrographic surveys that are located 10 feet below the LWRP (project depth is 9 feet below the LWRP; however, the -10 contour was chosen for simplicity).

One way to evaluate the effectiveness of the Prototype Reach contraction is to compare conditions that existed "before" and "after" its construction. The 1959 hydrographic survey and the 1972 hydrographic survey were taken at approximately the same average stage so they were chosen for the first comparison. The average stages of these surveys were 15.2 ft. and 15.9 ft. above the LWRP, respectively. The average navigation width in 1959 was 876 feet compared to the average navigation width in 1972 of 976 feet. See Plate 5. As in previous reports, it can be seen that where there were breached dikes or excessive spacing between dikes, the navigation widths did not improve as desired.

The 1966 and 1971 hydrographic surveys were taken at average stages of 3.9 ft. and 5.6 ft. above the LWRP, respectively. Since these were relatively similar, comparisons between these two surveys were made. The average navigation width in 1966 was 850 feet and in 1971 was 1,045 feet. See Plate 4.

To see what impact the dikes have on navigation widths at high river stages, two partial surveys of the prototype reach were made in 1975. The surveys were limited to miles 154 to 148 because this is the only area where the horizontal survey control points are still available at high water. These surveys were compared with the 1970 survey that was made using only that part of the 1970 survey between miles 154 to 148.

The average stage of the 1970 survey was 23.3 ft. above the LWRP. The February 1975 average stage was 20.9 ft. above the LWRP and the May 1975 average stage was 26.5 ft. above the LWRP. The navigation width was 1,082 feet, 1,375 feet and 1,435 feet, respectively. See Plate 6.

Table No. 2

Average Navigation Widths

Low Stages	
1966 (before construction)	850 feet
1971 (after construction)	1,045 feet (22% increase)
Medium Stages	
1959 (before construction)	876 feet
1972 (after construction)	976 feet (11% increase)
High Stages (there were no high water surveys made before the Prototype Reach was constructed)	
1970 (after construction)	1,082 feet
February 1975 (after construction)	1,375 feet
May 1975 (after construction)	1,435 feet

An examination of this data indicates that at the lower stages, when channel dimensions are the most important, the dikes have improved the navigation widths substantially. As the stage increases above the dike contraction elevation, some reduction in width is observed; however, when the stage increases towards the bankfull elevation, the navigation widths, once again, begin to increase.

b. Average Depth Below the LWRP

The navigation depth is of primary importance to the river engineer. Once again, in order to place this topic in its proper perspective, reference is made to the Annual Report of the Chief of Engineers, dated 1880. The following is an extract pertaining to navigation depths:

"The shoals in the Mississippi are constantly shifting their position, and there are very few spots now occupied by them where there has not been deep water within a recent period. It is pretty well established that there was in former years a depth of water throughout the navigable channel at the lowest stage at least equal to what we shall endeavor to obtain by our works."

The river in 1880 had deteriorated to such an extent that it was almost impossible to navigate. The goal of the 1881 project was to return the river to a condition that had previously existed under natural conditions (early 1820's).

The 1966 and the August 1971 hydrographic surveys were selected to compare "before" and "after" conditions of the navigation depth within the Prototype Reach at low stages. The navigation depth, for this report, is defined as the average depth below the LWRP. It is calculated by dividing the area below the LWRP by the width at the LWRP.

The average depth in 1966 was 10.4 feet and the average depth in August 1971 was 13.8 feet. See Plate 7.

The 1959 hydrographic survey and the 1972 hydrographic survey were selected for "before" and "after" conditions at medium stages. The 1959 average depth below the LWRP was 11.5 feet and in 1972 it was 12.9 feet. See Plate 8.

For high flows the 1970, February 1975, and the May 1975 hydrographic surveys were compared. The average depth in 1970 was 12.4 feet, in February 1975 it was 14.0 and in May 1975 it was 15.0. (Only that portion of the 1970 survey was used in these calculations that matched the partial surveys that were taken in 1975, i.e., miles 154 to 148.) See Plate 9.

Table No. 3

Average Depth Below the LWRP

Low Stages		
	1966 (before construction)	10.4 feet
	Aug. 1971 (after construction)	13.8 feet (33% increase)
Medium Stages		
	1959 (before construction)	11.5 feet
	1972 (after construction)	12.9 feet (12% increase)
High Stages		
	1970 (after construction)	12.4 feet
	Feb. 1975 (after construction)	14.0 feet
	May 1975 (after construction)	15.0 feet

It appears that around mid-bank stages there is a small decrease in navigation depths and as the stages increase more towards bankfull, the depths below the LWRP begin to increase. The dikes become less effective as the stages increase to about mid-bank and then it appears that increased flows begin to compensate for the loss of contraction.

c. Average Area Below the Low Water Reference Plane

As can be expected, similar results should be obtained when you combine width and depth and investigate the area below the LWRP.

The 1966 and the August 1971 hydrographic surveys were selected for the low water comparisons. The 1966 average area below the LWRP was 17,608 sq. ft. and the average area below the LWRP in August 1971 was 19,668 sq. ft. See Plate 10.

For the medium stages, the 1959 and the 1972 hydrographic surveys were selected. In 1959, the area below the LWRP was 18,122 sq. ft. and in 1972 it was 17,849 sq. ft. See Plate 11.

For the high stages, the 1970, February 1975 and May 1975 hydrographic surveys were selected. The area below the LWRP in 1970 was 19,744 sq. ft. and in February 1975 it was 25,813 sq. ft., and in May 1975, it was 28,287 sq. ft. (Only the portion of the 1970 survey was used that coincided with the partial surveys made in 1975.) See Plate 12.

Table No. 4

Average Area Below the Low Water Reference Plane

Low Stages	
1966 (before construction)	17,608 sq. ft.
Aug. 1971 (after construction)	19,668 sq. ft. (12% increase)
Medium Stages	
1959 (before construction)	18,122 sq. ft.
1972 (after construction)	17,849 sq. ft. (1% decrease)
High Stages	
1970 (after construction)	19,744 sq. ft.
Feb. 1975 (after construction)	25,813 sq. ft.
May 1975 (after construction)	28,287 sq. ft.

d. Prototype "Pause"

The observance of a hesitance in the river channel geometry to improve at stages near mid-bank, led to a closer examination of this phenomena. For lack of a better name, this hesitance was called the "Prototype Pause".

It was decided to recombine the variables already used and plot "stage vs area below the LWRP" and "discharge vs area below the LWRP". This approach proved to be very interesting.

In order to fully utilize the partial surveys that were made during high water in 1975, only the survey miles between 148 and 154 were used.

Comparisons were made at each mile using hydrographic survey ranges that most nearly approximated the same location. The surveys were plotted in two groups, "before" and "after" the construction of the Prototype Reach.

Once again it was evident that the "Prototype Pause" was present. See Plates 13 thru 22 for "before" and Plates 23 thru 33 for "after". There was an insufficient number and variety of points among the "before" surveys to state unequivocally that the "Prototype Pause" was not present before construction; however, it does appear after the Prototype Reach was constructed.

e. Analysis

The riverward ends of the dikes in the Prototype Reach are constructed to an elevation equivalent to a stage of 5 ft. on the St. Louis gage. When the river stages are equivalent to 5 ft. St. Louis, or lower, there is a 1200-ft. contraction available. As the stages increase, the amount of contraction decreases continuously until the stages are above the elevations of the dikes and the width of the water surface extends from bankline to bankline.

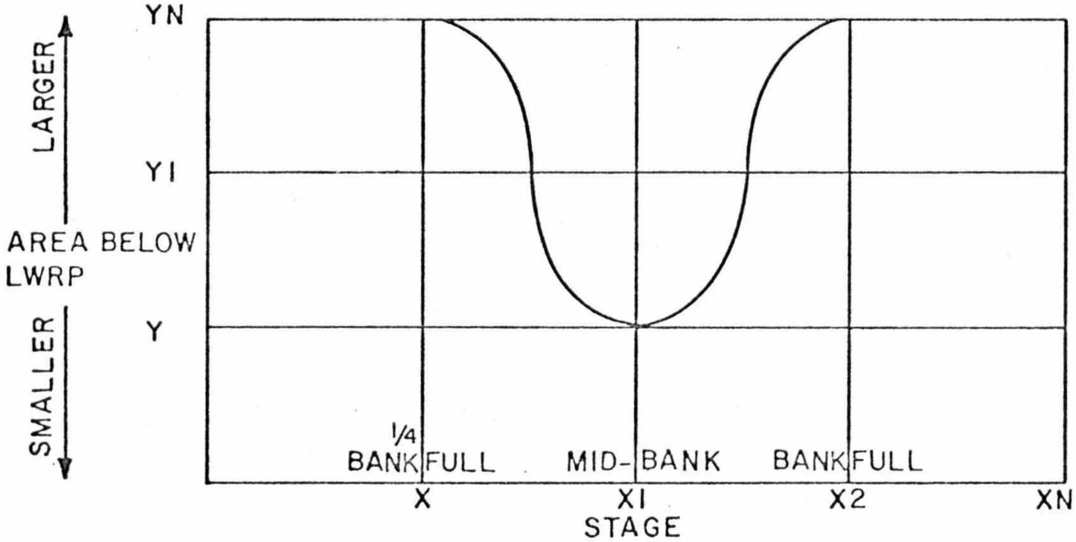
When stages begin to rise, the contraction in the Prototype Reach begins to lose its effectiveness before the increased flows can compensate for this loss of contractive effort. If this had occurred in a reach of river when the contractive effort had been less than 1200 ft. (at low flows), there would most probably have been a less than adequate depth available in portions of the navigation channel.

As Colonel J. H. Simpson stated in 1875, "... the dikes should be of such height as to produce action upon the bed when the river is first approaching the low stage, so as to prepare the channel, in some degree, for the less powerful effect of the diminished low-water volume." He goes on further to say, "... the works erected should begin to act as some intermediate stage. This should be before the want of depth is felt ... ."

As the stages begin to decrease in the Prototype Reach, the diminishing volume of water loses some of its power before the effect of the low-water contraction can be fully developed and then as the stages approach a stage equivalent to 5-ft. on the St. Louis gage, the contraction becomes great enough to permit the channel dimensions to "catch-up" and to continue their improvement.

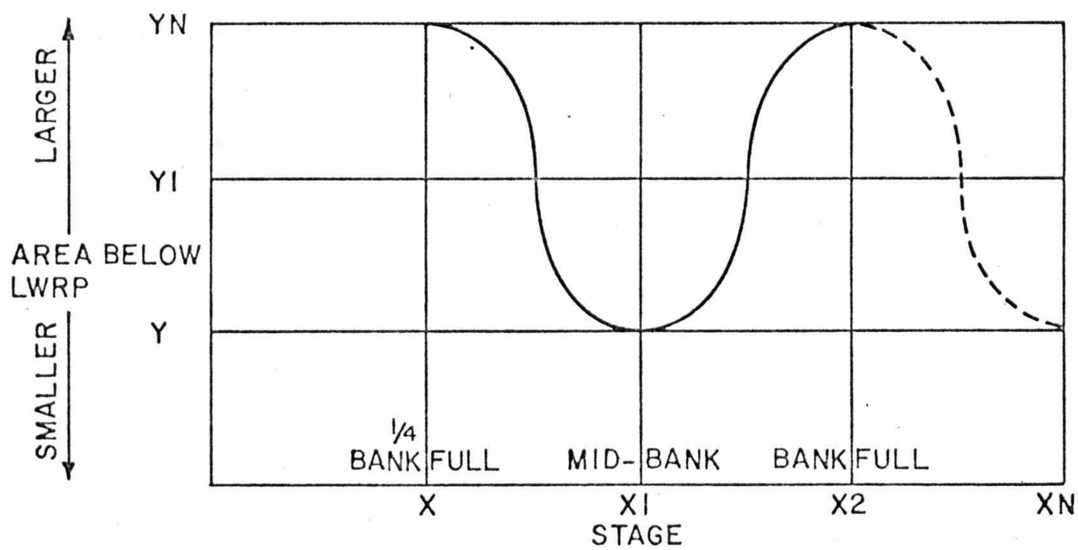
To more fully understand the best combination of dike height and amount of contractive effort, another test reach has been designed and is presently being constructed. This test reach is located between Mississippi River, miles 87.0 to 93.0. This test reach is being constructed with a 1500-ft. contraction (instead of the 1200-ft. contraction used in this study) and the riverward end of the dikes are being built to an elevation equivalent to 5-ft. on the St. Louis gage. This test reach has been named by the Chief, River Stabilization Branch as "Prototype 76." The old community of Seventy-Six, Missouri, at mile 90.3 R, the year of construction of this test reach and the Bicentennial celebration all combined, indicate that this name is appropriate for the above mentioned reasons.

The "Prototype Pause," if properly used, can be a "yardstick" by which the river engineer can measure the effectiveness of his design criteria.



The above graph shows a theoretical "Prototype Pause." At low stages, there is sufficient area below the LWRP; at mid-bank stages, the area decreases; and as the stages continue to increase, the area once again begins to improve.

Although there were no hydrographic surveys made above bankfull stages, field observations have indicated that the area below the LWRP decreases during flood stages (above bankfull).



In developing the optimum design criteria for regulating works, it is desired that adequate width and depth dimensions be available at low river stages. These dimensions must begin to develop before they are needed (while the river stages are decreasing).

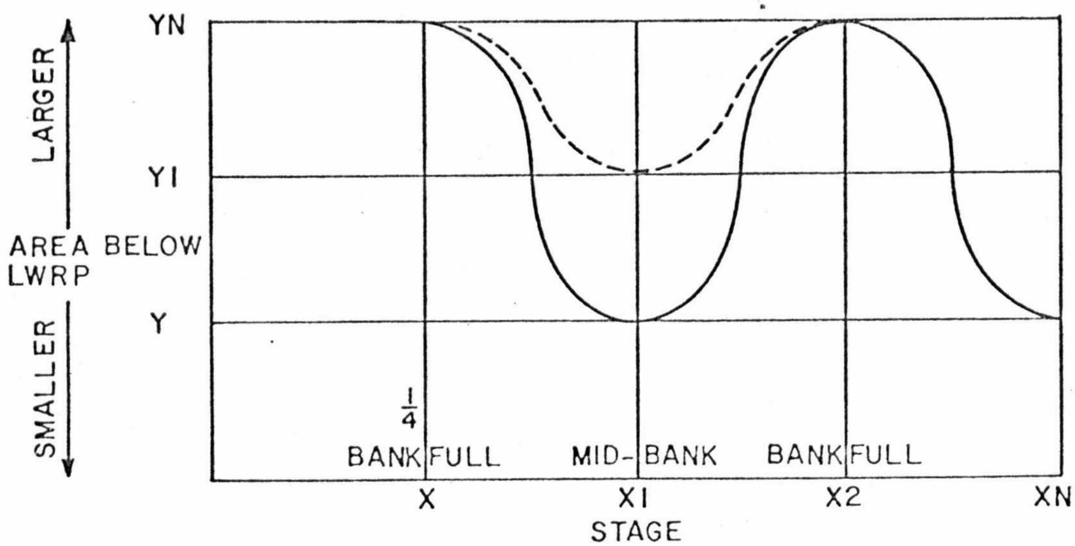
As can be seen, at some stage above bankfull, XN, the navigation channel is being filled with deposition; at bankfull stages, X2, the dimensions have improved; at mid-bank stages, X1, the dimensions resemble conditions at XN and at low stages, X, the dikes have created a condition resembling conditions at X2.

It is important for the river engineer to realize that similar channel geometry may exist for different stages and must keep this in mind when analyzing his data. The desired area below the LWRP, YN, occurs at X and X2 and a smaller area below the LWRP occurs at X1 and XN.

This knowledge could be valuable in analyzing dredge surveys. For example, assume that a dredge survey was made at X1 when Y conditions were present. It would appear from this survey that in order for traffic to navigate this area, extensive dredging would be required; however, as stages decrease to X, the river will develop YN conditions and no dredging is necessary.

This information could decrease preventive maintenance dredging done at the higher stages and reduce overall channel maintenance costs.

Of course, the goal of the river engineer is to try to keep Y as large as possible in the most economical manner. If Y becomes too small at X1, the river has to work harder to achieve YN at X. There are several ways to increase Y at XI, one is to increase the contractive effort, another is to increase the height of the dikes. As explained, the Prototype Reach was designed with a 1200-ft. contraction at a stage equivalent to 5-ft. on the St. Louis gage. This produced YN at X.



If Y can be increased to Y1 at X1, perhaps a smaller contractive effort would be required. This might be achieved by raising the riverward elevation of the dikes. Based on field experience and observations, it appears at this time that a 1500-ft. contraction, constructed to mid-bank elevations will be the most efficient way to achieve this goal. Future studies will examine this theory.

f. Water Temperature

From data developed for use in this report, it was decided to see if any surveys could be used to evaluate the effects of water temperature on channel dimensions. A paper written in April 1965 by Pearl Pierce Burke of the U.S. Army Engineer District, New Orleans, Louisiana, entitled, "Effect of Water Temperature on Discharge and Bed Configuration," states the following:

"... it is concluded that water temperature has a significant effect on riverbed configuration and an influence on the gage stage - discharge relationship."

The Jan.-Feb. 1971 and the August 1971 hydrographic surveys have been chosen to see how temperature affects channel dimensions at low stages in the Prototype Reach. The average stages were 5.1 ft. and 5.6 ft. above the LWRP, respectively.

The average water temperature for the winter survey was 35° F and the average water temperature for the summer 1971 survey was 81° F, a difference of 46° F. The following results were observed:

TABLE NO. 5*

	Area Below LWRP, ft.	Width at -10 LWRP, ft.	Ave. Depth Below LWRP, ft.
Winter 1971	22,136	1216	14.5
Summer 1971	19,309	1069	12.7

The winter 1971 channel dimensions were larger than the summer 1971 channel dimensions. The area below the LWRP was 15% larger, the average width at 10 ft. below the LWRP was 14% greater and the average depth below the LWRP was 14% deeper.

There is insufficient data available in this report to determine just what the mechanisms are that improved the channel geometry; however, it is apparent that temperature is a factor that should not be overlooked in the analysis of river mechanisms. See Plates 34 thru 36.

* Note: Only the miles between 146 to 153 were considered in this table. The winter survey was not completed because of heavy ice conditions on the river.

g. Conclusions

The design criteria that was used to construct the Prototype Reach has proven successful. A dependable navigation channel, with adequate dimensions, has been developed.

The goal of future potamology studies will be to investigate other design criteria to see if channel dimensions can be achieved in a more economical and efficient manner.

APPENDIX

APPENDIX A - HISTORICAL INFORMATION (1881 to 1910)

a. 1881 General Plan of Improvement

In the year 1881, a general plan of improvement was adopted for the Mississippi River between the mouth of the Ohio River and the city of St. Louis. The initial point of work was St. Louis and then the work proceeded downstream in a continuous manner. The plan contemplated a reduction of the low-water width of the river to an approximate width of 2500 feet and the protection of the alluvial banks from erosion. The methods employed were to build up new banks with the sediment caught from the river by means of hurdles and stabilization of the banks with revetment. The object of the improvement was to eventually obtain a minimum depth, at standard low water, of 8 feet from St. Louis to the mouth of the Ohio. The condition of the river before these works were initiated was that the depth at low water was in many places less than 4 feet. See Plate 37.

b. Description of Hurdles (1881)

The following is a general description of the construction procedures used on this project. This information was obtained from the 1894 Annual Report of the Chief of Engineers:

"A hurdle, as the term is here used, is one of many silt-arresting devices that have been experimented upon in this country and elsewhere. The hurdle consists, essentially, of a row or parallel rows of piling, the piles driven either singly or in clumps, the piling being connected lengthwise of the hurdle by wattling of fine brush or by curtains composed of brush and lodged against the upstream side of one of the rows of piles, the whole forming a permeable dike through which the silt-laden current can pass, though with greatly diminished velocity, resulting in deposits of silt above and below the hurdles. See Plates 38 and 39.

"These deposits are generally soon overgrown with willows or cottonwood, and after they arrive at sufficient height they can be revetted on their river fronts.

"To guard against loss by scour of the piles, a broad flexible mattress is first sunk on the line of the hurdle. Through this mat the piles and clumps of piles are driven.

"During the past year the hurdles have been constructed of clumps of piles, three piles and upward to each clump. These piles are driven so that when their upper ends are drawn together by means of a wire rope they form a sort of pyramidal structure, the horizontal distances of the piles from each other at the surface of the river bed being 8 to 10 feet, depending mainly upon the depth of the water.

"The wire ropes are made on the worksite; they are composed of 14 to 18 strands of No. 14 galvanized-iron wire. They are drawn taut by means of the pile-driver machinery. At each turn of the rope round the upper end of the clump of piles a spike is driven as an additional guard against the rope slipping, though the wire itself generally binds or cuts into the piling sufficiently to prevent any slip. This method of drawing the upper ends of the piles together appears to be better than the old one of bolting them.

"The tops of the piles are generally at an elevation of 20 feet above extreme low water, excepting that in the curtain or wattling row the top of one pile of the clump is at an elevation of about 25 feet above that stage in order to intercept drift at high stages and prevent it from crossing the line of hurdle and dragging the top of the latter with it.

"The curtain or wattled row is braced by vertical diagonal braces heeled against a row of clumps spaced at such distance below as to make the angle of the braces about 45 degrees. See Plate 40.

"The heel of the brace is held by a clevis passing around one of the piles of the lower clump, with its pin through the brace. At top the brace is bolted to one or more of the piles in the upper clump.

"The piling of the hurdle row is so spaced as to represent an equivalent of one pile to the linear foot of hurdle. The piles are driven by means of the hydraulic jet as well as by the hammer, the latter weighing 2,400 pounds, and sometimes by both combined.

"The completed curtain, or the wattling, whichever may be used, is generally carried finally to a height of 20 feet above extreme low water. The mattress is from 60 to 135 feet in width, depending upon the depth of water and consequent length of piles, as well as upon liability of the bed to suffer from scour. It is fabricated upon floating ways, in place, by wattling brush upon poles spaced about 5 feet apart and in any length desired. Continuity is obtained by lapping the poles and fastening them together with spikes and wire. When additional strength is required wire cables are used across and in the direction of the length of the mattress. The brush is spiked to the poles at the edges of the mattress and at other points, about one spike to every third pole. In sinking the mat a little less than 1 cubic yard of broken rock is required to a cord of brush.

"The piles used in the hurdles run in lengths from 25 to 60 feet, and their average penetration in the bottom is about 15 feet. They are driven with the large end down.

"At the shore end of the hurdle the bank is revetted for about 300 feet, of which 200 feet are below the axis of the hurdle." See Plate 40.

c. <u>Description of Revetment (1881)</u>

"In constructing the shore revetment a mat about 120 feet or more in width, its inner edge at the surface of standard low water, is sunk. The bank is then eventually graded to a slope of 1 on 2 and covered with riprap. Where necessary to grade the bank by artificial means the grading is done by the hydraulic method or by means of shovels, etc." See Plates 41 thru 44.

d. <u>Construction Progress (1889-1910)</u>

The area now known as the Prototype Reach was initially divided into several smaller reaches known as:

1.	Fosters Island Reach	Approx. mile 154 (above the Ohio River)
2.	Lucas Reach	Approx. mile 153
3.	Cornice Island	Approx. mile 149

4. Michaels Landing Approx. mile 144

5. Rush Tower Reach Approx. mile 140

The lengths of these reaches were modified several times as the project continued. See Plate 37.

The plan for work in the upper portion of the Prototype Reach was adopted in 1888. It consisted of contracting the low-water river width to 2500 feet. The work in this reach began in March 1889. A general summary of the subsequent work performed is as follows:

Year	Lin.Ft. of Hurdles & Bank Protection 1/	Number of New Hurdles Constructed
As of 30 June 1889	7,170	4
As of 30 June 1890	4,050	2
As of 30 June 1891	600	2
As of 30 June 1892	9,710	7
As of 30 June 1893	10,140	2
As of 30 June 1894	2,370	0
As of 30 June 1895	6,010	5
As of 30 June 1896	17,134	11
As of 30 June 1897	3,550	1
As of 30 June 1898	9,450	0
As of 30 June 1899	5,150 2/	5
As of 30 June 1900	9,510	4
As of 30 June 1901	19,150 3/	0
As of 30 June 1902	0	0
As of 30 June 1903	13,360	4

Year	Lin.Ft. of Hurdles & Bank Protection 1/	Number of New Hurdles Constructed
As of 30 June 1904	600	0
As of 30 June 1905	4,650	0
As of 30 June 1906	0	0
As of 30 June 1907	4,806	1
As of 30 June 1908	3,265	0
As of 30 June 1909	2/	0
As of 30 June 1910	2/	0

1/ Includes repair work
2/ Lin.Ft. of repairs not reported
3/ All Bank Protection

The rate of progress on this project was often very slow. The hurdles, made of wood, were very vulnerable to scour, winter ice, river traffic and spring floods. It was not unusual for the subsequent construction season to be devoted mainly to repairing and rehabilitating the previous years efforts. A review of the construction activities located in Part ~~V~~ B of this report will more fully illustrate this.

e. Portable Jetties (1896)

During the low-water seasons of 1896 and 1897, experiments were made with cheap devices designed to concentrate the water at shoal places, and by increasing its velocity, induce a scour that gave a depth of channel sufficient for the pressing needs of navigation. These devices were removed as soon as they had accomplished their task or the river had risen.

The results were reported to be very gratifying and led to the adoption of a system which was described as follows:

"Having determined upon the direction that should be given to the jetty in order to produce the best results and admit of the easiest possible construction, piles are driven firmly into the bed of the river along this line at distances apart varying 10 to 20 feet, depending upon the depth of water and the strength of current. In extreme cases, instead of single piles, clumps of two or three may be driven. Along these piles at a proper distance above the water surface other piles are made fast longitudinally either by wire or rope. These are to support the upper ends of corrugated sheet steel panels, the lower end of which is to rest upon the bottom of the river. Each panel is 10 feet in width measured in the direction of the jetty and from 10 to 20 feet long, depending upon the depth of water in which it is to be used. It is made of No. 14 United States standard gauge corrugated sheet steel, riveted to three 5 inch I beams, 12.5 pounds per foot. Suitable links or clevises are provided for handling the panels. To prevent scour taking place along the lower edge of the panels, and thus permitting them to swing through between the piles, a mattress from 8 to 10 feet wide is made by placing small fascines side by side. This is tied to the lower edge of the panels and sunk with rocks." The method of constructing these jetties is shown in Plate 45.

At the end of the low-water season the jetties were removed. The panels were taken up, cleaned, painted and stored. The piles were also removed to be used in future work. In 1897, there was in store and ready for use sufficient corrugated steel panels to construct 9,000 feet of portable jetty. A party and outfit on the site with the material could put this in place at the rate of 400 feet per day.

f. Lumber Mattress Bank Protection (1897)

The following narrative was written by Assistant Engineers W. S. Mitchell and John O. Holman in 1901. This is a description of the bank-protection mattress made of lumber which was used since the fall of 1897, when the first of its kind was placed at Ste. Genevieve, Mo., and Beach Ridge, Ill. Even though this description is rather lengthy and tedious, it is reproduced here in its entirety because of historical reasons and also because it serves to show how thorough and knowledgeable the old river engineers were.

"The lumber used was the cheapest and commonest 'cull' which could be procured of any variety, the only requirement being that it shall be sound and free from such large knots and other defects as would cause breakage in weaving. In dimensions it was received from 4 to 6 inches wide, 1 inch thick, and in lengths not less than 12 feet. This included all stock lumber and even waste that may be sawed.

"Lumber less than 4 inches wide or 1 inch thick was deficient in strength for the purpose, and that wider than 6 inches or much thicker than 1 inch entailed a waste of material. The wider lumber, although making a stronger mat, also increased the strains in sinking by presenting greater surfaces to the current, the spacing between planks being fixed by the size of sinking stone used. Lengths under 12 feet did not catch 'weavers' enough to insure strength in construction.

"The mattress was made on ordinary way flats such as had been used for brush work. Each flat was 40 feet by 16 feet and carried two way pieces, spaced 8 feet between centers and rising at about 4 feet above the deck at their after ends, under which were fitted sloping platforms for convenience in handling and weaving the lumber. Eight flats were used in a weaving set for the construction of the standard width (120 feet to 125 feet) mattress. They were lashed side to side, the set projecting eight flats wide from the bank, with the ways sloping upstream. Five flats in the set were provided with small hand capstans with which to launch the mattress from the ways, to tighten cables, etc.

"Construction began by laying across the foot of the ways one or two (or more, if necessary, in very deep, swift water) thicknesses of plank, breaking joints and thoroughly fastened with nails and wire, forming the under half of the 'head block.' At right angles with this (longitudinally with the bank to be protected) and with their ends on top of it, selected 'weaver planks' of the same lengths and ordinarily of single thickness were placed almost 3 feet 9 inches between centers, so that short 12-foot planks would weave across at least four 'weavers.' These 'weavers' were nailed and wired to the lower head block, and over their ends was spiked and wired the upper half of the latter, similar in every respect to the lower half just described. The weaver ends being thus clamped within the head block. See Plate 46.

"Weaving was carried on this system of longitudinals by two gangs of laborers, working from each edge of the mattress toward the middle.

"The planking ran over and under the weavers (like large split-basket work laid out flat), each course breaking joints with the next, and as far as possible, by the use of planks of different lengths, leaving the plank ends on top of the weavers. All planks passing over the weavers were nailed to them by 'nailers,' who attended solely to this duty. Whenever a plank failed to reach a weaver, the next plank would lap back on it to the last weaver caught, as the quicker and cheaper method of making a joint, wiring two plank ends together consumed too much time. The courses of planking were not run down to contact, but were spaced 4 inches to 5 inches apart, so that stone would not pass through the mattress when broken to conform to specifications that each piece should weigh not less than 20 pounds.

"When a weaver length was filled the weavers were extended, the joints being made points of careful attention and thoroughly secured with twisted wire strand and nails, and when a ways length was filled that section of the mattress was launched overboard. About 2 feet of the structure was held on the ends of the ways, and the construction proceeded as before, the mattress being built continuously to any desired length.

"Launching was done with the capstans by lines which ran through very flat single blocks at the ends of the flats and which took hold of the mattress near the tops of the ways. See Plate 47.

"Sometimes in dropping off the ends of the flats to the water, 'weavers' were broken. These must be found and repaired, or in swift water a tear in the mattress could result. For this reason it was very desirable that the launching ends of the flats be as low as possible, thus diminishing the span between the way end and the water.

"As each weaver length was woven full, 'top stringers' were laid in single or double thickness above every weaver in strong water and always above the five or six weavers near the outer edge of the mattress to prevent sinking stone rolling off; and also invariably above every weaver from the shore edge to that which will rest at the bottom of the bank slope, to prevent revetment stone sliding down the slope. In slack currents the stringers throughout the middle of the mat may be at wider intervals. The essential purpose of these stringers was to retain the revetment and sinking stone in position, but they also served to stiffen and strengthen the structure, in themselves and with the underlying weavers, to which they were securely wired and spiked.

"To take up the longitudinal strain in sinking, wire cables were made fast to the head block and each was twined around a weaver and its top binder, under strain from a capstan, and was clamped with spikes. The number of cables used varied with the strength of current and the depths encountered, but usually from four to six were put along the outer edge of the mattress, one to each weaver, the spacing then growing wider toward the middle of the mat, and sometimes near the shore the cables were omitted altogether.

"The cables were made in sections about 35 feet in length, being twisted by hand machines, and were of fifteen to eighteen strands of No. 14 galvanized wire (standard adopted for all mattress work under this office), and had an eye worked in at each end for joining. Their cost was slightly less than 1 cent per linear foot, two laborers making about five cables per hour, each containing 10 pounds of wire.

"Crossing over the tops of the longitudinal stringers were 'cross binders' of two to three thicknesses of planks, breaking joints spiked to the top stringers and wired through the mattress. These served to stiffen the latter and aid to withstand the thrust against the bank in sinking, and to break the mat into shallow pockets or cribs for the retention in position of the slope while sinking, as the mattress in going down passed through many degrees of slope or inclination in various directions.

"Sometimes the head block was deepened and with a cross binder, but mostly the first was placed 5 feet to 10 feet from the head block to form a fastening for the head lines on which the mattress was sunk. Thereafter the binders were spaced every launch or two launches (25 feet to 50 feet) or farther apart.

"Lumber work of every description was finished, so far as was possible, on the ways previous to launching, yet a few men were employed after the launch was in the water, repairing broken plank, in strengthening weak places developed by the launch, and in tightening any wire fastenings which were found to be loose through the working in the waves of so flexible a structure, or from their having been tightened with the mattress on the ways in a position slightly abnormal to that assumed in the water.

"In starting construction, the head of the mats was usually held up by slip lines under and around the head block to a row of flats or to a barge moored across and immediately above it. Attached in the body of the mattress at the first cross binder long headlines pass under the mooring flats or barge with easy lead to anchorage ('deadmen' in river parlance) on shore. These were to take the entire weight of the mattress when sinking the head, and were usually 5-inch manila bolt ropes of the best quality. Larger lines (which might reduce the number to be used, which in its turn depends on the strength of current and depth prevailing) were too stiff and heavy to place and strain by hand, even aided by the 'Spanish windlass,' which was supplied to each line to regulate its strain.

"Similar but shorter ropes and sometimes wire strands, such as have been described, were attached to the shore edge of the mattress to anchor it to the bank, and long lead lines were also run out well into the mattress, especially to the outer edge, to aid in sinking it continuously, the points of attachment being well distributed through the structure.

"All anchor lines (except shore wire cables) were recovered after sinking, being attached (after passing down through the mattress, around and under a weaver with its overlying stringer and the cross binder, and up again through the planking) either to toggles which may be released by their buoy lines, or by making long bow lines in them which may be freed above the water surface. With all precaution it occasionally happened that a line would be fouled in the mattress past recovery without actually lifting the latter off the bottom or tearing it. In such cases the lines were cut, and to prevent undue strain ever being applied during attempts at recovery, only small hand capstans, mounted on flats, were permitted to be used.

"In sinking, a barge of stone was moored at the upper outside corner of the mattress, and from it stone was wheeled into the cribs or pockets between the head block and the first cross binder, the weight being held up on slip lines to the mooring barge or flats. At the same time the mattress was ballasted with stone, well distributed, in gradually decreasing quantities downstream for 150 feet to 800 feet, sufficient stone being used in the upper barge length to sink the mat deep enough to permit swinging the loaded barge across it. Then the crew, lining both sides of the barge, threw off stone rapidly, the barge being dropped slowly broadside downstream, and the head of the mat was lowered quickly and steadily to the bottom.

"Sufficient stone was unloaded on the first 200 feet of the mat to make it a certain anchorage for the remainder of the structure, and the sinking thereafter proceeded more slowly, about as much mattress being sunk each day as was made, by a small gang of men under the immediate supervision of the general overseer. Care was taken that the stone was well distributed; that the heaviest pieces were not thrown on the uncovered mat from the barge height, but were dropped off the upstream side of the barge so that they settled through the water to the mattress without danger of breaking the thin planks of which it was made; that the portion of the mat sloping from the bottom to the surface was not so heavily weighted as to 'bay,' and in deep water and swift currents, that the sinking did not approach too near the way flats, as, under these conditions, the sinking sometimes ran ahead from 100 feet to 300 feet without any stone whatever, the mat afterwards slowly rising and recovering. As the strains thus set up may be very great and the mat may be torn by them and by heavy waves from passing steamers or from storms, it was frequently necessary to buoy up and support the unsunken portion of the mattress, usually at the top of the rising section, by slip lines from flats moored across it, the lines being slackened once or twice daily as the mat grew heavy from water soak and deposit, and assuming therefrom a lower slope, until the sinking party reached that section, when the flats were moved farther downstream if they were needed, until the danger point or swift water had passed.

"As construction may be carried on at any and often during greatly varying stages of the river, the shore edge of the mattress was rarely sunk exactly at the contour of low water, as was desirable (constant submergence being 'sine qua non' to the preservation of the lumber), but usually overlapped that line, it having been found cheaper to allow this than to drive guide piles. The overlapping portion of the mattress was completely covered with stone, spalls were freely used to fill the irregularities in the bank next the mat edge, and these in turn were covered with stone which was carried up the natural slope to the foot of the abrupt bank, where the stone revetment was stopped for the season, awaiting the next high water to grade the upper part of the bank before completing the protection.

"In the foregoing description the details of weaving, fastening, strengthening, and sinking were very similar to the corresponding operations in brush construction from which they were derived.

"The lumber mattress in cost and speed of construction was much superior to that of brush; its durability was of course the same, except possibly along the shore edge where, being much lighter, it was more liable to be broken by steamers running into it when landing. Because of this lack of material it was much more flexible and difficult to handle, its tendency to buckle being marked. For this reason, in very deep and swift water it had been stiffened, in one instance with heavy poles for top stringers and cross binders, and in other cases (one in bank protection, several in hurdle foundations) it had been combined with brush, about one-third of the mattress next the shore being made of brush to withstand the thrust, and the remainder of lumber.

"On several days during fall of 1900, the rate of construction ran as high as 350 linear feet per day, and for the season the average rate for four parties, building in the aggregate over 7 miles of mattress in sections of various lengths (the longest section yet built in 1899, near the mouth of the Missouri River, was 10,030 feet) at a dozen localities, was 210 linear feet by 125 feet for each day consumed in building and sinking, with a force of about 86 men, exclusive of the mess and quarters crew of about 10.

"This force was divided into the following classes of labor: 1 overseer, 2 suboverseers, 1 subinspector, 1 watchman, 6 boatmen and linesmen, 75 laborers (9 wire cutters, twisters, cable makers; 18 unloading and passing lumber; 18 weaving; 18 nailing, repairing, tightening cables, etc.; 12 sinking).

"The final cost of the mattresses made in 1900 was 2.60 cents per square foot. This included all charges for labor, plant, and materials used in making and sinking.

"Of the wire used 50 per cent was made into cables. The remainder was cut into short lengths (about 3 feet, 4-wire strand) and loosely twisted by hand by the wire cutters enumerated for plan fastenings.

"Of the nails and spikes about 40 per cent each were 10-penny and 20-penny wire nails and 20 per cent 6 inches by 1/4-inch boat spikes for cable fastenings.

"Of the use of lumber mattresses for hurdle foundations it is unnecessary to speak at length. They had been used with great success and were inferior to brush in no respect only, that in driving the piling through the mattress the thin, flat planking was badly broken and required reinforcing after the piles were driven. This had been done by laying narrow, 12 feet to 15 feet wide, plank mats along each side of the piling and filling in the shallow trench thus formed with stone and spalls, and in some cases the narrow mats had been omitted and stone alone used among the piles."

g. Project Modifications (1903 to 1910)

In 1903, the Board of Engineers for Rivers and Harbors met and discussed the desirability of continuing the 1881 project on the Mississippi River, between the Ohio and Missouri Rivers, or modify it.

The Board decided to modify the 1881 project by depending more on the dredges and less on the permanent works. They suggested that only minor sums of money be appropriated for permanent work and full funding be appropriated for dredging until the results of the increased dredging be known.

There was one vote cast against this recommendation. It was cast by a former St. Louis District Engineer, Major Ed W. Burr. He believed that permanent works should be continued under the existing project and with appropriations sufficient to push the project to completion within a reasonable time. He further added that pending the completion of the permanent works, dredging should be carried on more extensively than in the past in order to provide the best channel practicable.

The recommendations of the Board were adopted by Congress in the River and Harbor Act of 3 March 1905.

As reported in the Annual Report of the Chief of Engineers in 1906, the interpretation of this act virtually stopped all construction for the permanent improvement of the river within the St. Louis District.

A request for the construction of works urgently needed was made in 1906, but the act was passed too late to be effective during the construction season. The 1907, 1908, 1909 and 1910 Annual Reports of the Chief of Engineers state that due to the small balance of funds available, operations were confined to the repair, maintenance and completion of the hurdles and revetments already in existence.

The River and Harbor Act of 25 June 1910 revived the project of 1881 (modified to include dredging). The revival of the 1881 project was partially a result of a report made by a special board on examination and survey of the Mississippi River from the Lakes to the Gulf. This report, dated 20 March 1909, recommended completion of the 1881 project.

h. Dredging (1896-1910)

The 1881 project was modified by the River and Harbor Act of 3 June 1896. This modification permitted the construction and operation of dredges to help obtain project dimensions. As stated before, the project was again modified to some extent in 1903 by the Board of Engineers for Rivers and Harbors in a report dated 12 November 1903 which was adopted by Congress in the River and Harbor Act of 3 March 1905. This act placed more importance on dredging activities and nearly stopped the construction of all permanent works. By 1908, three dredges were working in the St. Louis District and two suction dredges, required by the act of Congress (dated 3 March 1905), were under construction. In 1909, the two new dredges (designated as No. 5 and 6) were given tests before they were put into service. In 1910, permanent works, supplemented by dredging, were restored to the 1881 project. The dual role of permanent works and dredging have been the major methods used to obtain project dimensions since this time.

APPENDIX B - DETAILED CONSTRUCTION HISTORY (1889-1910)

In order to provide future river engineers with as much background information as possible, a search was made of any old data that was available and pertained to construction activities within the Prototype Reach.

The following information was extracted from the annual reports of the Chief of Engineers for the years 1888 thru 1910:

LUCAS ISLAND, 29 Miles Below St. Louis

(See Plate 48)

1889

The project for work at this locality was adopted in 1888. It consists of contracting the river width to 2,500 feet, and preventing the waste of water now flowing through the chute behind Calico Island. This is a new work; four hurdles were built here whose aggregate length is 7,170 linear feet; they have been constructed since March, 1889, and the effect of the work can not be absolutely stated until low water. It is the continuation of the general project which has succeeded above.

1890

At this locality the work consisted in the repair of small gaps in the hurdles of last year and in the construction of two additional hurdles, Nos. 5 and 6; 4,050 linear feet of hurdle was completed in this locality in addition to the repairs mentioned above. The work at this locality was projected and begun in March, 1889, and has continued since. The object was to concentrate the water at Lucas' Crossing and close the false channel behind Calico Island. The work has been of great benefit to navigation, straightening and deepening the channel at this crossing.

1895

Some additions, extensions, and repairs were made to the hurdles built at this place in 1888-1890. Total linear feet of hurdle built during the year, 150. The work at this point is still in progress.

1896

This locality extends from the foot of Foster Island, 20 miles below St. Louis, downstream about 3 miles to Cornice Island. The work consisted in building a number of short hurdles to reestablish in efficiency the series formerly built here and new lines of hurdles to extend the work downstream. Considerable work was done in strengthening the upper hurdles of the series where the water was deep and the trend of the channel decidedly toward shore.

Work was continued in this locality until October 19, resumed November 14, and continued until November 24, the close of the season. It was again resumed March 14, 1896, and suspended for a more favorable stage of water April 11, when the working party was transferred down the river to Liberty Reach.

The work done here during the season is represented by 9,420 feet of hurdle constructed, 312,981 square feet revetment at ends of hurdles, and a large amount of other work pertaining to them; 7,825 piles were driven.

1899

Much difficulty was experienced at this locality during the last low-water season on account of shoal and badly located channels and crossings. The local project had not provided a sufficient contraction of width and the projected works had not all been constructed to their full projected lengths. A new local project has been adopted providing for a further extension of the Illinois system of hurdles in order to contract the river to the generally projected width of 2,500 feet, with minor rectification of the irregular Missouri shore should it be subsequently deemed necessary. Hurdle Nos. 14 and 16 were constructed: Hurdle Nos. 9, 11, 13, and 15 were repaired and extended at both their inshore and channel ends, and the mattresses for Hurdle Nos. -4, -4, and -2 were made and placed, the aggregate new work being equivalent to 5,150 feet of hurdle.

1900

During the past fiscal year Hurdle Nos. -4, -3, -2, and -1 were constructed and completed excepting as to the channel end of Hurdle No. -1. Work was also done upon Hurdle Nos. 0, 1/2, 5 1/2, 6, 7, 11, 13, 14, and 16. The total construction was 4,960 feet of hurdle. No difficulties were experienced in this reach during the low-water season.

1903

For the further improvement of this reach four additional hurdles were built during the year: No. 1 on the Missouri side in front of Herculaneum, Mo., about 300 feet above the mouth of Joachim Creek; Nos.

16 1/2, 18, and 19 1/2 on the Illinois side. The total construction amounted to 4,500 linear feet of hurdles.

A good depth was maintained in the channel during the year.

CORNICE ISLAND, 30 Miles Below St. Louis

(See Plate 49)

1895

Construction work commenced at this locality on the 1st of June on hurdles 1, 2, 3, 4, and 5, and the work was in progress at the close of the year. Total linear feet of hurdles built, 2,510.

1896

The work in this locality was the completion of the series of five hurdles begun during the preceding year. The work was in progress at the beginning of the year and closed August 6. During the season 495 feet of hurdle was constructed and 1,965 feet strengthened; 1,910 linear feet of curtain was made; 7,170 square yards of bank revetment was placed at the ends of the hurdles, and other work done. This work was finished August 6 as far as the stage of the river would admit.

CALICO ISLAND (30 Miles Below St. Louis)

(See Plate 49)

1892

See Rush Tower Reach

1900

See Rush Tower Reach

JAMES LANDING

(See Plate 49)

1907

James Landing, Illinois, (34 miles below St. Louis). New bank protection. During the last few years the river at this locality had become excessively wide, with consequent bad navigation, the caving on the Illinois shore having entirely destroyed the James Landing hurdles, built 1891 and 1892. In order to check this movement of the channel to the east, and, incidentally, protecting the Monroe County levee, which was endangered, it was decided to extend the Osborne Field revetment upstream. The work was done during September and October (1906), 3,900 feet of mattress being placed, 650 feet of lumber on hand, the remainder, 3,250 feet, of brush, the width varying from 130 feet to 100 feet, depending on the depth of the water. The lower end of the mattress was connected with the shore-end mattress of old hurdle No. 3, thus making the total length of protection above that hurdle 4,030 feet. The entire length of bank along the mattress was graded and revetted with stone to the 14-foot stage, and 500 linear feet were raised to the 16-foot stage.

1908

JAMES LANDING, ILL.

(Sept. 3 - Oct. 18)

New bank protection. During the spring and summer of 1907 continuous caving, with a rapid recession of the bank line, occurred between the end of the work of 1906 (James Landing) and the head of the work of

1904 (Osborne Field). In order to check this recession, primarily to protect the work at Osborne Field, Ill., from being outflanked by the river, the work of 1906 was extended downstream to a junction with the work of 1904. Incidental protection was also given to the Monroe County levee which, at this locality, is in dangerous proximity to the river bank. The work was done during September, October, and November; 3,265 linear feet of brush mattress - 100 feet wide - were placed, connecting with the upper end of the mattress at Osborne Field, Ill., and above this mattress the bank was graded and the stonework placed to the 18-foot stage. The bank above the revetment of 1906 having been graded by the river to a slope favorable for the reception of stone, the stone work was raised from the 14-foot contour to the 19-foot throughout, except for 465 linear feet covered with silt.

The extent of the protection now in place at this locality is as follows: 11,200 linear feet of mattress; 500 linear feet of stonework raised to the 16-foot stage; 5,265 feet to the 19-foot stage; 3,335 feet to the 18-foot stage, and at Osborne Field, 1,850 feet to the 11-foot stage, leaving 250 feet still unrevetted with stone. Revetting this small portion of the bank and making the contour of the stonework at Osborne Field uniform throughout has been prevented since the spring of 1905 by a bar along the river front denying approach with materials.

<u>1909</u>

JAMES LANDING, ILL.

Repairs to bank protection. The revetment placed in 1906 and 1907 was found in good condition, with the exception of a small dry pocket 150 feet below Hurdle No. 3, and several small slides between Hurdle Nos. 3 and 4. These were repaired by the construction in the pocket of a brush mattress weighted with stone and by replacing the stonework where the slides occurred.

In the work, 17,885 square feet of stone paving and 3,500 square feet of mattress were placed.

<u>MICHAELS, 36 Miles Below St. Louis</u>

(See Plate 50)

(See also Rush Tower Reach - 1893)

<u>1895</u>

The work here consisted in construction of Hurdle No. 1 and in the repair, so far as practicable, at the existing low stages of water, of No. 3 of the series which was built in 1892 (see Rush Tower, 1892). Eight buttresses of brush and stone were placed about 300 feet apart on a line 80 feet from the hurdle, on its upstream side, to serve as protection against moving ice, to watch this hurdle will be the most exposed. Four piers of stone connect the inshore end of this hurdle with the shore, the shelving rock near shore preventing pile driving for about 200 feet. Total number of linear feet of hurdles built, 3,250.

<u>1896</u>

At this point commences a series of work extending down the river about 9 miles, covering what is known as the Rush Tower Reach. The principal work done during the year consisted in repairs, extensions, and completion to hurdles previously commenced, and in bank protection. In the extension of one of the principal upper hurdles it was deflected downstream and connected with the upper end of a towhead, which was substantially revetted. A considerable current was thrown against this hurdle, to resist which the hurdle was made proportionately strong. The foundation mattress was increased in width to 130 feet. The length of hurdle built was 1,750 feet. Piles were placed in clumps of 3 and 4 each, 8 feet apart, and curtained to a height of 20 feet. The shore connections of the hurdles were strengthened, and the ice buttresses were raised and strengthened with stone. Heavy mattresses were made and sunk over the drift that had collected along the upper side of this hurdle. The following are items of principal work done in this locality: Piles driven, 1,025; foundation mat made and placed, 2,650 linear feet; curtains made, 2,500 linear feet; drift mat made, 3,502 linear feet.

At Danby Landing, in this locality, the project contemplated the revetment of the Missouri shore wherever the bank was eroded to the proposed shoreline. The position of the bank having reached that line, the revetment of the shore between this point and the head of the Chute between Ames and Lee Islands was begun September 18. A section 4,750 feet long was revetted by placing a mattress below low water and carrying the revetment about 75 feet above that line. The work was discontinued November 15.

1897

This point is the commencement of a series of works extending down the river about 9 miles, covering what is known as the Rush Tower Reach.

No. 1 hurdle of this series was broken last season by a loaded coal barge going through it after the tornado of May 27, 1896. The breach was enlarged to 750 feet during the high stages of last winter and this spring. The construction of a new hurdle, No. 2, in rear of this opening and the repairs to No. 1 were commenced on the 8th of June, this fiscal year, and are now in progress. No. 2 hurdle is 2,800 feet in length, of the ordinary type, and is nearly completed.

<u>1898</u>

In the last annual report mention was made of the fact that a breach had been made in Hurdle No. 1 of this series, and that Hurdle No. 2 was in the process of construction behind it. This hurdle was completed July 19. The stone dike for the shore connection at the west end of this line and the revetment of Osborne Towhead at the outer end were completed July 31. A large quantity of drift having lodged against this line it was sunk, thus adding much to the strength of the hurdle. No attempt was made to close the large gap of 750 feet in Hurdle No. 1. The checking of the water, drift, etc., by No. 2 seems to result in a shoaling of the water between the two hurdles.

<u>1900</u>

Hurdle No. 2 of this series was constructed in 1897, with a stone dike as a shore connection. This dike having settled somewhat, it was raised to a stage of 23 feet (St. Louis gage) by the use of 1,140 cubic yards of stone.

RUSH TOWER REACH

(See Plates 48 thru 51)

1891

The project for work at this locality was adopted in 1890 and consisted in an extension of the general plan of improvement, so as to take in this locality. Work was not commenced until June 15, so that but little could be accomplished up to the close of the year. Two hurdles, Nos. 4 and 5 of this system, were located and partially built, and 600 feet of bank protection was placed in position. This bank protection was necessary, as the bank at one place had caved so far as to be within 50 feet of the base of the levee, which protects the bottom lands from overflow.

1892

Operations at this locality consisted in the construction of hurdles on the east side near James Landing, also hurdles on the west side near Wilcox, and in the protection of the bank at Calico Island.

At the close of the previous fiscal year work was in progress on Hurdle Nos. 4 and 5, east side. These, as well as Nos. 2 and 3, were completed, and the bank between Nos. 4 and 5, which was rapidly caving, was revetted.

A large portion of the river flowed down the west side, spread out into three channels. To close these and force the water over to the east side of the river, three hurdles, Nos. 3, 4, and 5 were built. Owing to bedrock it was not possible to build the full length of these hurdles in the usual manner. They were extended as far out on the bar as was practicable at the stage of water and were then connected with the Missouri bluff shore by solid stone and brush dikes. During the winter and spring the hurdles were seriously damaged by ice and high water, those on the west side being nearly swept away, with the exception of the stone dikes. This work was all repaired, as well as the high and rapidly fluctuating stages of the river would permit.

The hurdles built aggregate 9,710 linear feet, of which 5,920 feet were on the east and 3,790 on the west side.

The protection of a portion of Calico Island became necessary, as the change in the direction of the current caused it to cave rapidly. A mattress 4,000 feet long by 120 feet wide was constructed and sunk so as to cover the eroded portion, and stone revetment was placed on 1,350 feet of the bank above the upstream end.

The effect of this work cannot be observed until low water, at which time it is expected that the water will be found confined in one channel.

<u>1893</u>

Operations consisted in the construction of 6,800 linear feet of protection of the Illinois shore above Durfees Landing. About 1,225 feet of bank along Lowrys Field was partially revetted. Three hundred linear feet of hurdle at Michaels was repaired. Construction of hurdles was begun at Fish Bend and 1,815 linear feet nearly completed.

1894

This reach, which extends from the head of Calico Island to Brickey's Mill, 37 1/2 miles below St. Louis, includes a number of detached works, viz: Protection of west side of the Island: hurdles on east side near James Landing: hurdles on west side below Kennett's Castle; bank protection from Osborne Field to Durfee's Landing; hurdles below Durfee's and works projected for regulating the river at Fish Bend. None of these works have been completed.

Work in this reach during the fiscal year consisted in repair of Hurdle No. 3, on west side, between Kennett's Castle and Perry Towhead, and in 1,970 feet of extension of the bank protection, Osborne Field to Durfee's, though this extension was not entirely completed.

1897

The bank protection placed in the years 1893 and 1894 between Osborne Field and Durfee's Landing, 38 miles below St. Louis, had never been completed to high water. The bank above the revetment had been eroded back until there was danger of the work being destroyed. Wherever this danger was most imminent additional rock was used to repair breaks and carry the revetment farther up the banks.

1898

(OSBORNE FIELD) The river bank in this vicinity was revetted in 1893 and 1894, but never completed to high water. There has been a gradual erosion of the upper part of the bank, and as opportunity offers rock is placed upon this. Between August 16 and September 17 about 4,700 linear feet of this bank was covered with stone. Five hundred linear feet had eroded back of the low water protection. This was regraded and covered with stone to a 10-foot stage.

1899

(OSBORNE FIELD, ILL. - 36 miles below St. Louis) The Illinois bank between Osborne Field and Durfee Landing was protected during the seasons of 1892-93 and 1893-94 by the customary type of revetment to a length of 8,770 feet, carried up to a 16 feet stage. Having been completed only to the foot of the bluff bank and not to high water, the work suffered somewhat during the high waters of 1896 and 1897, in both of which years slight repairs were made. In the spring of 1898 the revetment was again broken during high water, and during the past year the work was again thoroughly repaired.

1900

(CALICO ISLAND) The Calico Island protection was placed in 1891 and 1892, and was damaged at its upper end for about 350 feet. It was repaired by a subaqueous mattress and by such bank revetment as was required.

1900

(OSBORNE FILED, ILL.) The Illinois bank between Osborne Field and Durfees Landing was protected during the seasons of 1892-93 and 1893-94 by the customary type of revetment to a length of 8,770 feet, carried up to a

16-foot stage. Having been completed only to the foot of the bluff bank and not to high water, the work suffered somewhat during the high waters of 1896 and 1897, in both of which years slight repairs were made. In the spring of 1898 the revetment was again broken during high water, and subsequently thoroughly repaired. During the high water of 1899 damages again occurred, and during the past year repairs were made along 3,000 linear feet of revetment.

1901

(OSBORNE FIELD, ILL.) The bank continued to cave below the existing protection, and the latter was extended downstream 3,030 feet by a subaqueous mattress, the bank above it being protected to 13 feet above low water of 1863.

1903

(RUSH TOWER) The Illinois shore between Osborne Field and Kempers Landing was protected for 8,770 feet during 1892, 1893, and 1894. The protection was extended 3,030 feet further downstream in 1901, with subaqueous mattress and revetment up to the foot of the bluff bank, to an average stage of 16 feet above the low water of 1863.

The bank above the protection having been graded by the river, the revetment was repaired and was carried up to an average stage of 25 feet above the low water of 1863.

The total amount of revetment placed was 3,730 linear, or 116,700 square feet.

1905

(OSBORNE FIELD, ILL.) The Illinois bank at this place having caved rapidly and the channel threatening to follow it and become shoal, it was decided to hold the bank with an extension, upstream, of the original protection in this reach, placed in 1892. Work was begun November 4 and was continued until December 10. A mattress was placed, 3,700 feet in length by only 100 feet in width, narrower than standard width because of the comparatively shallow water encountered. About 1,600 feet of the bank above the mattress were graded and protected with stone to the level of the 19-foot stage; 1,850 feet were graded and revetted to the level of the 11-foot stage, but on account of the lateness of the season the remainder, 250 feet, was not revetted above the mattress.

There is an interval of unprotected bank, about 2,600 feet, between the new work and that of 1892.

(OSBORNE TOWHEAD, MO.) In October and November repairs were made to the stonework in the revetment on the east side of this towhead, that bank having suffered severely in the last two high waters. The revetment was put in thorough order, and was restored between the 14-foot and 24-foot levels, the work extending along 950 feet of bank.

1907

(OSBORNE FIELD) Repair of bank protection. In order to stop the caving which had been slowly taking place in the bank behind the revetment at Osborne Field, placed in 1892, and which had reached a maximum width of erosion of 500 feet, two short hurdles were planned to connect the old revetment with the present bank and induce a fill to the former line. Of these only one, Hurdle No. 2, was built, November, 1906, its length being 506 feet. The T-head was omitted, as the old revetment was deemed sufficient protection to the outer end.

In addition to the hurdle to check the erosion and rebuild the bank line, the lower end of the caving bank, about 1,400 feet below the hurdle, was protected by a mattress 400 feet in length and stonework laid on a graded slope to the 16-foot stage. This new revetment lies in the sharp angle between the caving bank and the original revetment which was gradually being destroyed.

In this work there were placed 368 piles, 17 stringers, 118,250 square feet of mattress, and 31,000 square feet of stonework, raised to the 25-foot stage.

1910

(FOREST HOME, ILL.) Repairs to bank protection. The protection at this locality had been damaged by several slides and washouts in the work placed in 1904.

In the repairs, brush mattresses were built and placed in the various recesses stations 68+35 to 72+60, and at stations 42 and 62 to check threatening eddies. At stations 75+80, 76+50 and 77+55, hurdles, respectively 36, 64 and 55 feet long, were constructed to a 25-foot stage, each consisting of a single row of 3-pile clumps at the river end and single piles at the shore end.

In this work 52,650 square feet of mattress and 38,770 square feet of stonework were placed; 64 piles were driven and 646 cubic yards of earth were moved in grading.

DANBY LANDING, MISSOURI (39 Miles Below St. Louis)

(See Plate 51)

1898

In 1895 the eroding bank just below this landing, for a distance of 4,750 feet, was protected to the height of the 16 foot stage. Subsequent high waters graded the bank back and threatened to get back of the revetment. Between September 18 and October 5 repairs were made to this at the point where the most damage had been done. It will be necessary to carry this revetment to the top of the bank whenever funds can be spared for the purpose. (Danby Landing first mentioned under Michaels Landing - 1896.)

1899

The protection of the caving bank at and below Danby Landing for a length of 1,750 feet was begun in 1895 and continued as the abrupt bank was graded by subsequent high waters. In the fall of 1897 some repairs were made at the lower end of the work where the current threatened to get behind the revetment. During the past year the work was thoroughly repaired and extended to the foot of the bluff bank, 16 feet above low water.

1900

The protection of the caving bank at and below Danby Landing for a length of 4,750 feet was begun in 1895 and continued as the abrupt bank was graded by subsequent high waters. In the fall of 1897 some repairs were made at the lower end of the work where the current threatened to get behind the revetment, and in 1899 the work was thoroughly repaired and extended to the foot of the bluff bank, 16 feet above low water. During the past year the bank above this work began caving, and the protection was extended 700 feet upstream by a subaqueous mattress. Additional work is necessary at this point for the protection of that already placed.

1901

A bad crossing exists at this locality and additional regulation is necessary. A middle bar crowds the low-water flow strongly along the Missouri bank and causes a scour to a greater depth than existed when the protection was placed. Several breaks have occurred progressively downstream with the movement of this bar. During the last low-water season five such breaks took place within a distance of 1,200 feet and were repaired.

1903

The protection at this locality was begun in 1895. The mattress had been placed for 5,450 linear feet and all except 700 feet at the upper end was revetted to stages of from 16 to 20 feet.

During the fiscal year 1903 the old work was repaired and all the revetment raised to a height of 26 feet above the low water of 1863; as high as the bank had been graded.

The total amount of bank covered was 5,400 linear, or 118,100 square feet.

1904

(DANBY LANDING) Several small breaks and slides in this revetment, which were developed this season by the falling river, were repaired. Their aggregate length was about 600 feet, but they were scattered along 3,000 feet of the protection.

RUSH TOWHEAD

(See Plate 51)

1901

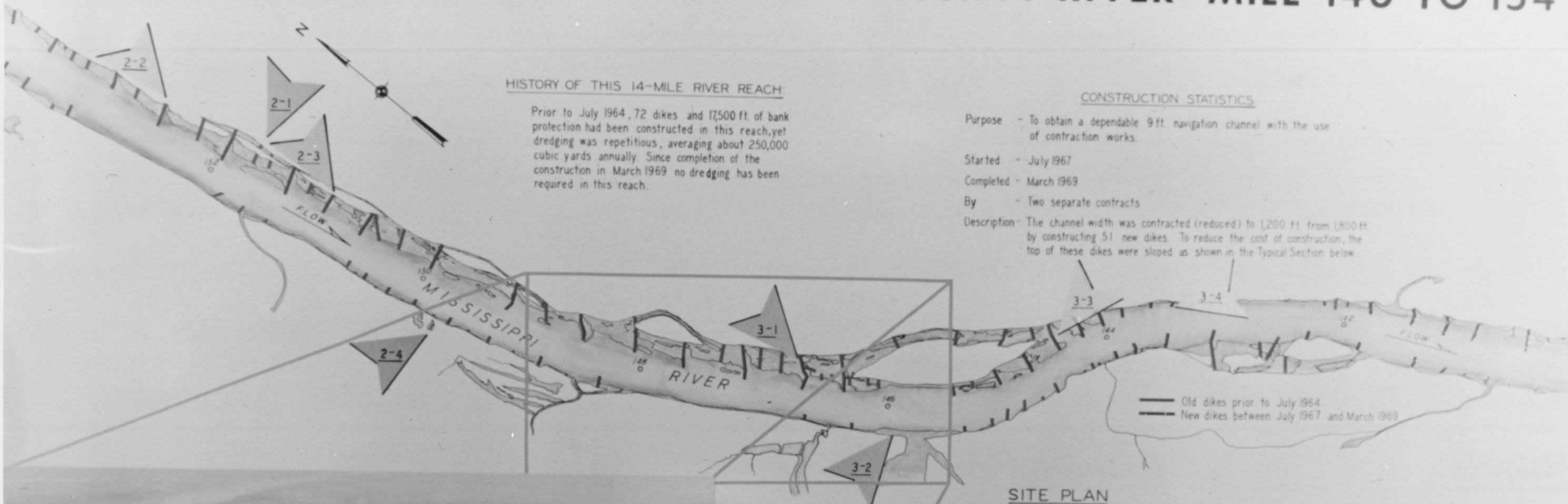
The channel through Fish Bend cut-off having attained a sufficient width, the protection of the face of Rush Towhead was undertaken to prevent further widening and to hold the bank in line with that of Penitentiary Point below. Two thousand four hundred and thirty-five linear feet of subaqueous mattress was placed and the bank was revetted to the 13-foot stage above low water of 1863.

1903

The protection, 2,435 feet long, built in 1901, was carried up to a 13-foot stage. It was extended 400 feet farther upstream, and all except 700 feet, made inaccessible to barges by a bar which formed in its front, was carried to the top of the graded bank at a 27-foot stage during 1903. The total amount of revetment placed was 1,835 linear or 61,200 square feet.

APPENDIX C

REGULATING STRUCTURES - MIDDLE MISSISSIPPI RIVER - MILE 140 TO 154



HISTORY OF THIS 14-MILE RIVER REACH:

Prior to July 1964, 72 dikes and 17,500 ft. of bank protection had been constructed in this reach, yet dredging was repetitious, averaging about 250,000 cubic yards annually. Since completion of the construction in March 1969 no dredging has been required in this reach.

CONSTRUCTION STATISTICS

Purpose - To obtain a dependable 9 ft. navigation channel with the use of contraction works.

Started - July 1967

Completed - March 1969

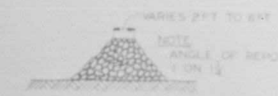
By - Two separate contracts

Description - The channel width was contracted (reduced) to 1,200 ft. from 1,800 ft. by constructing 51 new dikes. To reduce the cost of construction, the top of these dikes were sloped as shown in the Typical Section below.

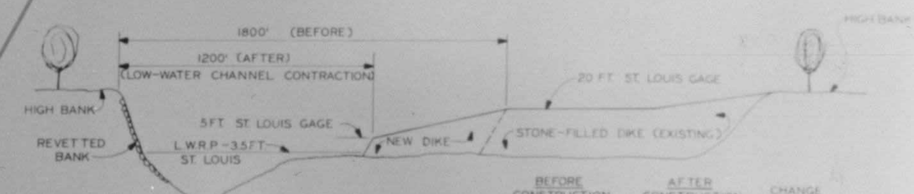
SITE PLAN

SCALE: 1" = 2,400'

Aerial view - Looking upstream (approx. mile 146.0) showing dike fields, barge loading facilities, towboat moving upstream, which typifies the improvements made to date through the construction of regulating structures. Current estimate of annual benefits contributable to construction of regulating structures on the Middle Mississippi River derived from savings in transportation costs exceed 24 million dollars annually. Current B/C ratio is 5.3 to 1.



TYPICAL SECTION
FOR STONE FILLED DIKE



	BEFORE CONSTRUCTION	AFTER CONSTRUCTION	CHANGE
AVERAGE WIDTH OF RIVER MEASURED AT THE ELEVATION OF THE L.W.R.P.*	1835 FT.	1530 FT.	-305 FT.
AVERAGE DEPTH OF WATER BELOW THE ELEVATION OF THE L.W.R.P.*	9.60 FT.	12.60 FT.	+3.00 FT.
AVERAGE AREA OF RIVER CROSS SECTION BELOW THE ELEVATION OF THE L.W.R.P.*	17,300 FT²	19,250 FT²	+1950 FT²

* LOW WATER REFERENCE PLANE BASED UPON A DISCHARGE OF 54,000 C.F.S.

TYPICAL RIVER CROSS-SECTION

Plate 1

2-1 Aerial view – looking west showing extensive accretion of material downstream of dike No. 152.0 L.
(River stage was approx. 8.0 feet on the St. Louis gage when these aerial photos were taken.)

2-2 Aerial view – looking southwest approx. mile 151.0 showing accretion of materials in newly constructed dike fields.

2-3 Aerial view – looking south approx. mile 150.0 showing accretion of materials in newly constructed dike fields.

2-4 Photo from high riverbank showing upbound tow with bulk commodities, e.g. sand, gravel, [illegible], etc.

Plate 2

3-1 Aerial view - approx. mile 146.3 showing how dike fields are constructed to improve the navigation channel and yet not impair the operation of existing dock facilities.

3-2 Aerial view - approx. mile 146.0 showing that new stone dike construction is more effective in trapping materials than pile dike construction. Pile dike is shown in upper left portion of photo.

3-3 Aerial view - approx. mile 145.0 showing how dikes are used to train the direction of current and develop the navigation channel.

3-4 Aerial view - approx. mile 144.0 showing chute closure built to a low elevation to confine low flows to the navigation channel. The low elevation of the chute closure permits flow during high river stages and provides excellent fish habitat during low river stages.

Plate 3

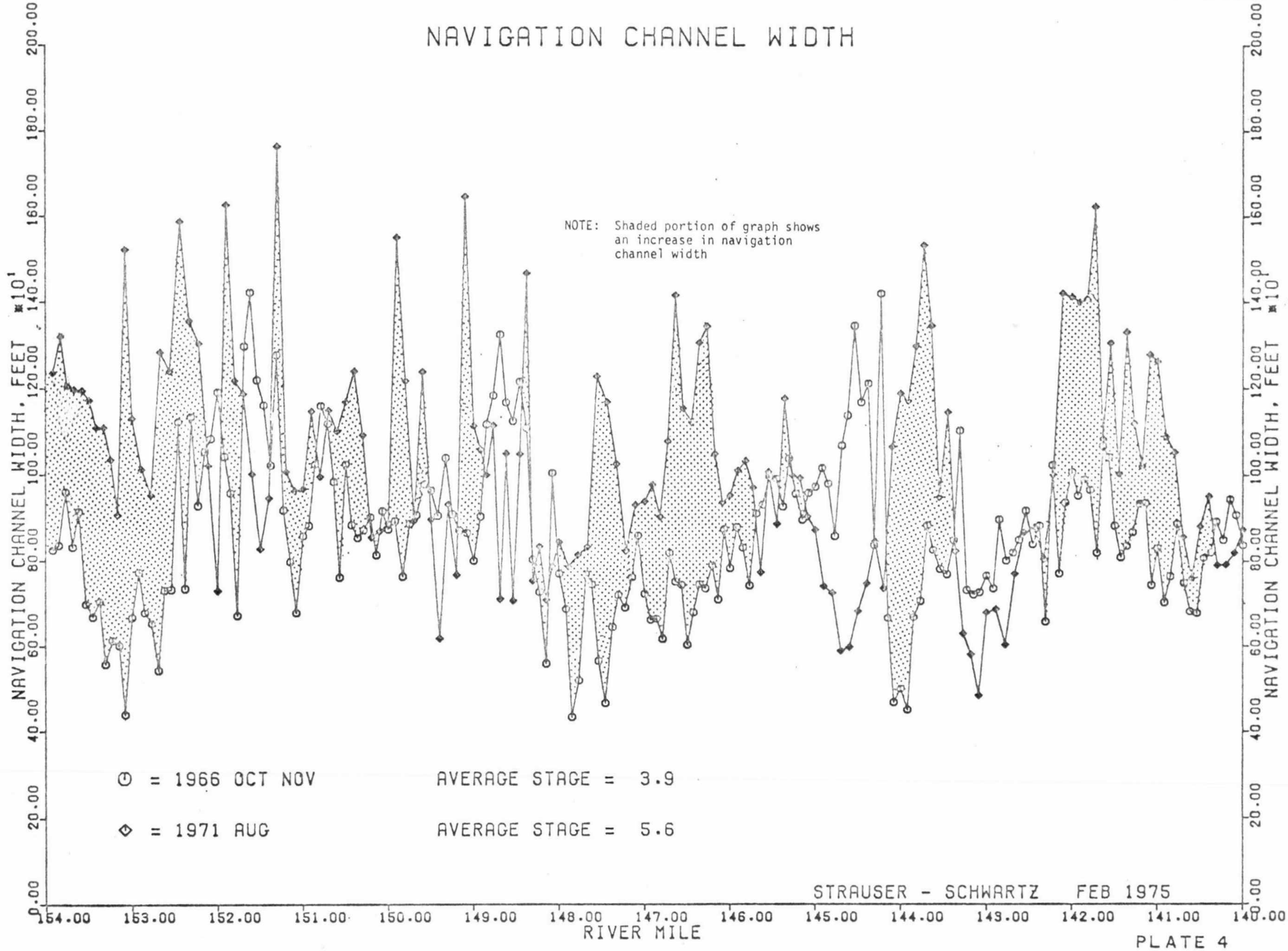
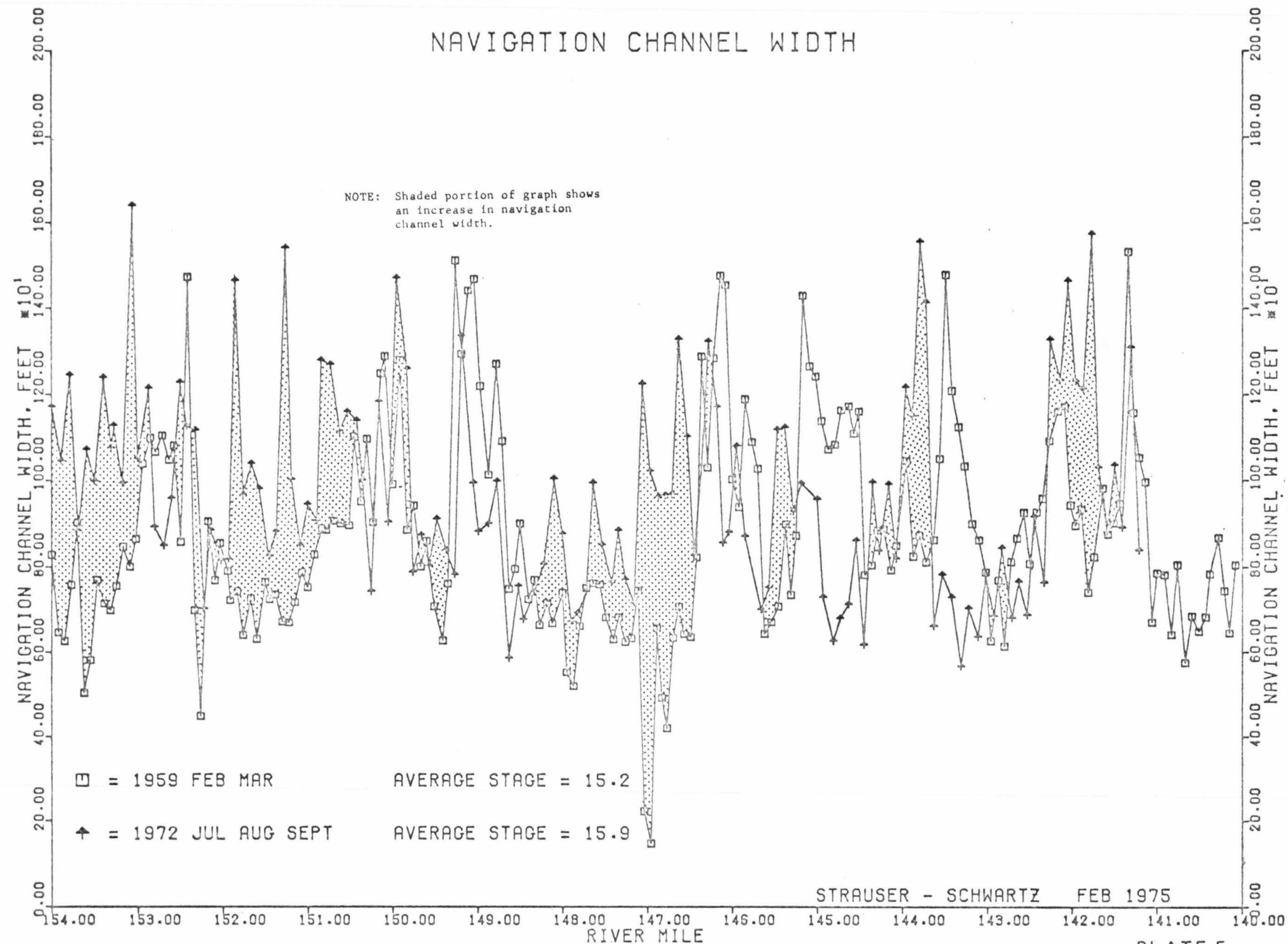

NAVIGATION CHANNEL WIDTH
NOTE: Shaded portion of graph shows an increase in navigation channel width
NAVIGATION CHANNEL WIDTH, FEET ✱10¹
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
180.00
200.00
154.00
153.00
152.00
151.00
150.00
149.00
148.00
147.00
146.00
145.00
144.00
143.00
142.00
141.00
140.00
RIVER MILE
⊙ = 1966 OCT NOV
AVERAGE STAGE = 3.9
◇ = 1971 AUG
AVERAGE STAGE = 5.6
STRAUSER - SCHWARTZ FEB 1975

PLATE 4



NAVIGATION CHANNEL WIDTH
NOTE: Shaded portion of graph shows an increase in navigation channel width.
NAVIGATION CHANNEL WIDTH, FEET *10¹
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
180.00
200.00
154.00
153.00
152.00
151.00
150.00
149.00
148.00
147.00
146.00
145.00
144.00
143.00
142.00
141.00
140.00
RIVER MILE
□ = 1959 FEB MAR
AVERAGE STAGE = 15.2
+ = 1972 JUL AUG SEPT
AVERAGE STAGE = 15.9
STRAUSER - SCHWARTZ FEB 1975

PLATE 5

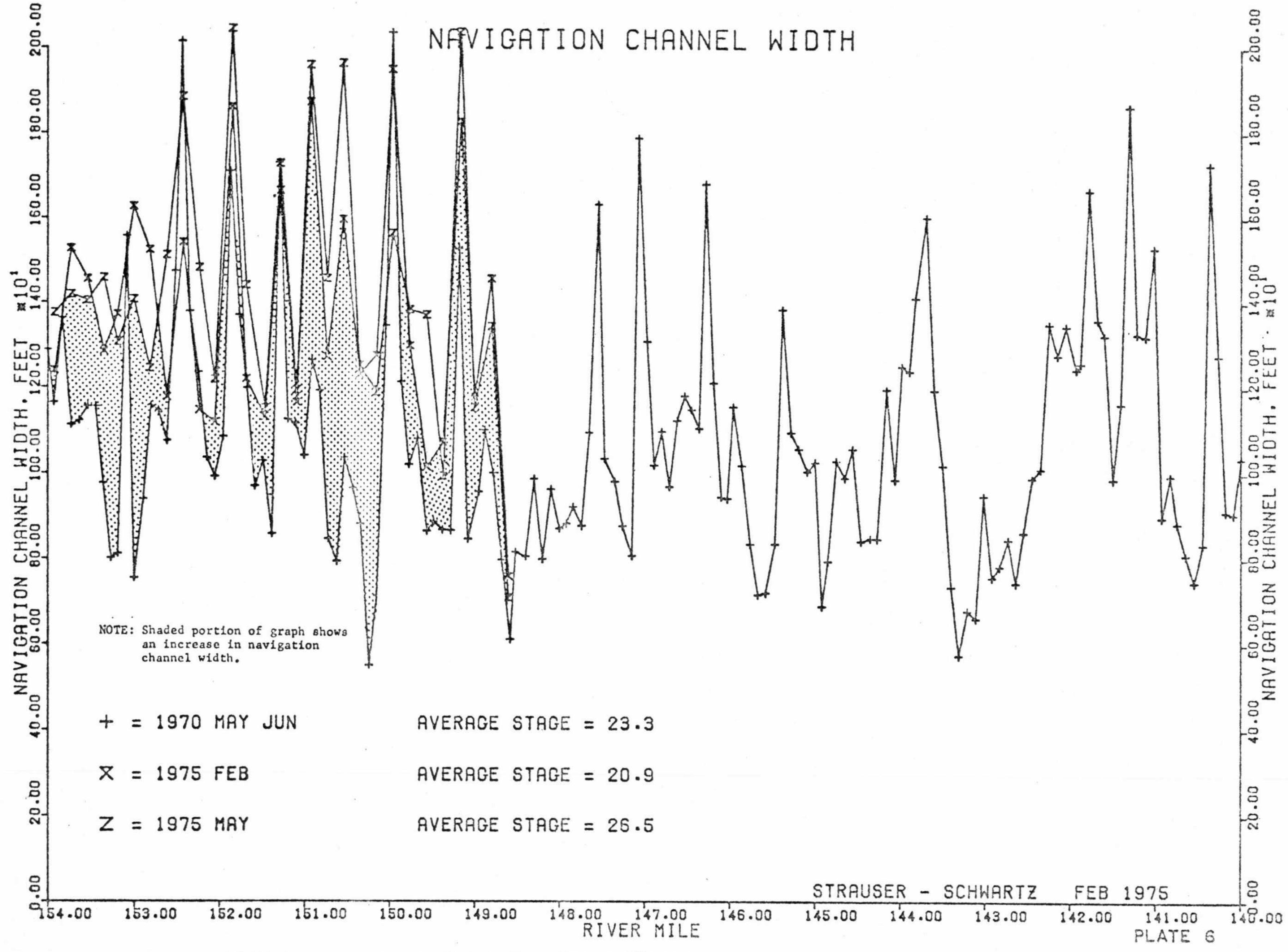

NAVIGATION CHANNEL WIDTH
NAVIGATION CHANNEL WIDTH, FEET ×10¹
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
180.00
200.00
154.00
153.00
152.00
151.00
150.00
149.00
148.00
147.00
146.00
145.00
144.00
143.00
142.00
141.00
140.00
RIVER MILE
NOTE: Shaded portion of graph shows an increase in navigation channel width.
+ = 1970 MAY JUN
AVERAGE STAGE = 23.3
X = 1975 FEB
AVERAGE STAGE = 20.9
Z = 1975 MAY
AVERAGE STAGE = 26.5
STRAUSER - SCHWARTZ FEB 1975

PLATE 6

AVERAGE DEPTH BELOW LOW WATER REFERENCE PLANE

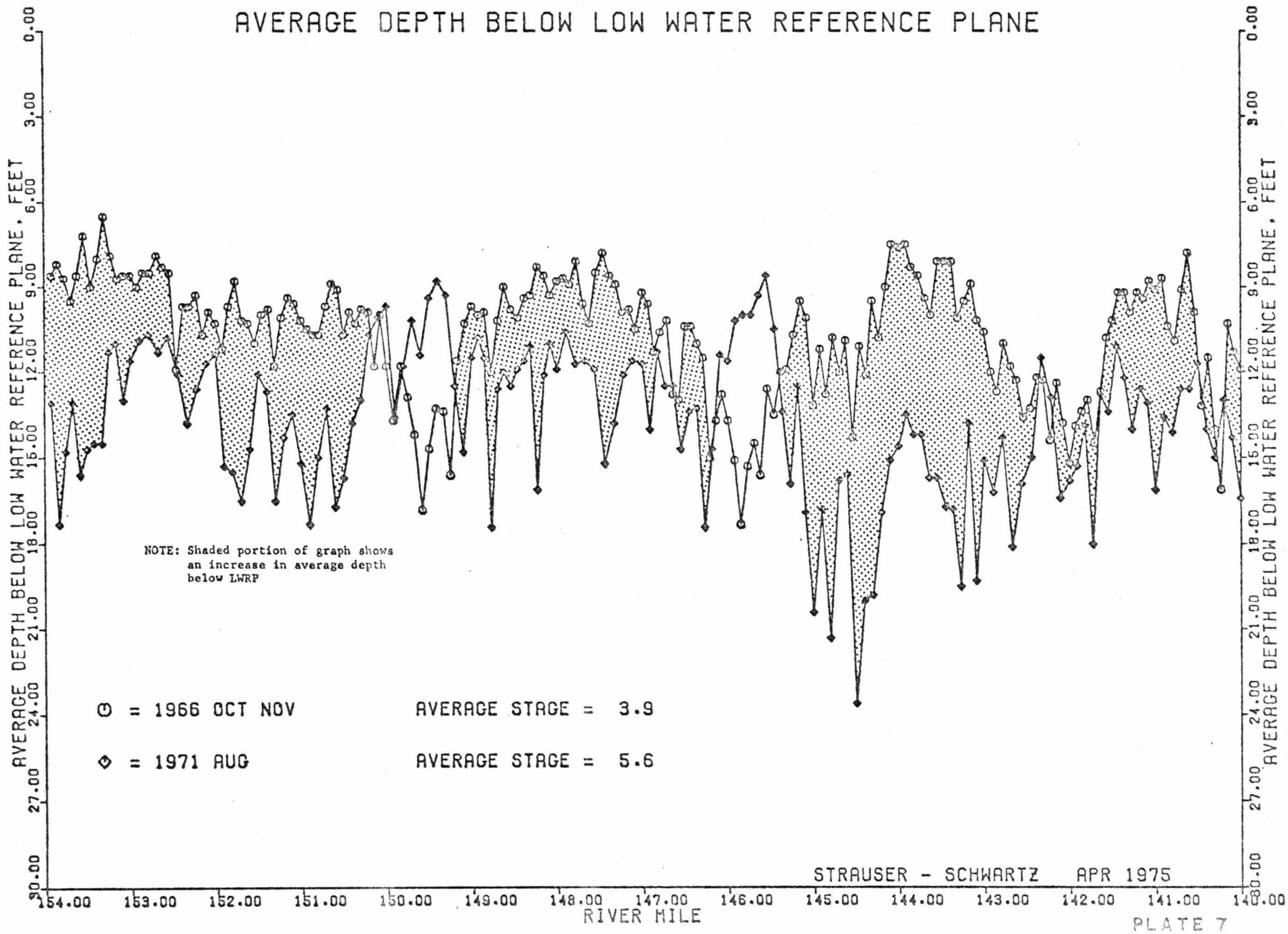


PLATE 7

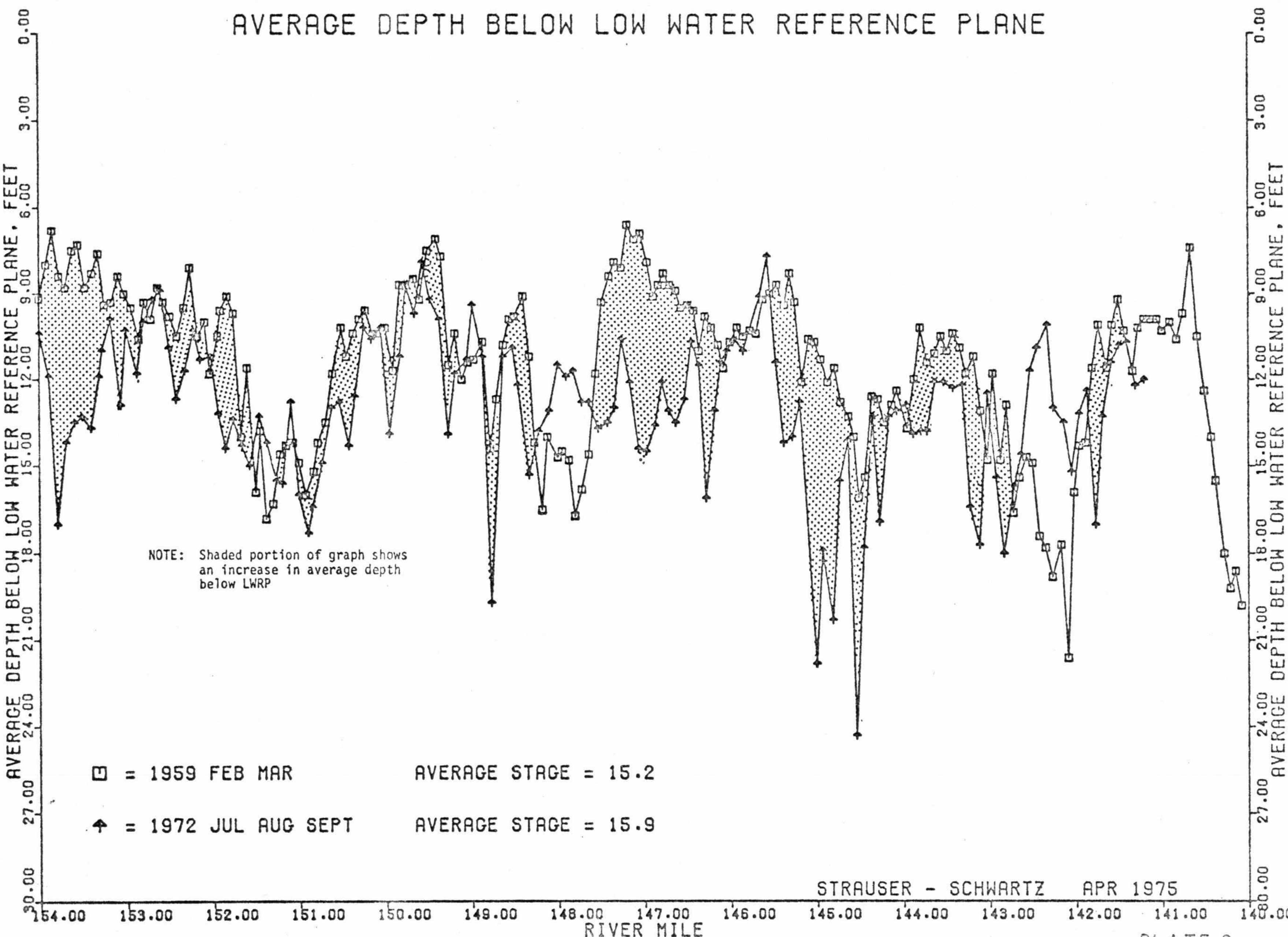
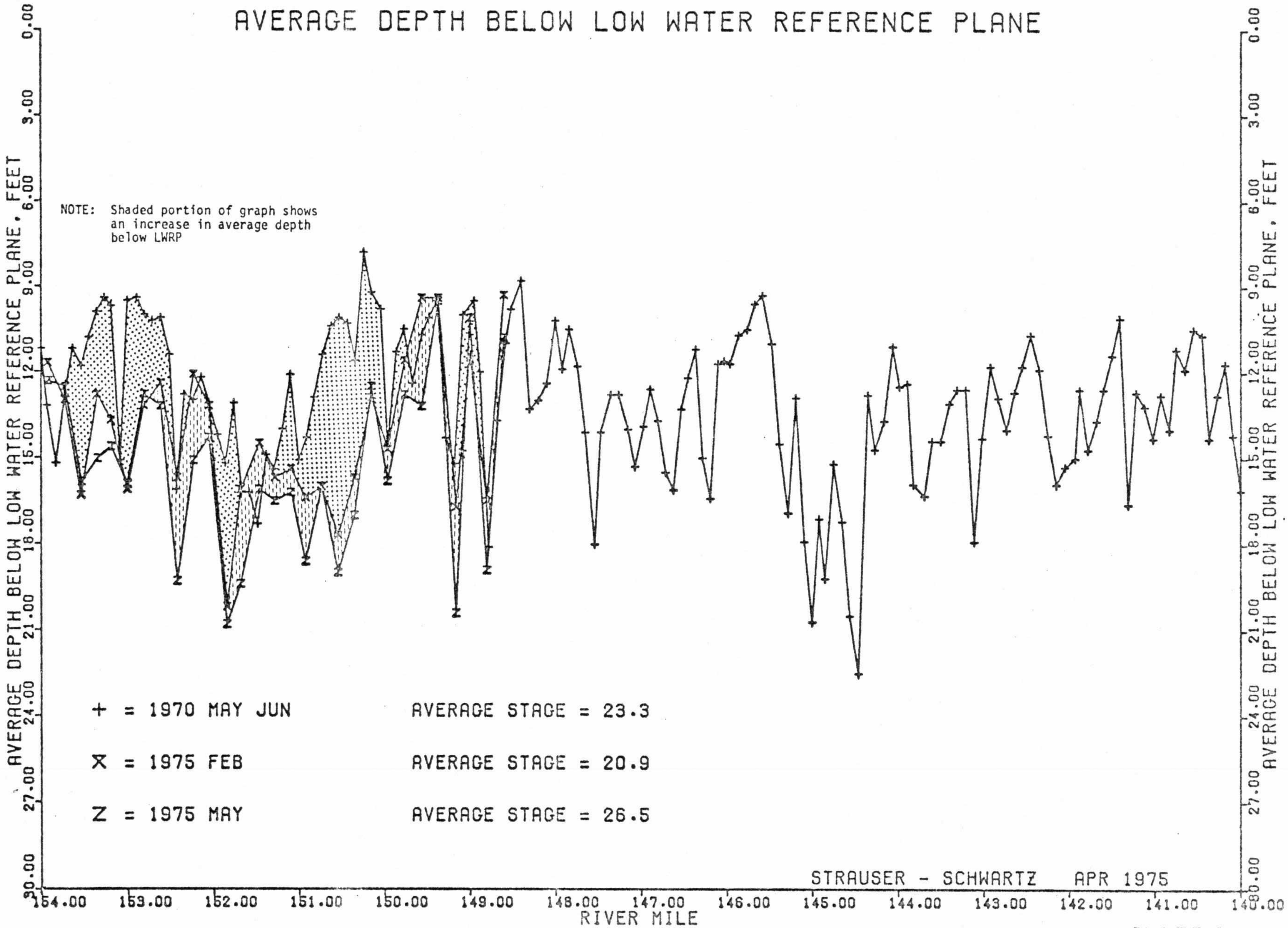

AVERAGE DEPTH BELOW LOW WATER REFERENCE PLANE
AVERAGE DEPTH BELOW LOW WATER REFERENCE PLANE, FEET
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00
30.00
NOTE: Shaded portion of graph shows an increase in average depth below LWRP
☐ = 1959 FEB MAR
AVERAGE STAGE = 15.2
✦ = 1972 JUL AUG SEPT
AVERAGE STAGE = 15.9
STRAUSER - SCHWARTZ APR 1975
154.00
153.00
152.00
151.00
150.00
149.00
148.00
147.00
146.00
145.00
144.00
143.00
142.00
141.00
140.00
RIVER MILE

PLATE 8



AVERAGE DEPTH BELOW LOW WATER REFERENCE PLANE
NOTE: Shaded portion of graph shows an increase in average depth below LWRP
AVERAGE DEPTH BELOW LOW WATER REFERENCE PLANE, FEET
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00
30.00
+ = 1970 MAY JUN
AVERAGE STAGE = 23.3
X = 1975 FEB
AVERAGE STAGE = 20.9
Z = 1975 MAY
AVERAGE STAGE = 26.5
STRAUSER - SCHWARTZ
APR 1975
154.00
153.00
152.00
151.00
150.00
149.00
148.00
147.00
146.00
145.00
144.00
143.00
142.00
141.00
140.00
RIVER MILE

PLATE 9

AREA BELOW LOW WATER REFERENCE PLANE

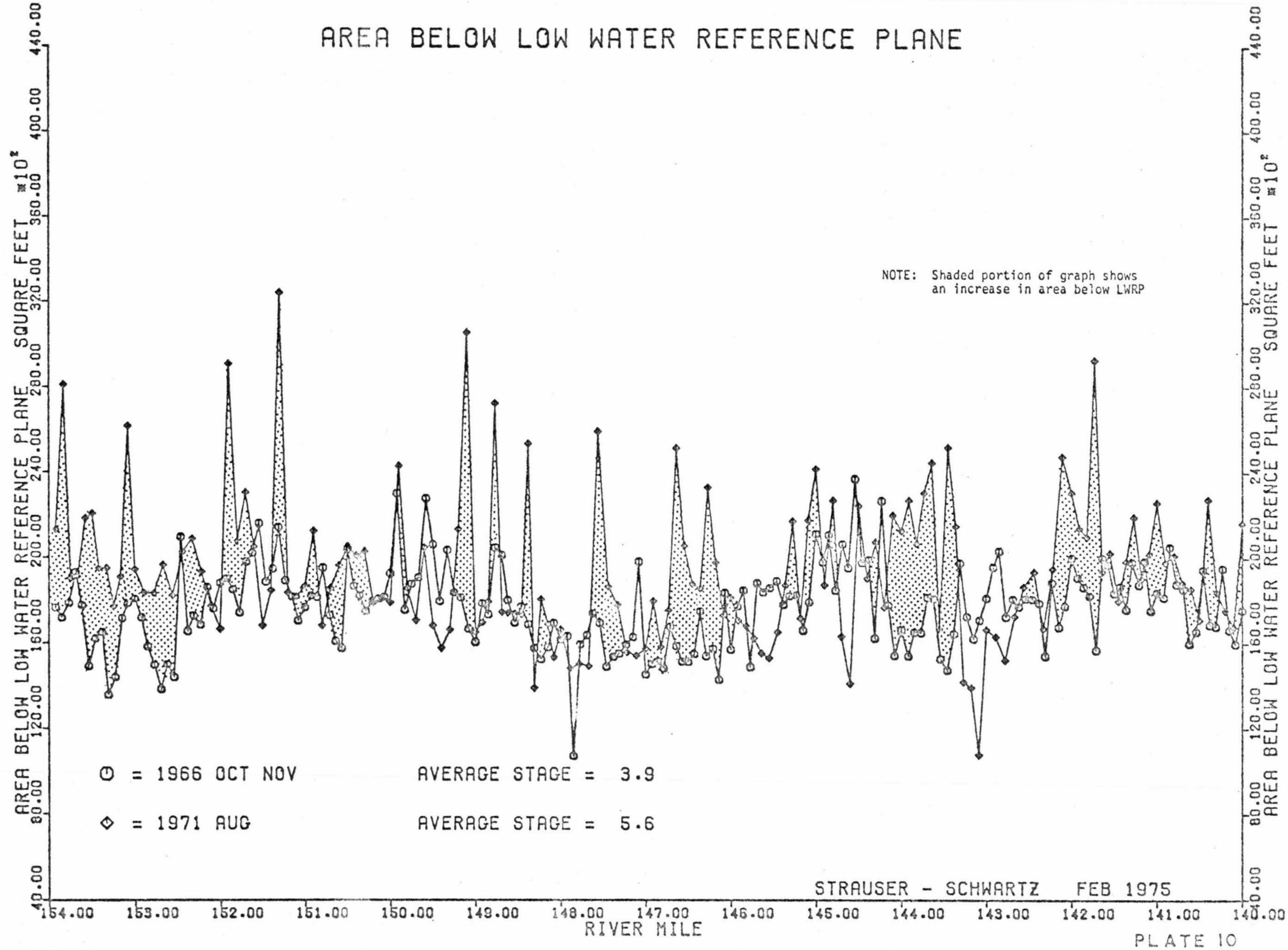


PLATE 10

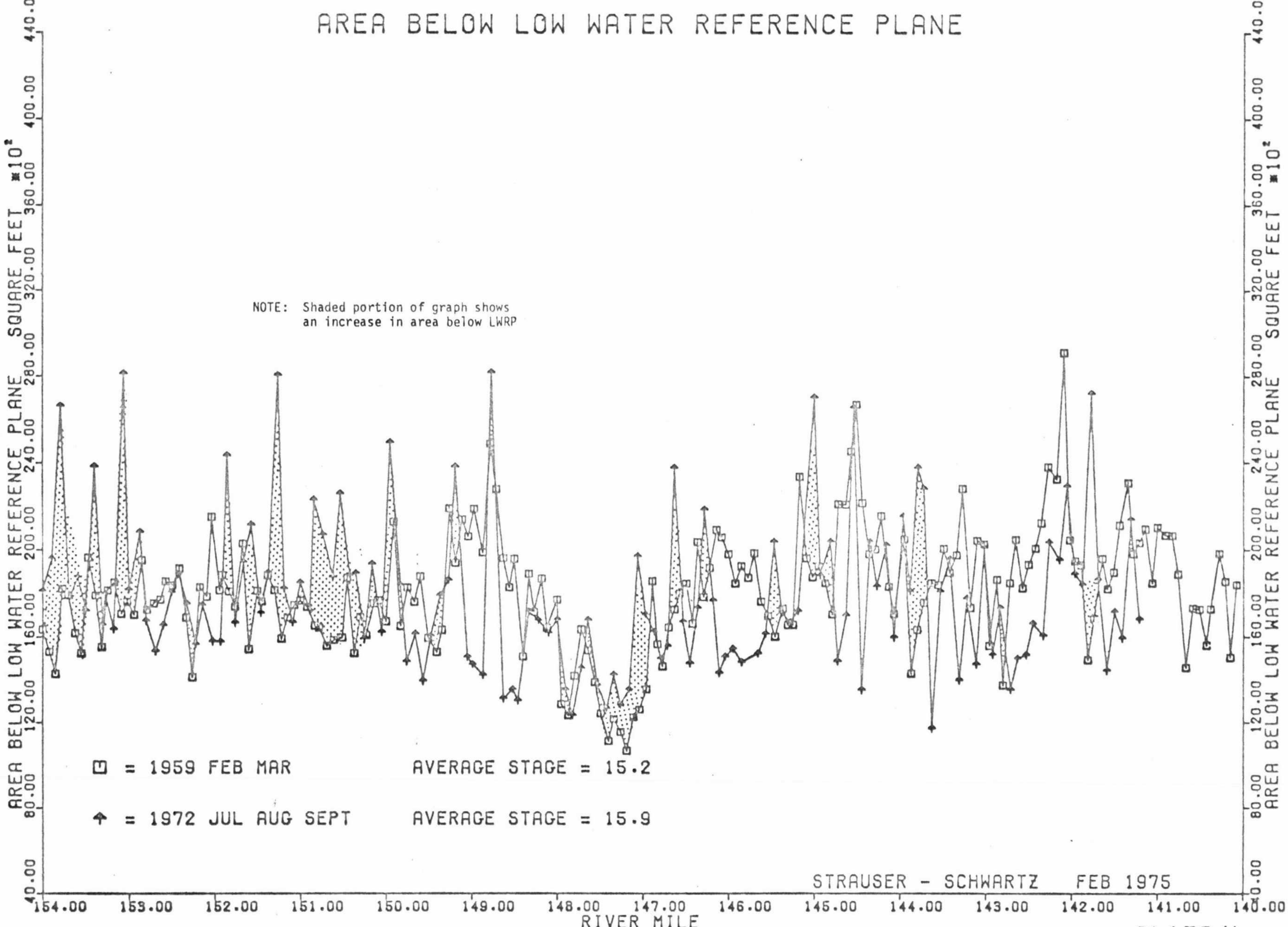
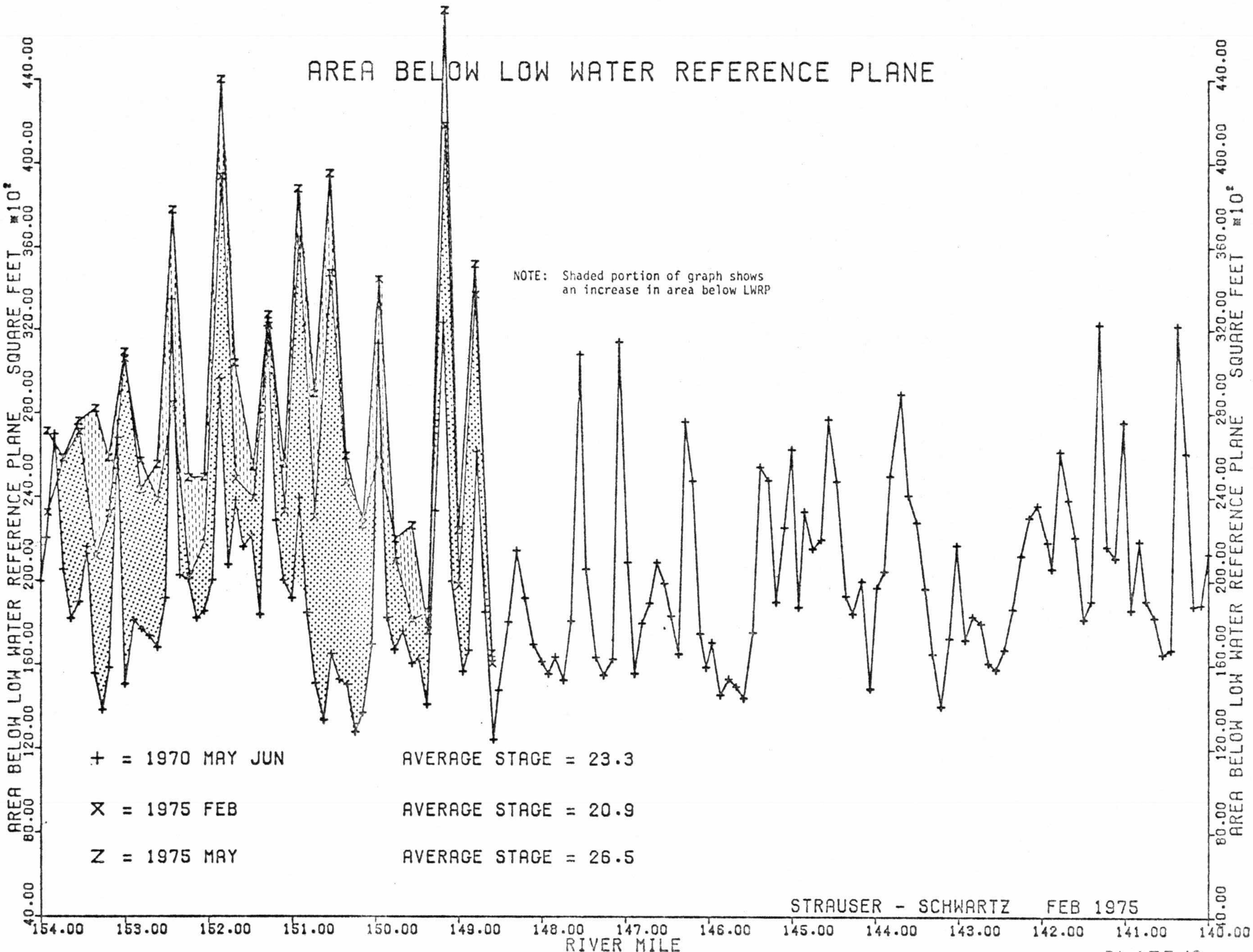
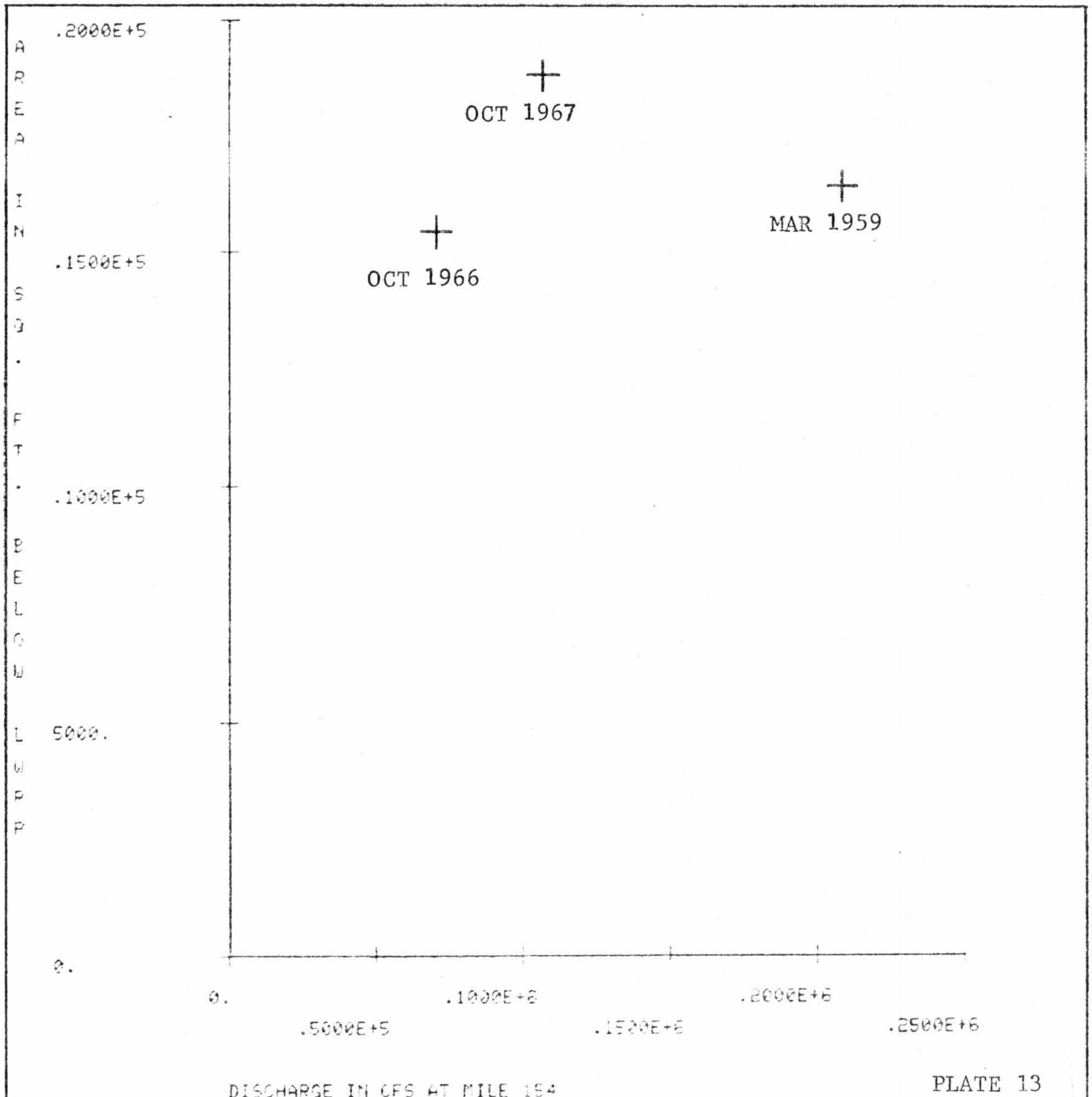

AREA BELOW LOW WATER REFERENCE PLANE
NOTE: Shaded portion of graph shows an increase in area below LWRP
AREA BELOW LOW WATER REFERENCE PLANE SQUARE FEET *10²
40.00
80.00
120.00
160.00
200.00
240.00
280.00
320.00
360.00
400.00
440.00
154.00
153.00
152.00
151.00
150.00
149.00
148.00
147.00
146.00
145.00
144.00
143.00
142.00
141.00
140.00
RIVER MILE
◻ = 1959 FEB MAR AVERAGE STAGE = 15.2
↑ = 1972 JUL AUG SEPT AVERAGE STAGE = 15.9
STRAUSER - SCHWARTZ FEB 1975

PLATE II



AREA BELOW LOW WATER REFERENCE PLANE
NOTE: Shaded portion of graph shows an increase in area below LWRP
+ = 1970 MAY JUN
AVERAGE STAGE = 23.3
X = 1975 FEB
AVERAGE STAGE = 20.9
Z = 1975 MAY
AVERAGE STAGE = 26.5
STRAUSER - SCHWARTZ FEB 1975
AREA BELOW LOW WATER REFERENCE PLANE SQUARE FEET ×10²
40.00
80.00
120.00
160.00
200.00
240.00
280.00
320.00
360.00
400.00
440.00
154.00
153.00
152.00
151.00
150.00
149.00
148.00
147.00
146.00
145.00
144.00
143.00
142.00
141.00
140.00
RIVER MILE

PLATE 12



AREA IN SQ. FT. BELOW LWPP
.2000E+5
.1500E+5
.1000E+5
5000.
0.
OCT 1967
MAR 1959
OCT 1966
0.
.5000E+5
.1000E+6
.1500E+6
.2000E+6
.2500E+6
DISCHARGE IN CFS AT MILE 154

PLATE 13

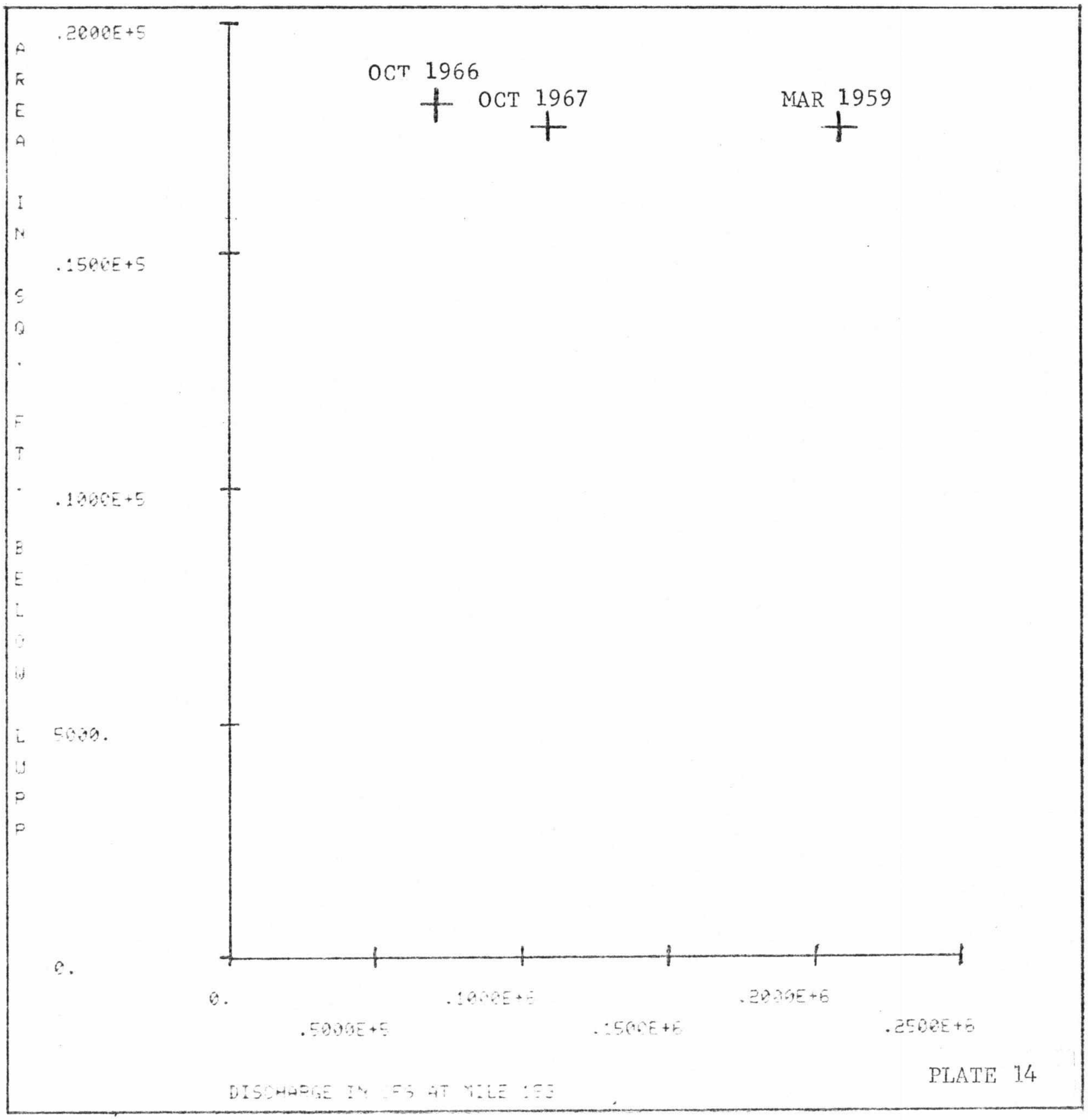
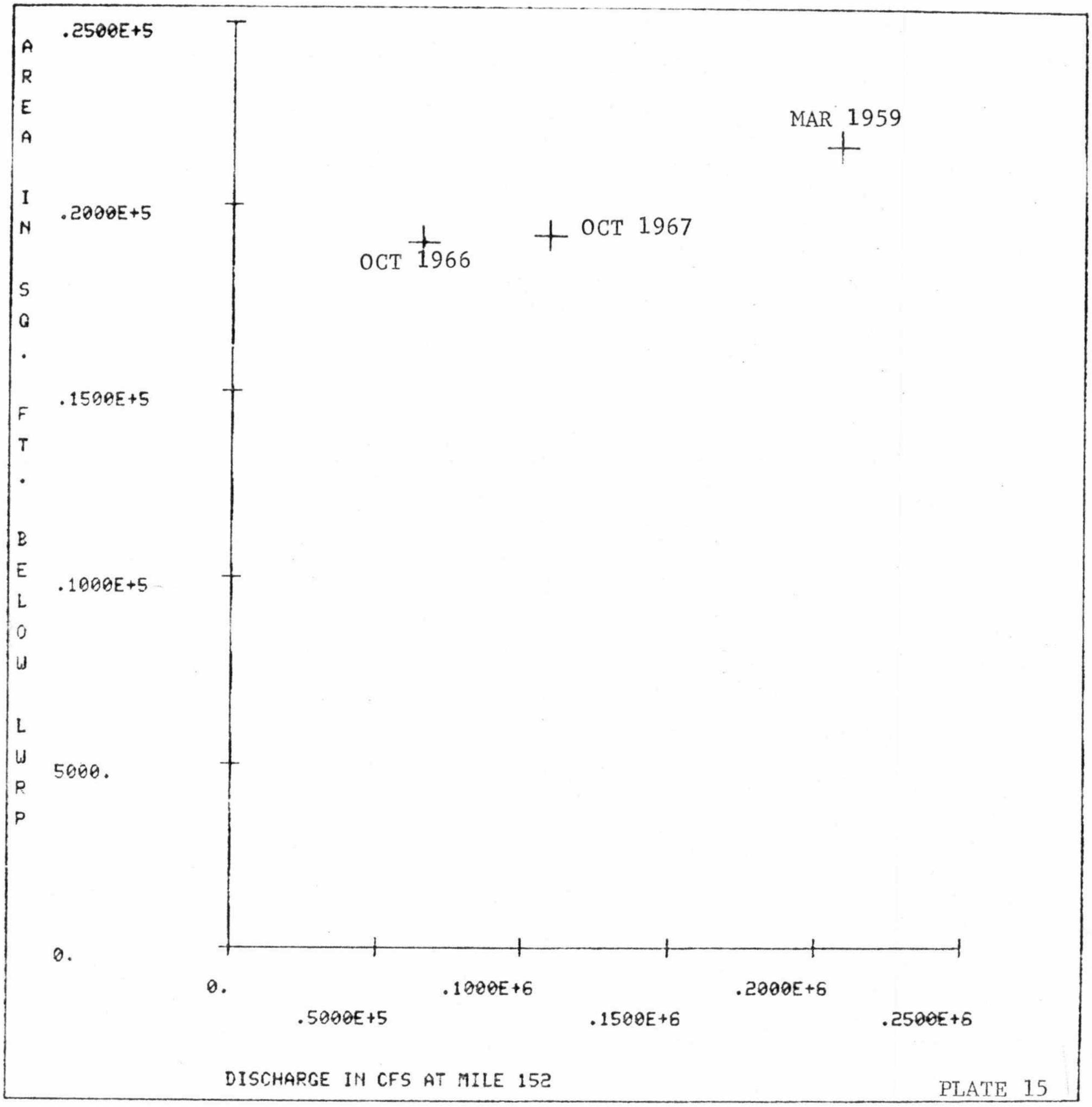

AREA IN SQ. FT. BELOW LUPP
.2000E+5
.1500E+5
.1000E+5
5000.
0.
OCT 1966
OCT 1967
MAR 1959
0.
.5000E+5
.1000E+6
.1500E+6
.2000E+6
.2500E+6
DISCHARGE IN CFS AT MILE

PLATE 14


AREA IN SQ. FT. BELOW LWRP
.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
MAR 1959
OCT 1967
OCT 1966
0.
.5000E+5
.1000E+6
.1500E+6
.2000E+6
.2500E+6
DISCHARGE IN CFS AT MILE 152
PLATE 15

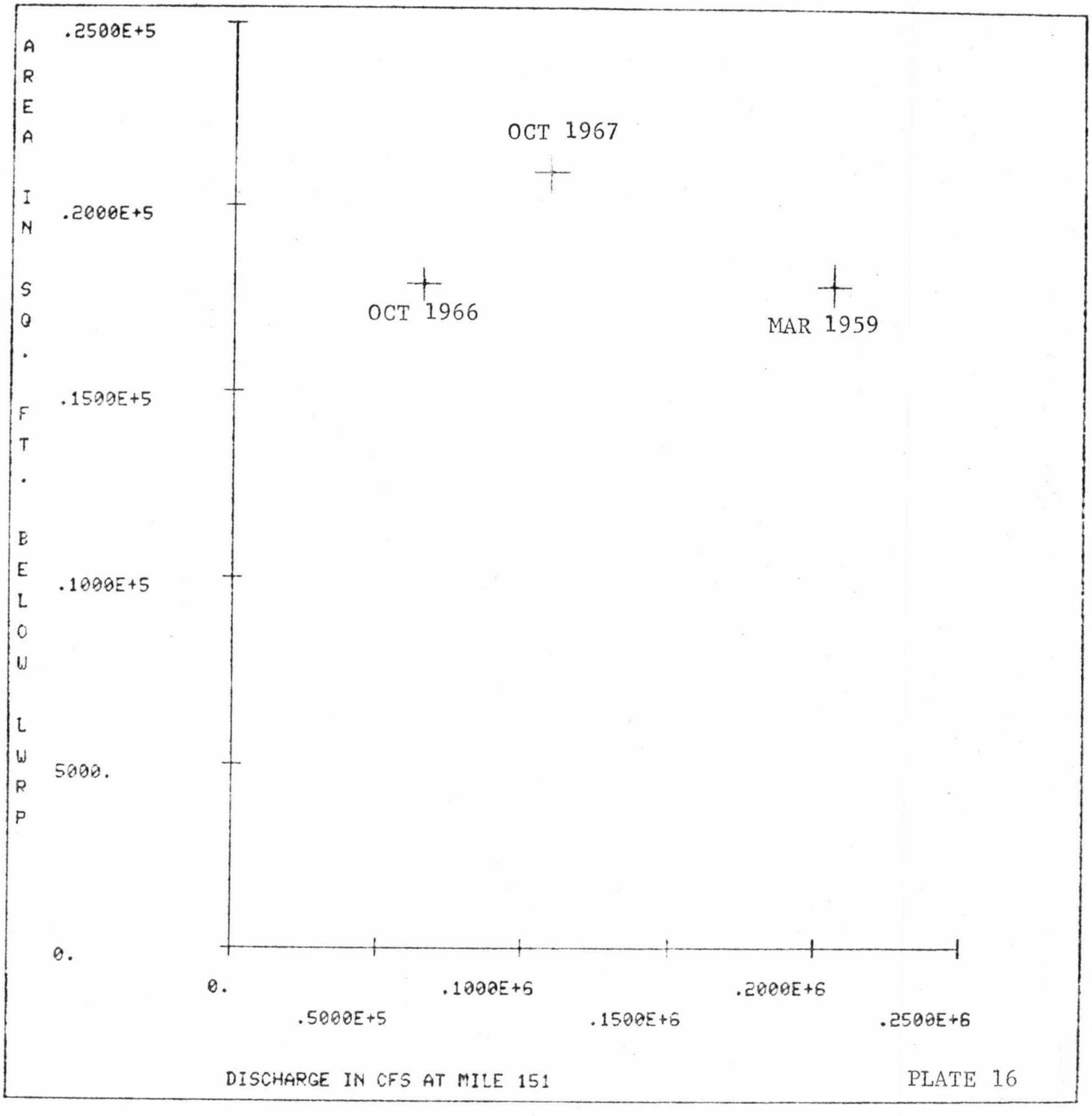
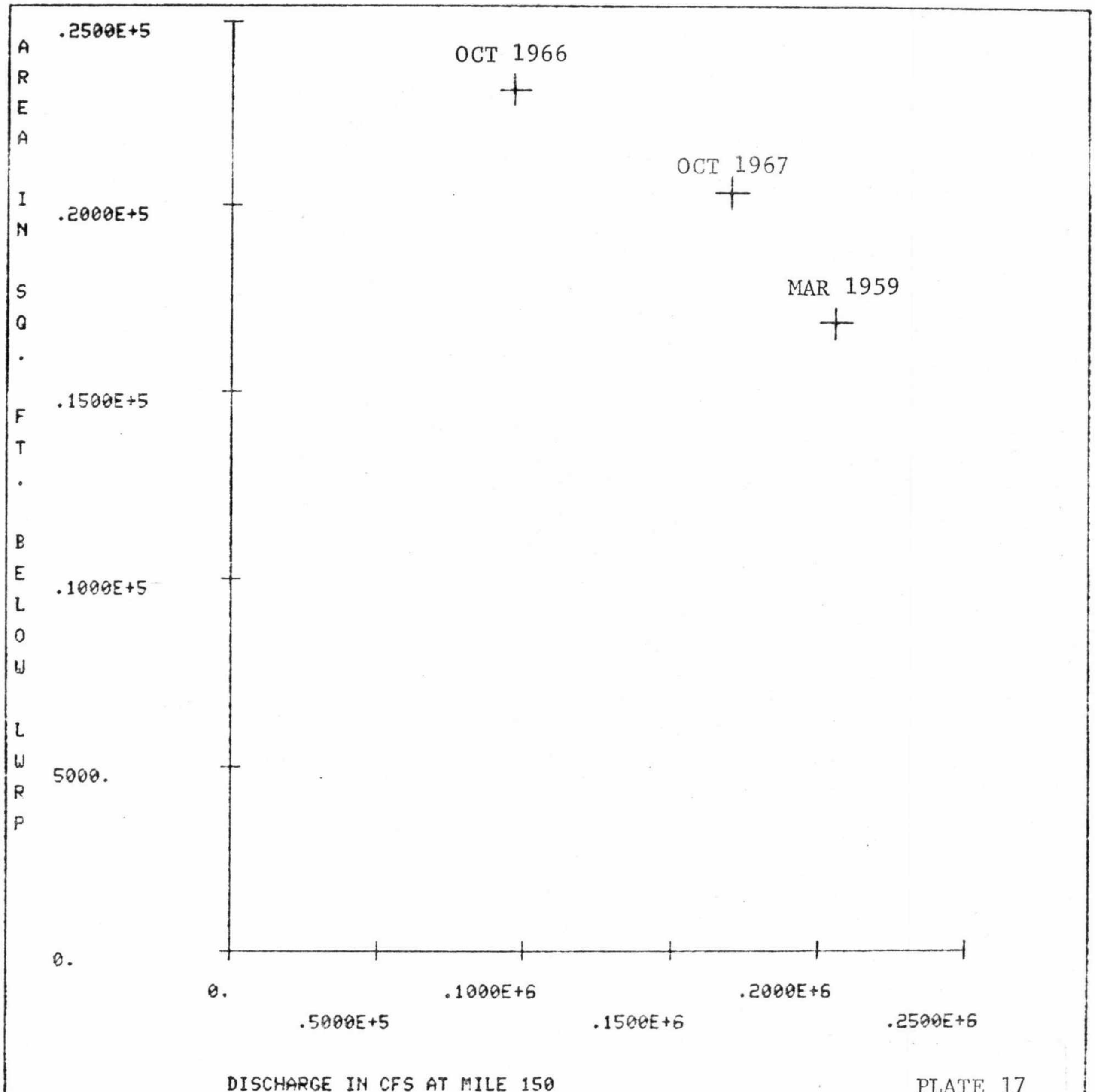
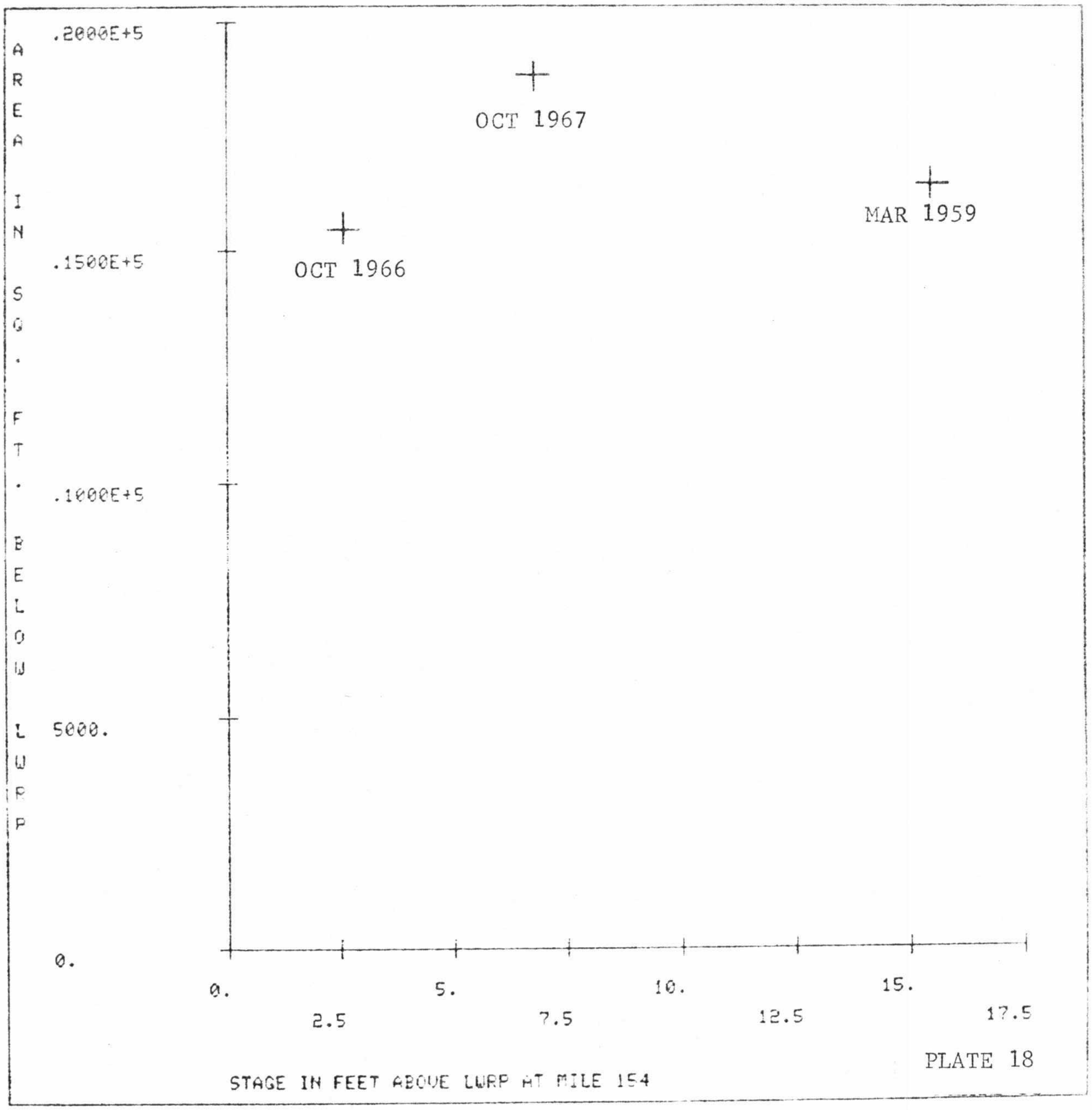

.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
AREA IN SQ. FT. BELOW LWRP
OCT 1967
OCT 1966
MAR 1959
0.
.1000E+6
.2000E+6
.5000E+5
.1500E+6
.2500E+6
DISCHARGE IN CFS AT MILE 151

PLATE 16



AREA IN SQ. FT. BELOW LWRP
.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
OCT 1966
OCT 1967
MAR 1959
0.
.5000E+5
.1000E+6
.1500E+6
.2000E+6
.2500E+6
DISCHARGE IN CFS AT MILE 150

PLATE 17



AREA IN SQ. FT. BELOW LWRP
.2000E+5
.1500E+5
.1000E+5
5000.
0.
OCT 1967
MAR 1959
OCT 1966
0.
2.5
5.
7.5
10.
12.5
15.
17.5
STAGE IN FEET ABOVE LWRP AT MILE 154

PLATE 18

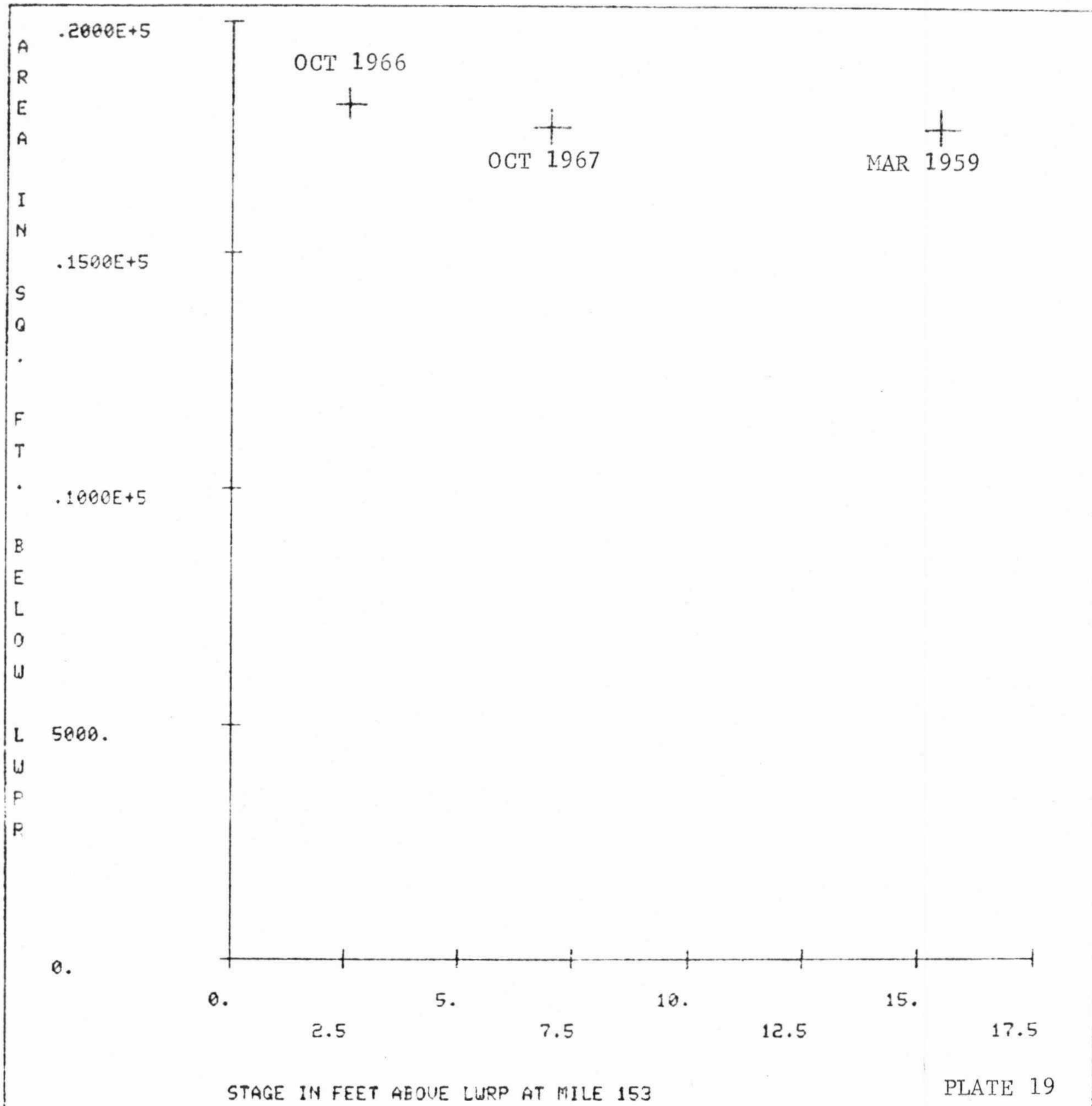

AREA IN SQ. FT. BELOW LWPR
.2000E+5
.1500E+5
.1000E+5
5000.
0.
OCT 1966
OCT 1967
MAR 1959
0.
2.5
5.
7.5
10.
12.5
15.
17.5
STAGE IN FEET ABOVE LWRP AT MILE 153

PLATE 19

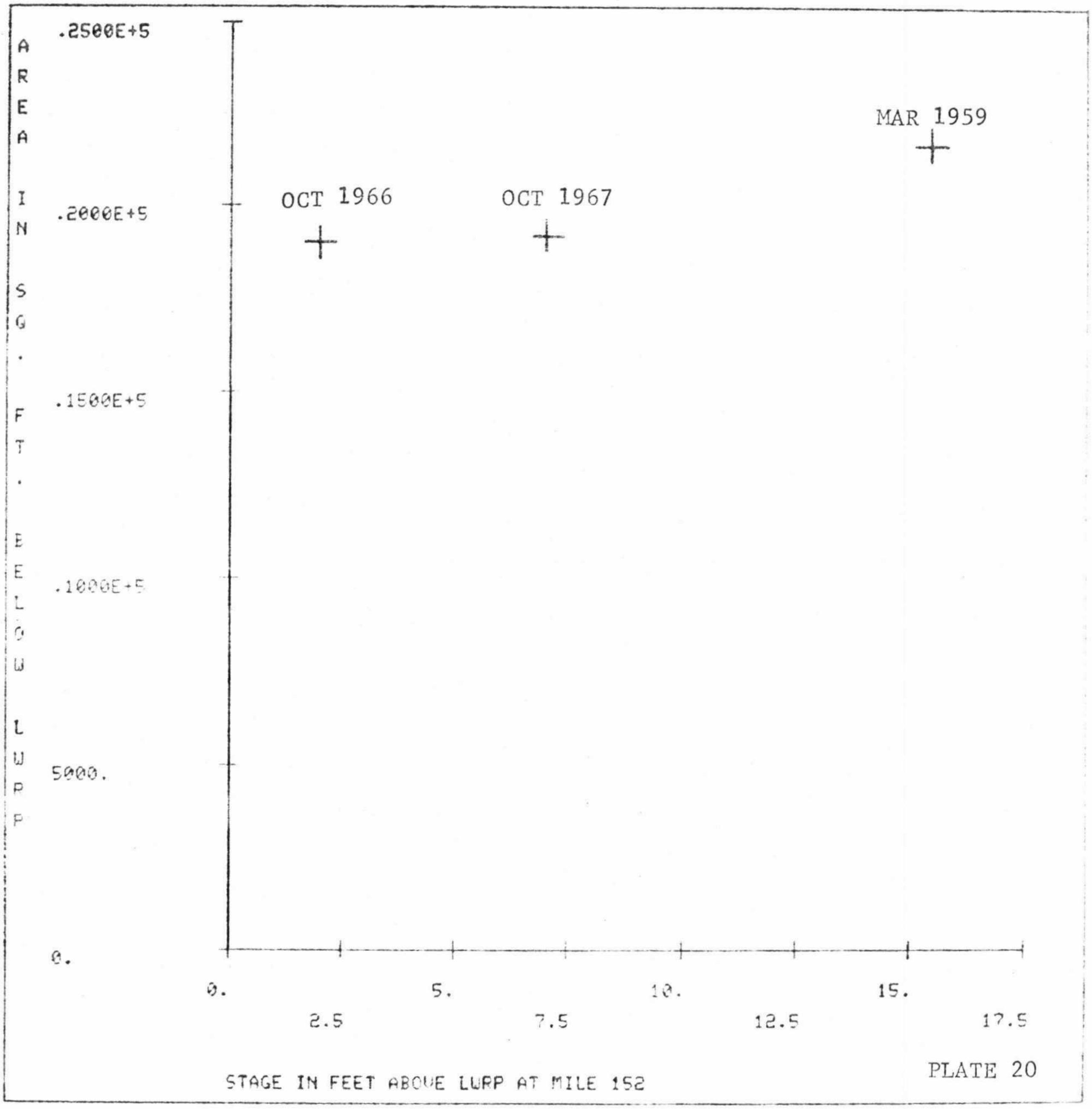

AREA IN SQ. FT. BELOW LWRP
.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
MAR 1959
OCT 1966
OCT 1967
0.
5.
10.
15.
2.5
7.5
12.5
17.5
STAGE IN FEET ABOVE LWRP AT MILE 152

PLATE 20

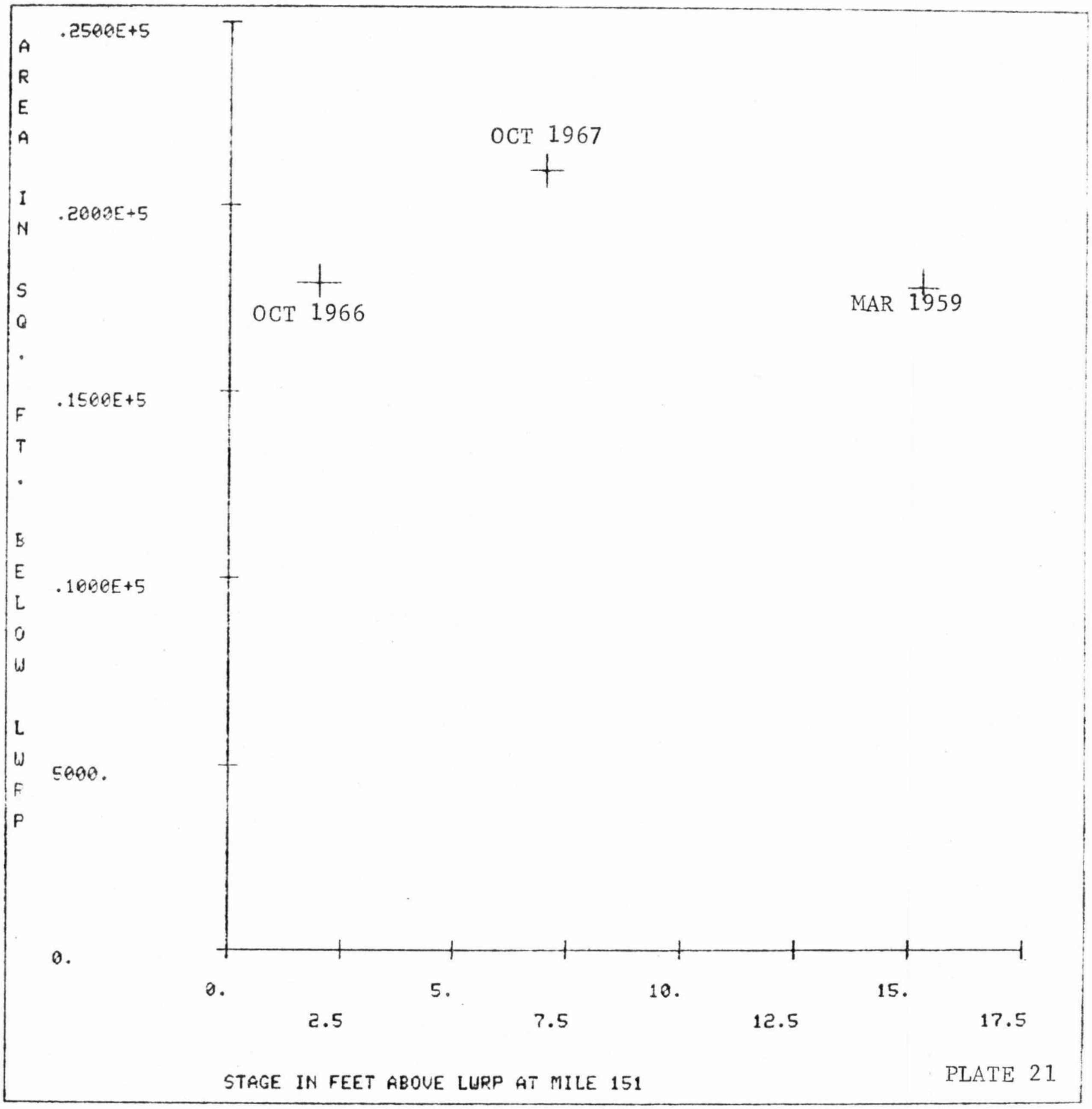

AREA IN SQ. FT. BELOW LWFP
.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
OCT 1967
OCT 1966
MAR 1959
0.
2.5
5.
7.5
10.
12.5
15.
17.5
STAGE IN FEET ABOVE LWRP AT MILE 151

PLATE 21

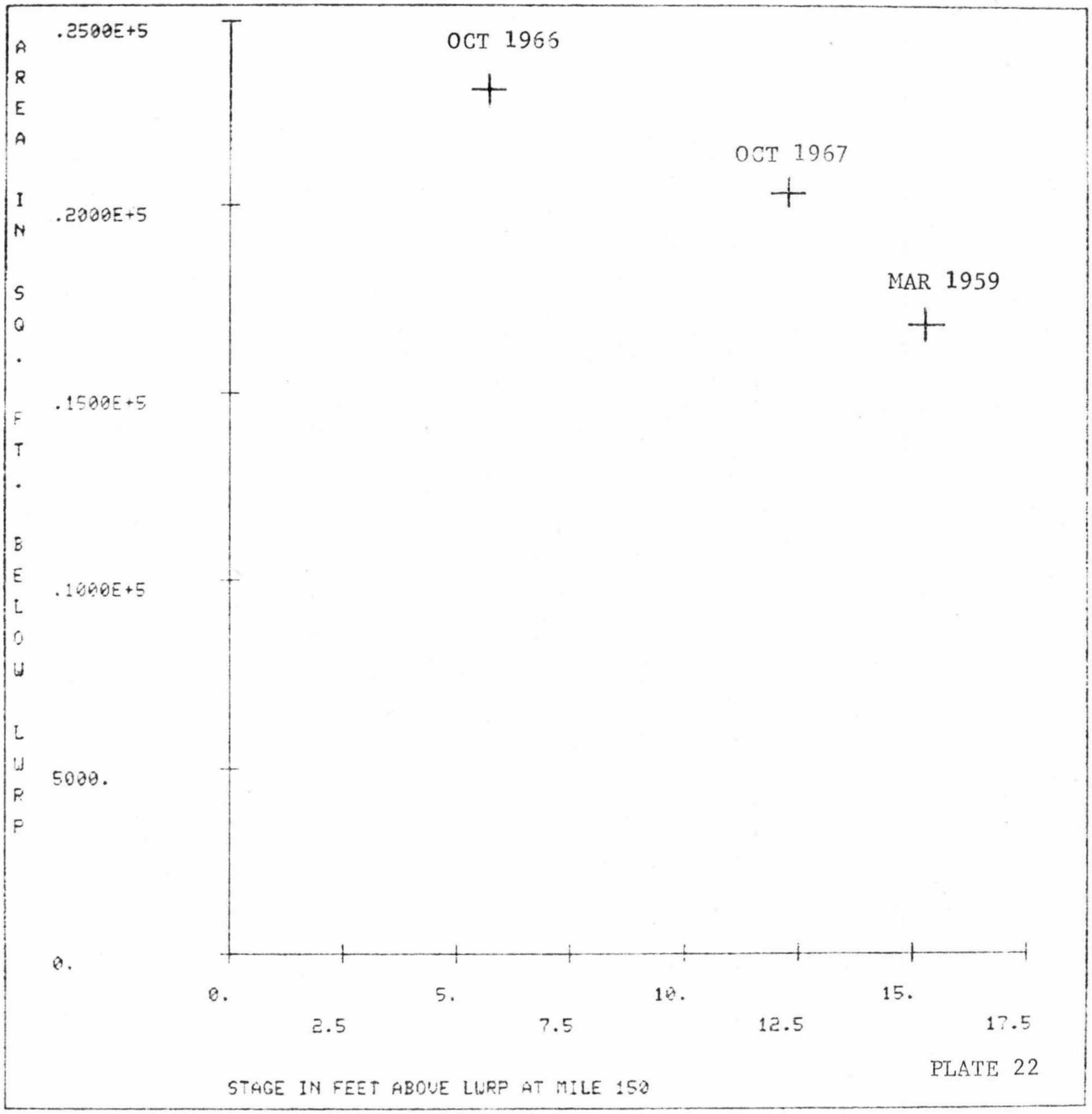
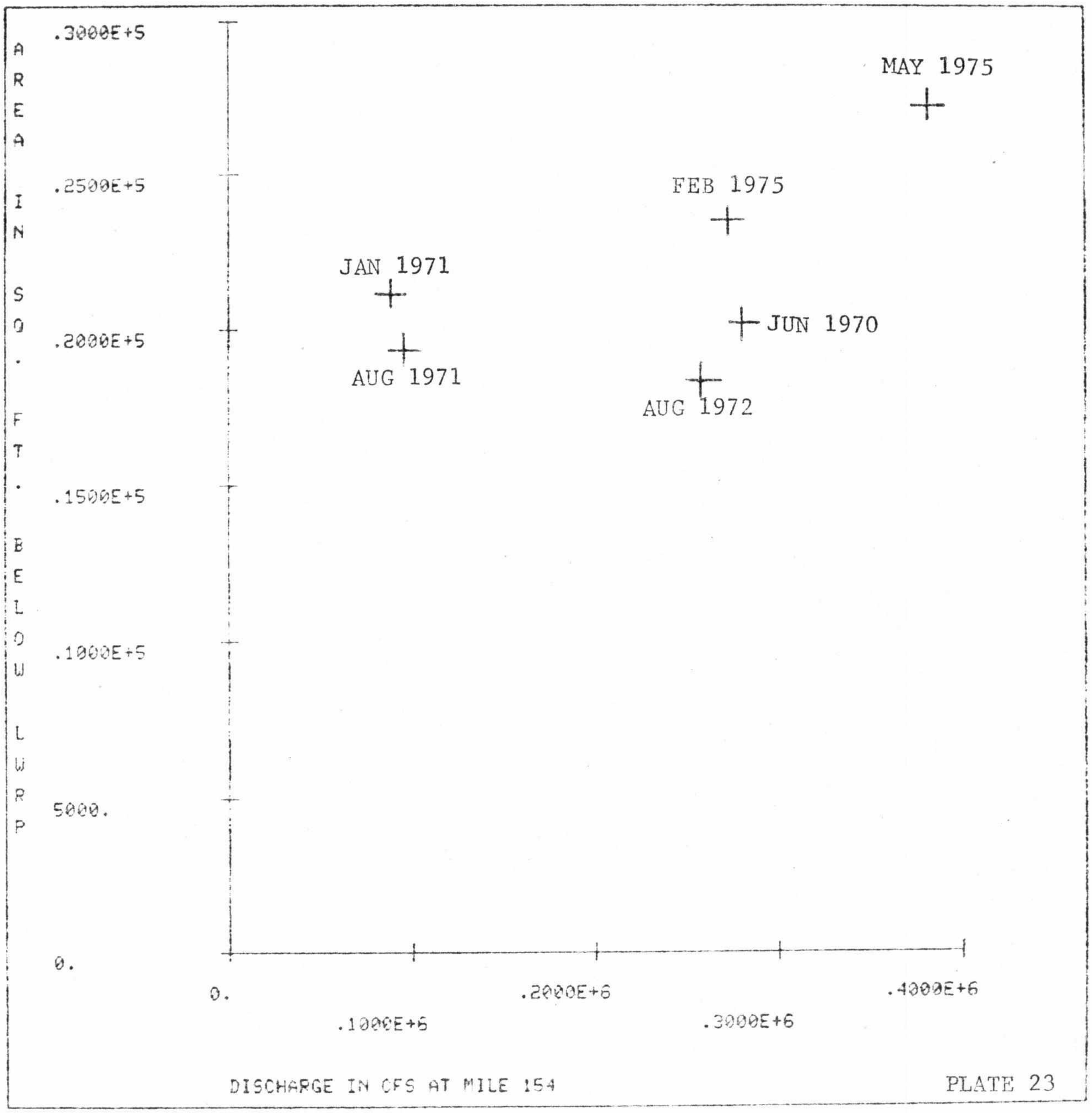
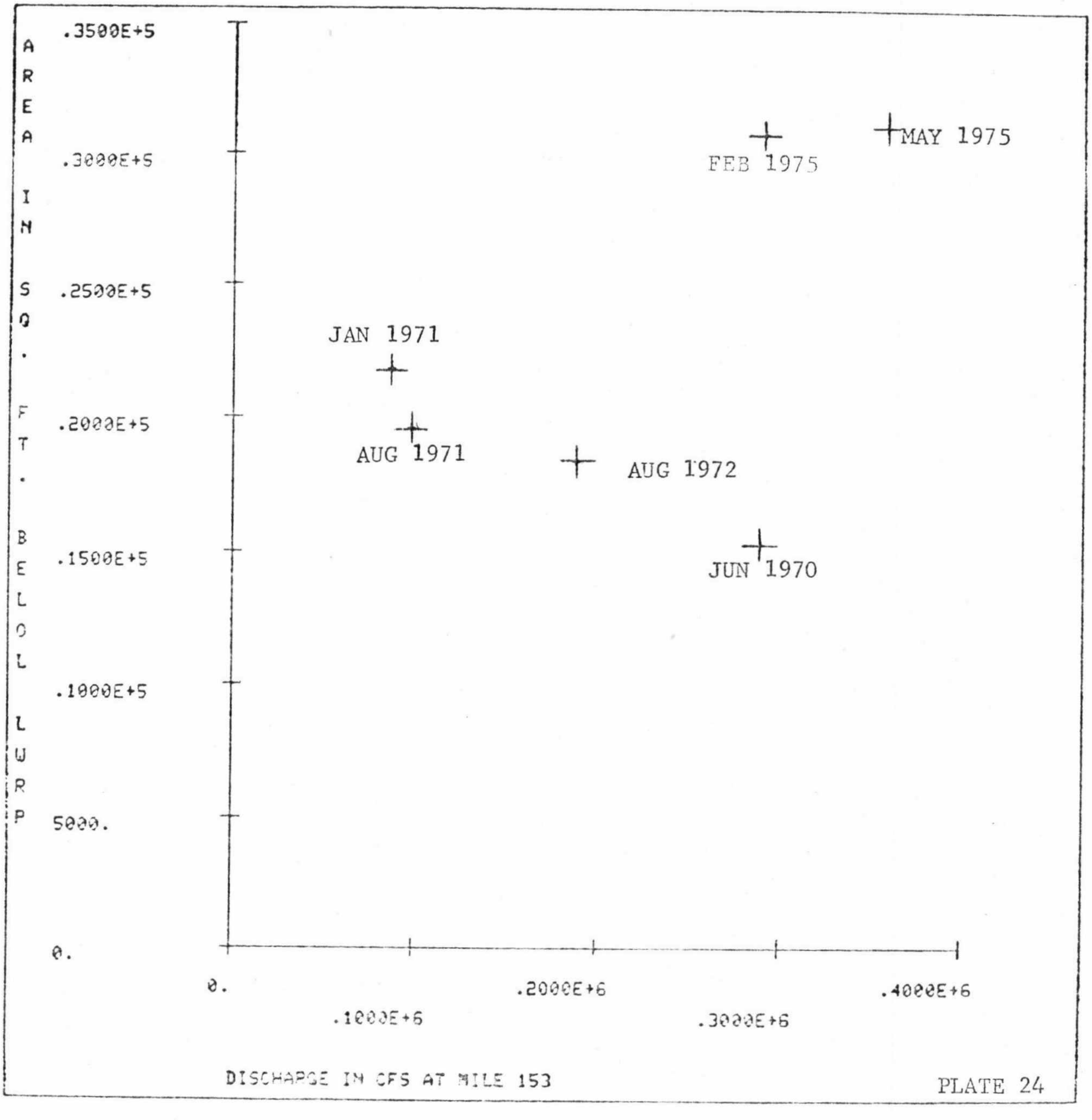

AREA IN SQ. FT. BELOW LWRP
.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
OCT 1966
OCT 1967
MAR 1959
0.
5.
10.
15.
2.5
7.5
12.5
17.5
STAGE IN FEET ABOVE LWRP AT MILE 150

PLATE 22



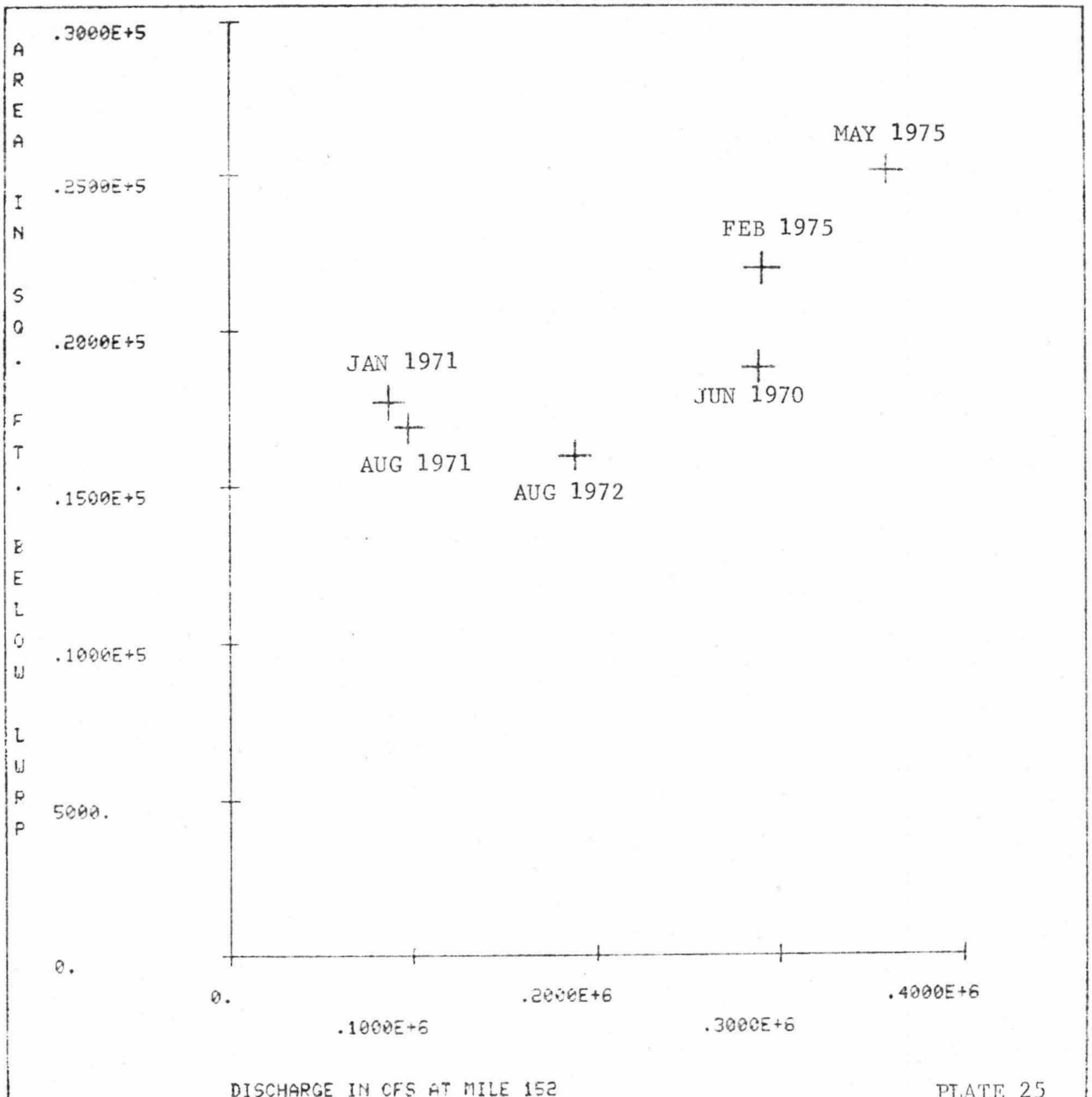
AREA IN SQ. FT. BELOW LWRP
.3000E+5
.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
MAY 1975
FEB 1975
JAN 1971
JUN 1970
AUG 1971
AUG 1972
0.
.1000E+6
.2000E+6
.3000E+6
.4000E+6
DISCHARGE IN CFS AT MILE 154

PLATE 23



AREA IN SQ. FT. BELOW LWRP
.3500E+5
.3000E+5
.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
JAN 1971
AUG 1971
AUG 1972
JUN 1970
FEB 1975
MAY 1975
0.
.1000E+6
.2000E+6
.3000E+6
.4000E+6
DISCHARGE IN CFS AT MILE 153

PLATE 24



AREA IN SQ. FT. BELOW LWPP
.3000E+5
.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
MAY 1975
FEB 1975
JAN 1971
JUN 1970
AUG 1971
AUG 1972
0.
.1000E+6
.2000E+6
.3000E+6
.4000E+6
DISCHARGE IN CFS AT MILE 152

PLATE 25

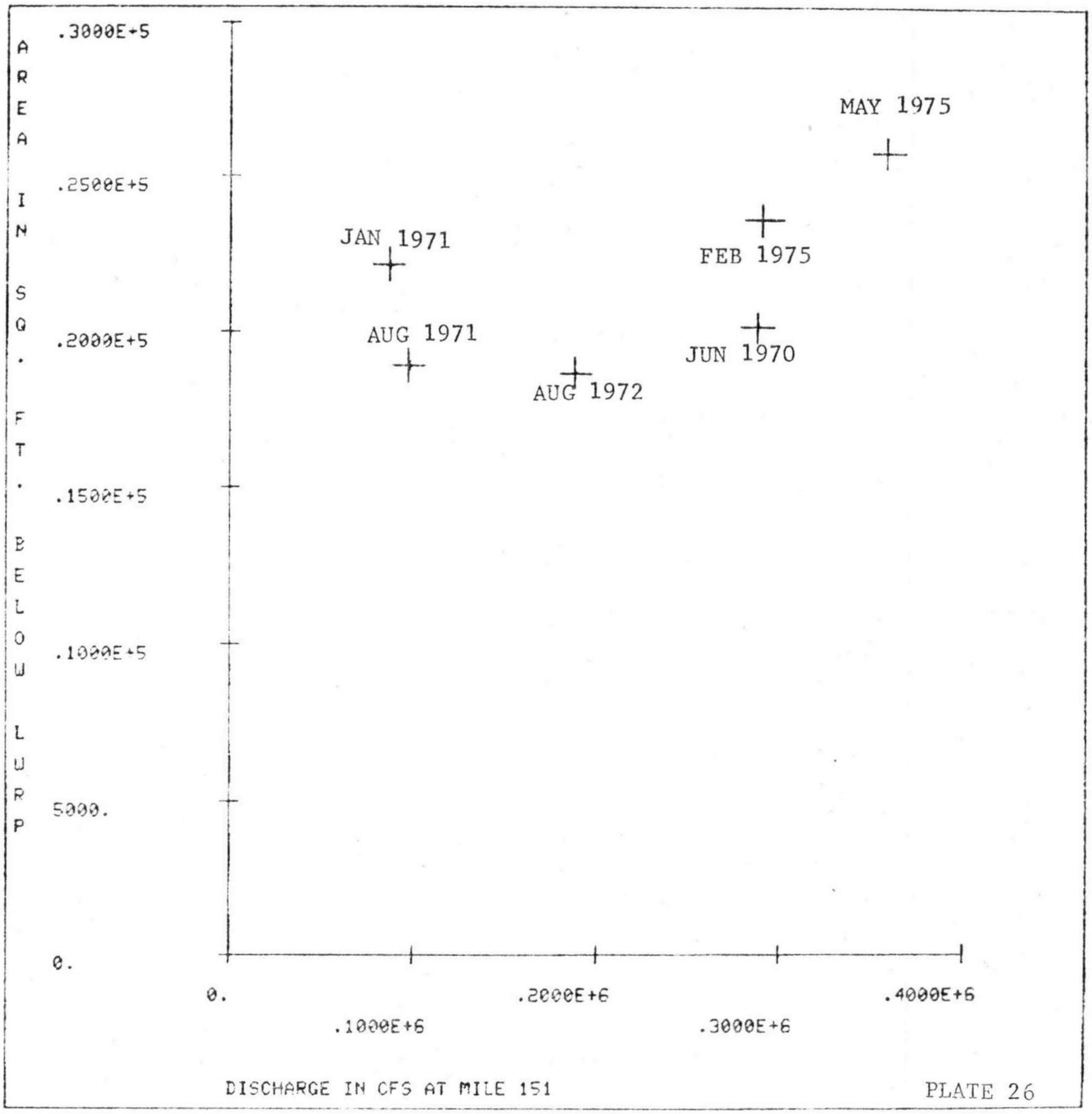

.3000E+5
.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
AREA IN SQ. FT. BELOW LURP
MAY 1975
JAN 1971
FEB 1975
AUG 1971
JUN 1970
AUG 1972
0.
.1000E+6
.2000E+6
.3000E+6
.4000E+6
DISCHARGE IN CFS AT MILE 151

PLATE 26

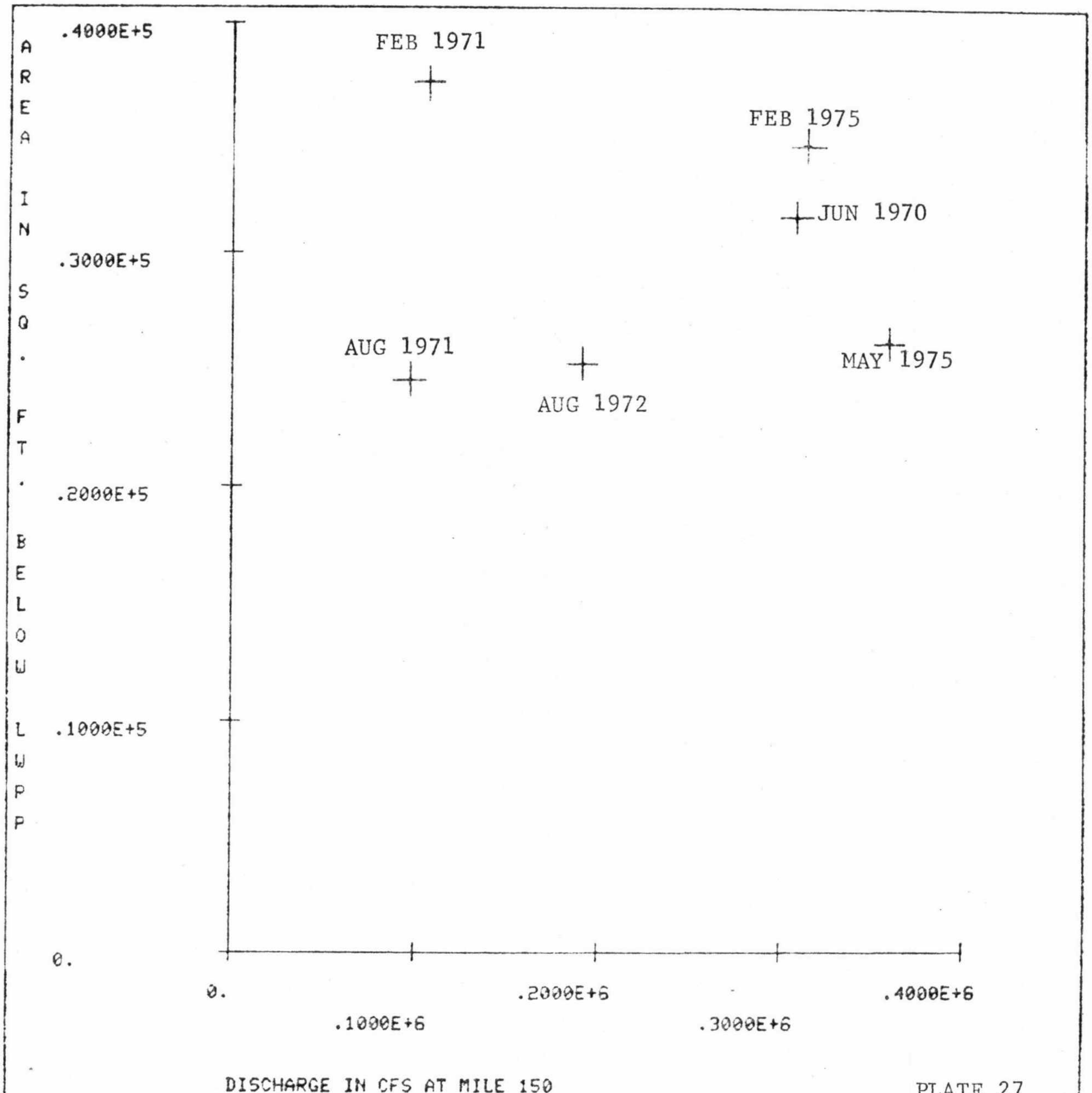

.4000E+5
.3000E+5
.2000E+5
.1000E+5
0.
AREA IN SQ. FT. BELOW LWPP
FEB 1971
FEB 1975
JUN 1970
AUG 1971
AUG 1972
MAY 1975
0.
.1000E+6
.2000E+6
.3000E+6
.4000E+6
DISCHARGE IN CFS AT MILE 150

PLATE 27

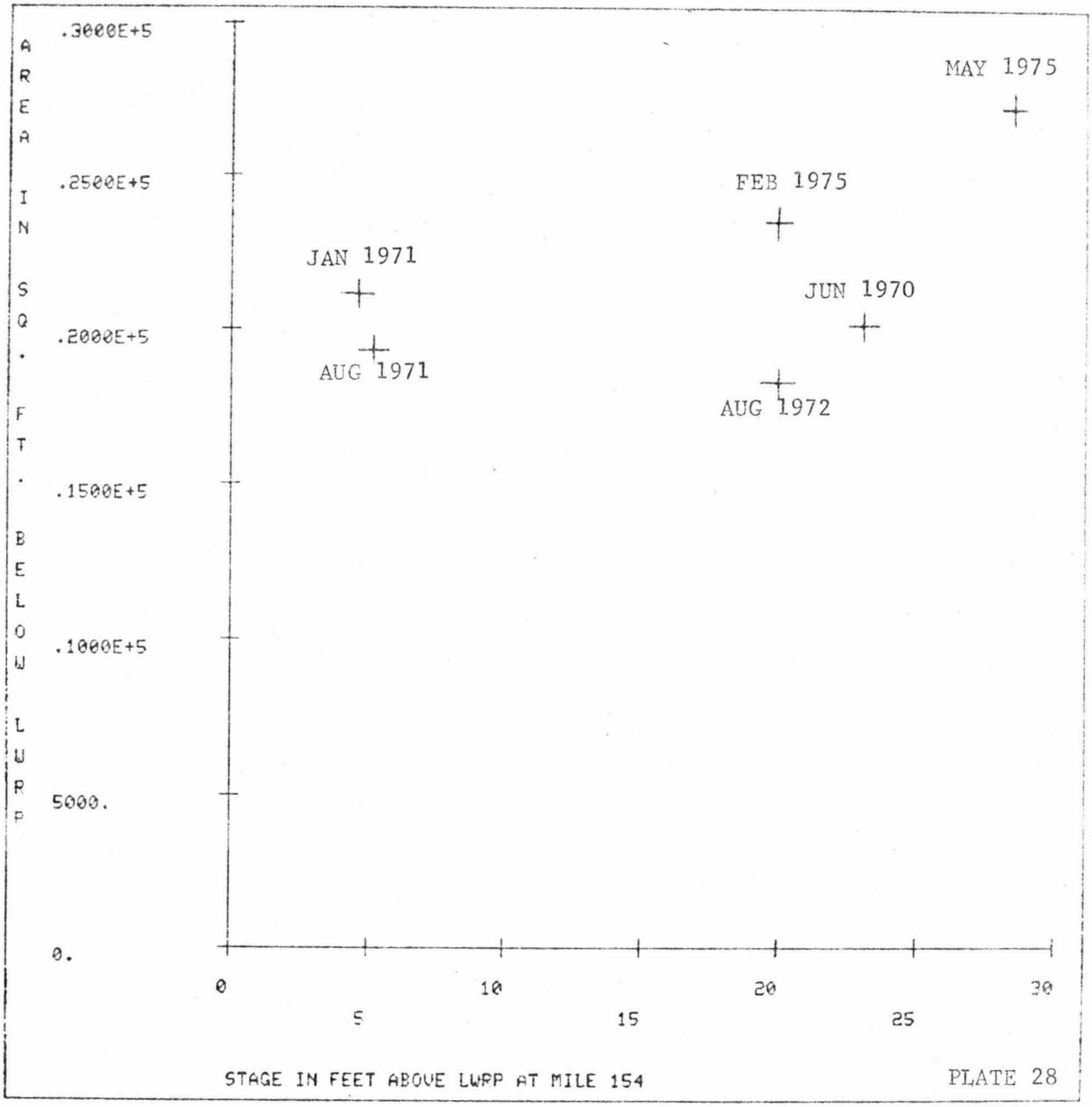

.3000E+5
.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
AREA IN SQ. FT. BELOW LWRP
MAY 1975
FEB 1975
JAN 1971
JUN 1970
AUG 1971
AUG 1972
0
5
10
15
20
25
30
STAGE IN FEET ABOVE LWRP AT MILE 154

PLATE 28

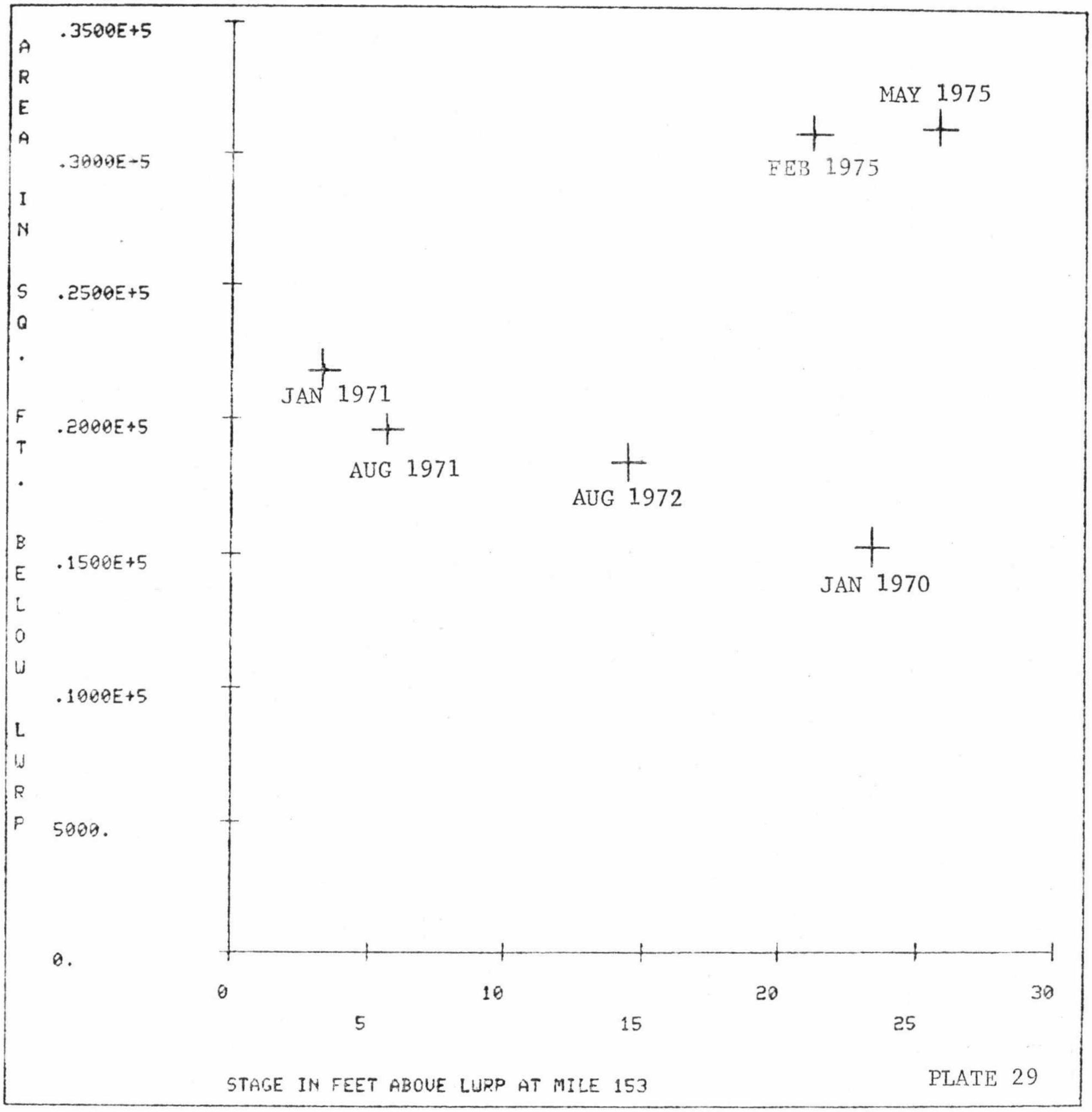

AREA IN SQ. FT. BELOW LWRP
.3500E+5
.3000E-5
.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
0
5
10
15
20
25
30
STAGE IN FEET ABOVE LWRP AT MILE 153
MAY 1975
FEB 1975
JAN 1971
AUG 1971
AUG 1972
JAN 1970

PLATE 29

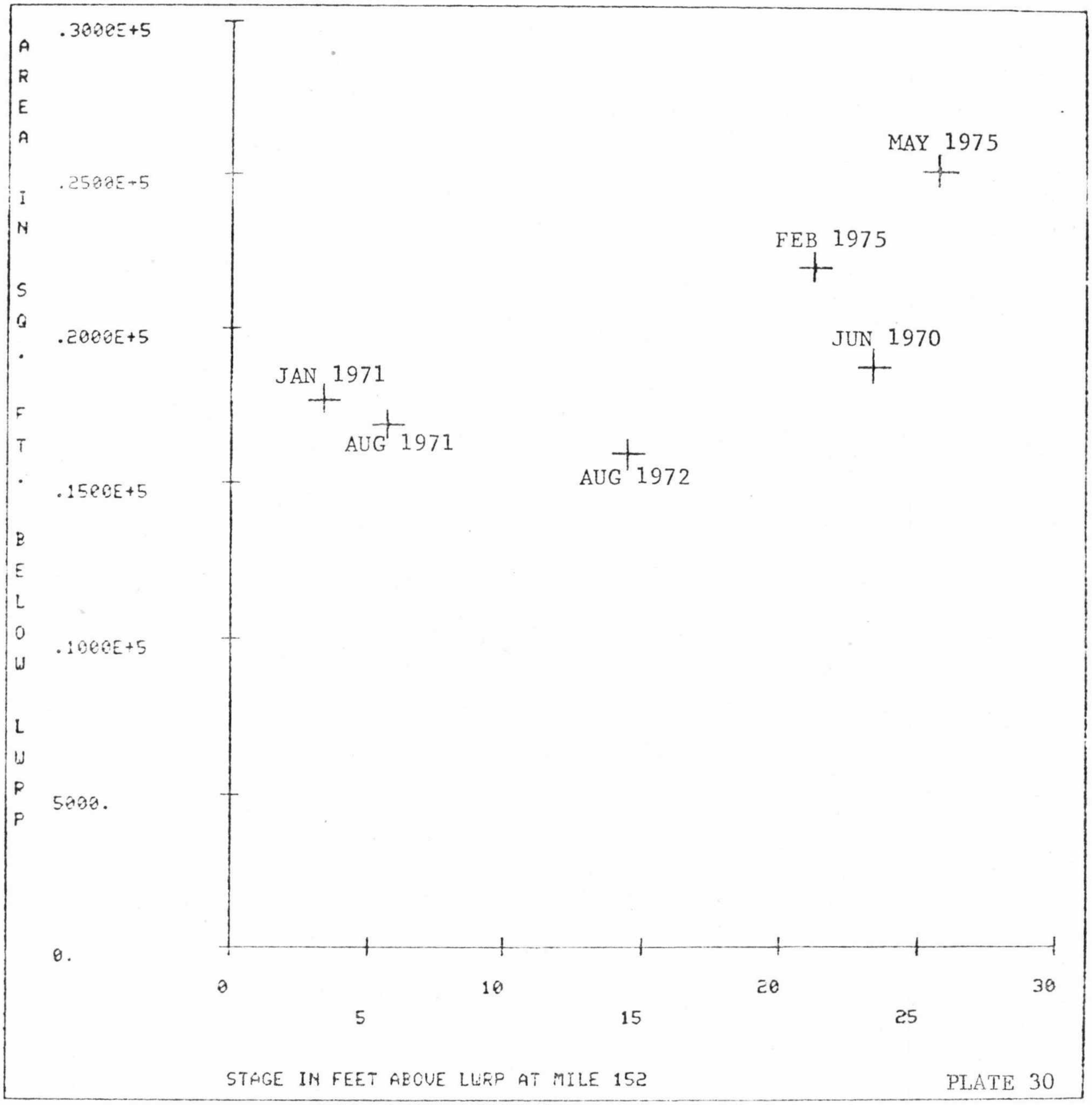
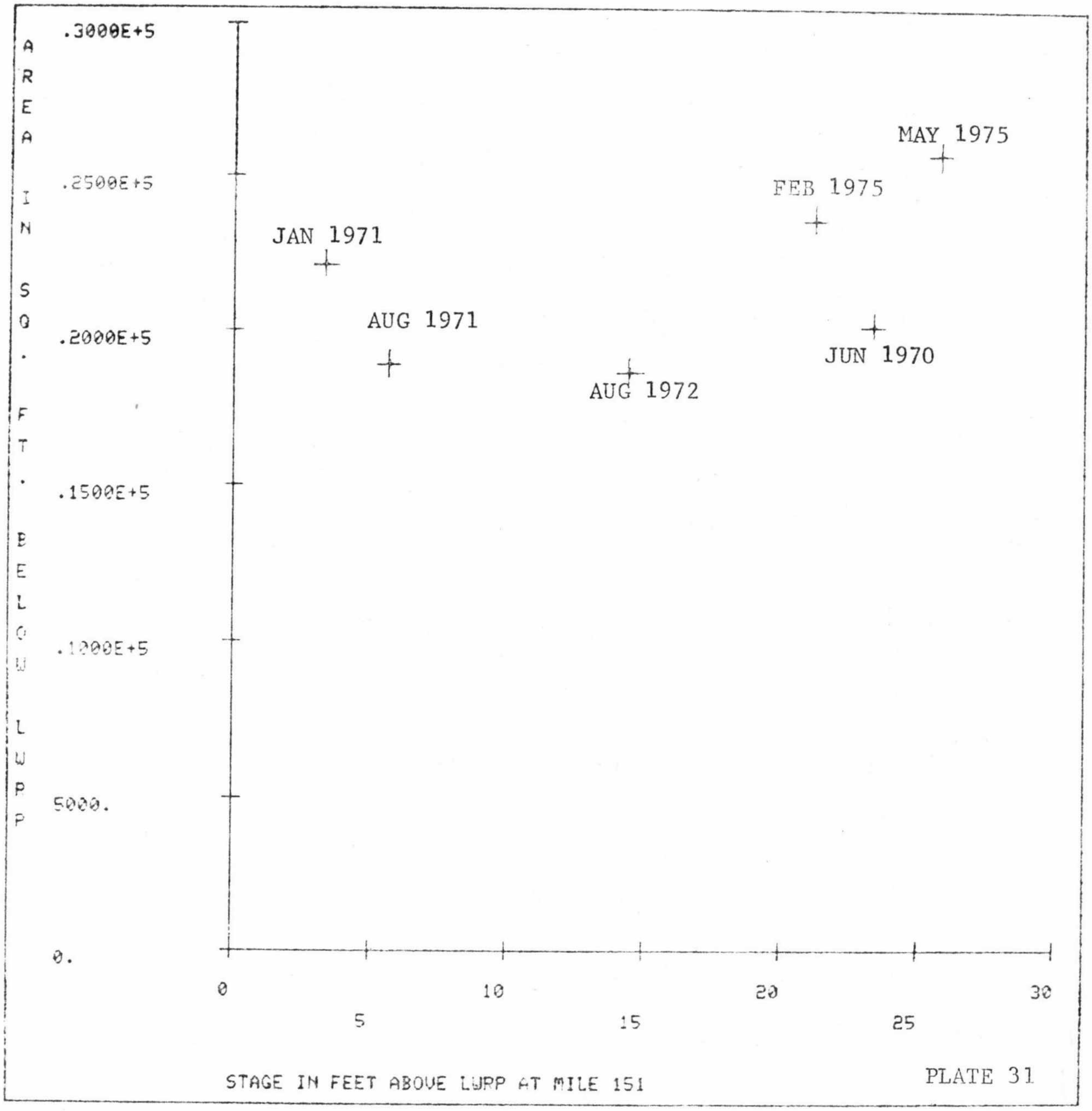
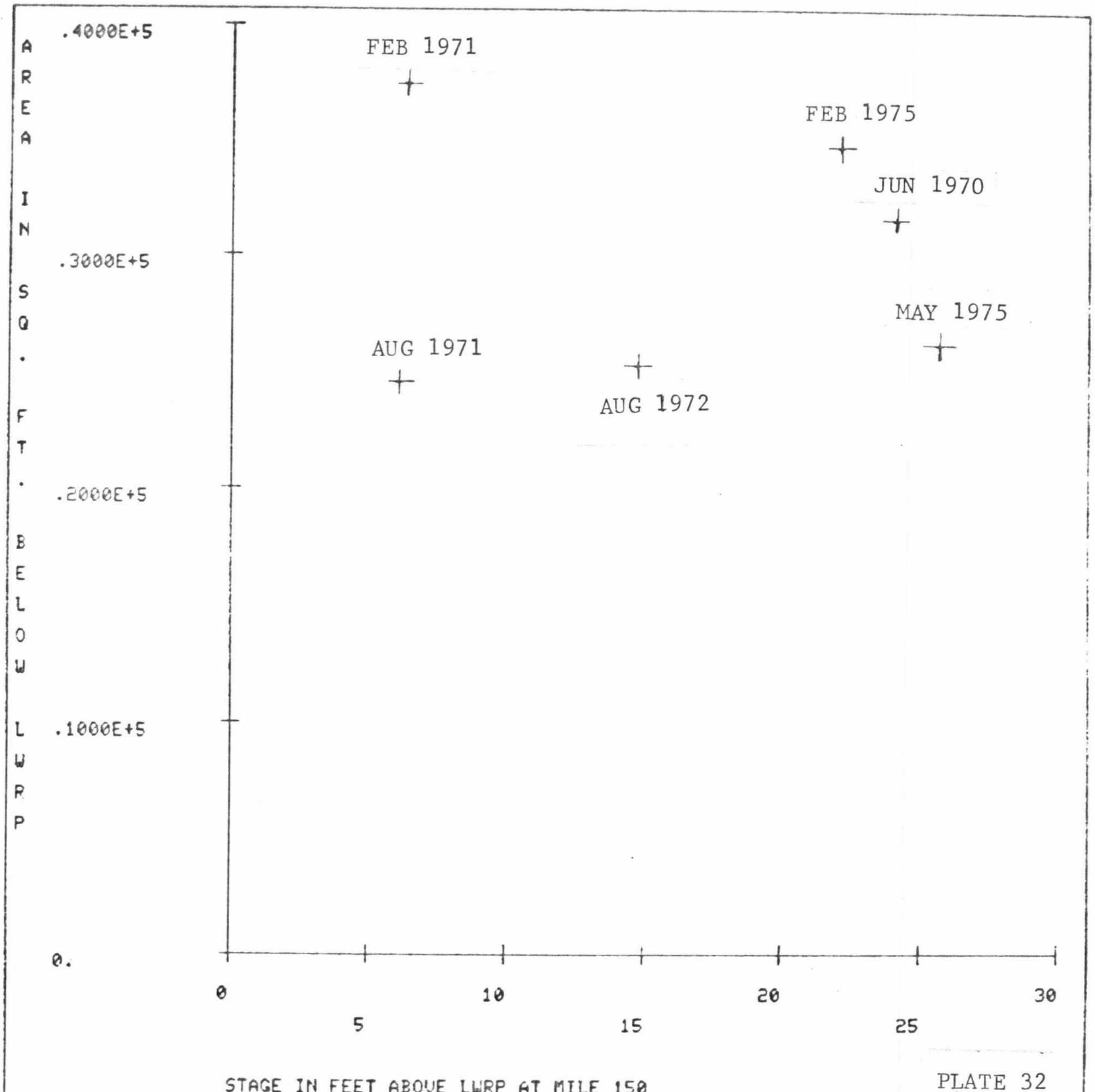

AREA IN SQ. FT. BELOW LWPP
.3000E+5
.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
MAY 1975
FEB 1975
JUN 1970
JAN 1971
AUG 1971
AUG 1972
0
5
10
15
20
25
30
STAGE IN FEET ABOVE LWRP AT MILE 152

PLATE 30



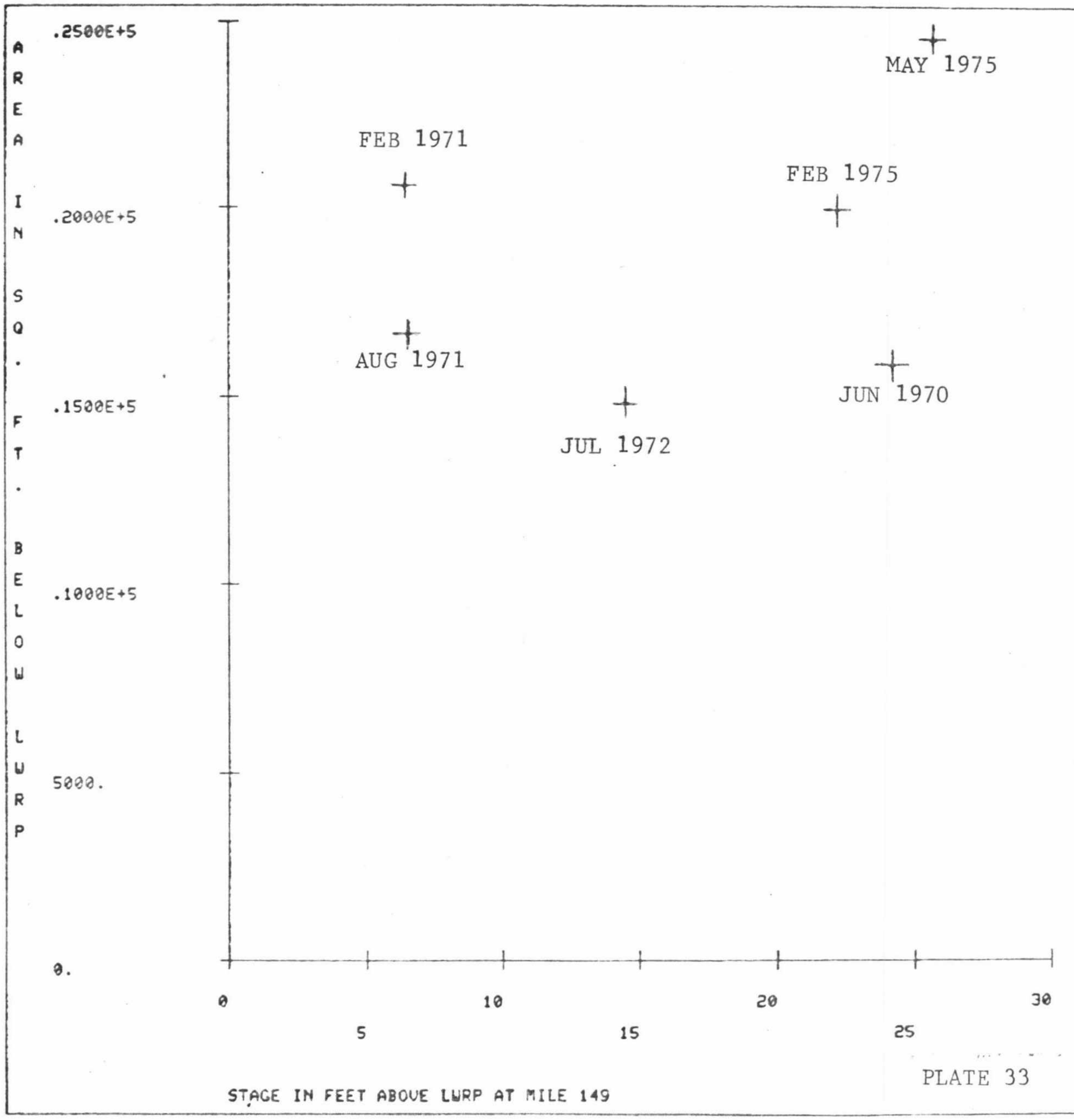
AREA IN SQ. FT. BELOW LWPP
.3000E+5
.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
JAN 1971
AUG 1971
AUG 1972
FEB 1975
MAY 1975
JUN 1970
0
5
10
15
20
25
30
STAGE IN FEET ABOVE LWPP AT MILE 151

PLATE 31



AREA IN SQ. FT. BELOW LWRP
.4000E+5
.3000E+5
.2000E+5
.1000E+5
0.
FEB 1971
FEB 1975
JUN 1970
MAY 1975
AUG 1971
AUG 1972
0
5
10
15
20
25
30
STAGE IN FEET ABOVE LWRP AT MILE 150

PLATE 32



.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
AREA IN SQ. FT. BELOW LWRP
MAY 1975
FEB 1971
FEB 1975
AUG 1971
JUN 1970
JUL 1972
0
5
10
15
20
25
30
STAGE IN FEET ABOVE LWRP AT MILE 149

PLATE 33

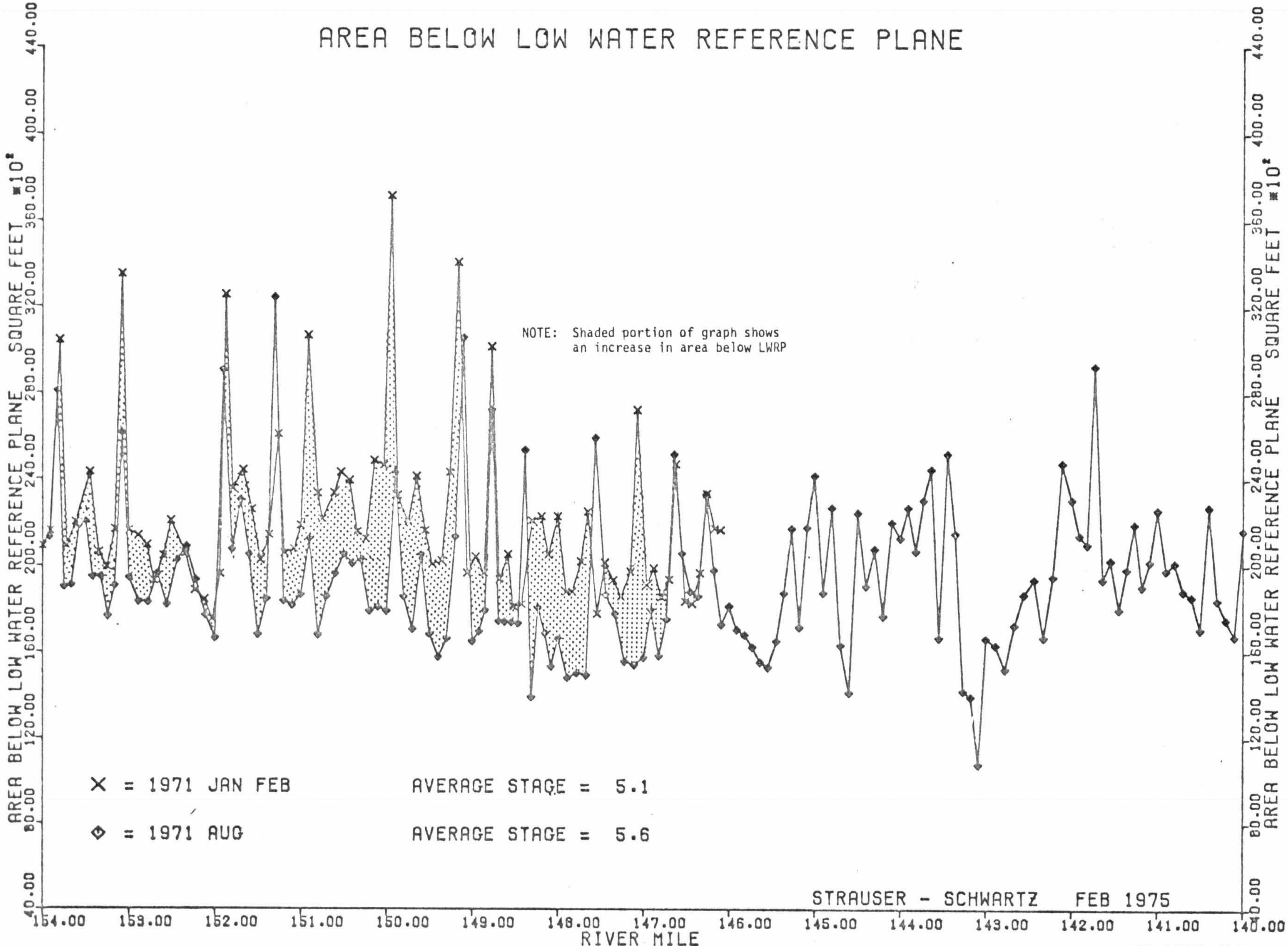

AREA BELOW LOW WATER REFERENCE PLANE
AREA BELOW LOW WATER REFERENCE PLANE SQUARE FEET *10²
40.00
80.00
120.00
160.00
200.00
240.00
280.00
320.00
360.00
400.00
440.00
NOTE: Shaded portion of graph shows an increase in area below LWRP
X = 1971 JAN FEB
AVERAGE STAGE = 5.1
◇ = 1971 AUG
AVERAGE STAGE = 5.6
STRAUSER - SCHWARTZ FEB 1975
154.00
153.00
152.00
151.00
150.00
149.00
148.00
147.00
146.00
145.00
144.00
143.00
142.00
141.00
140.00
RIVER MILE

PLATE 34

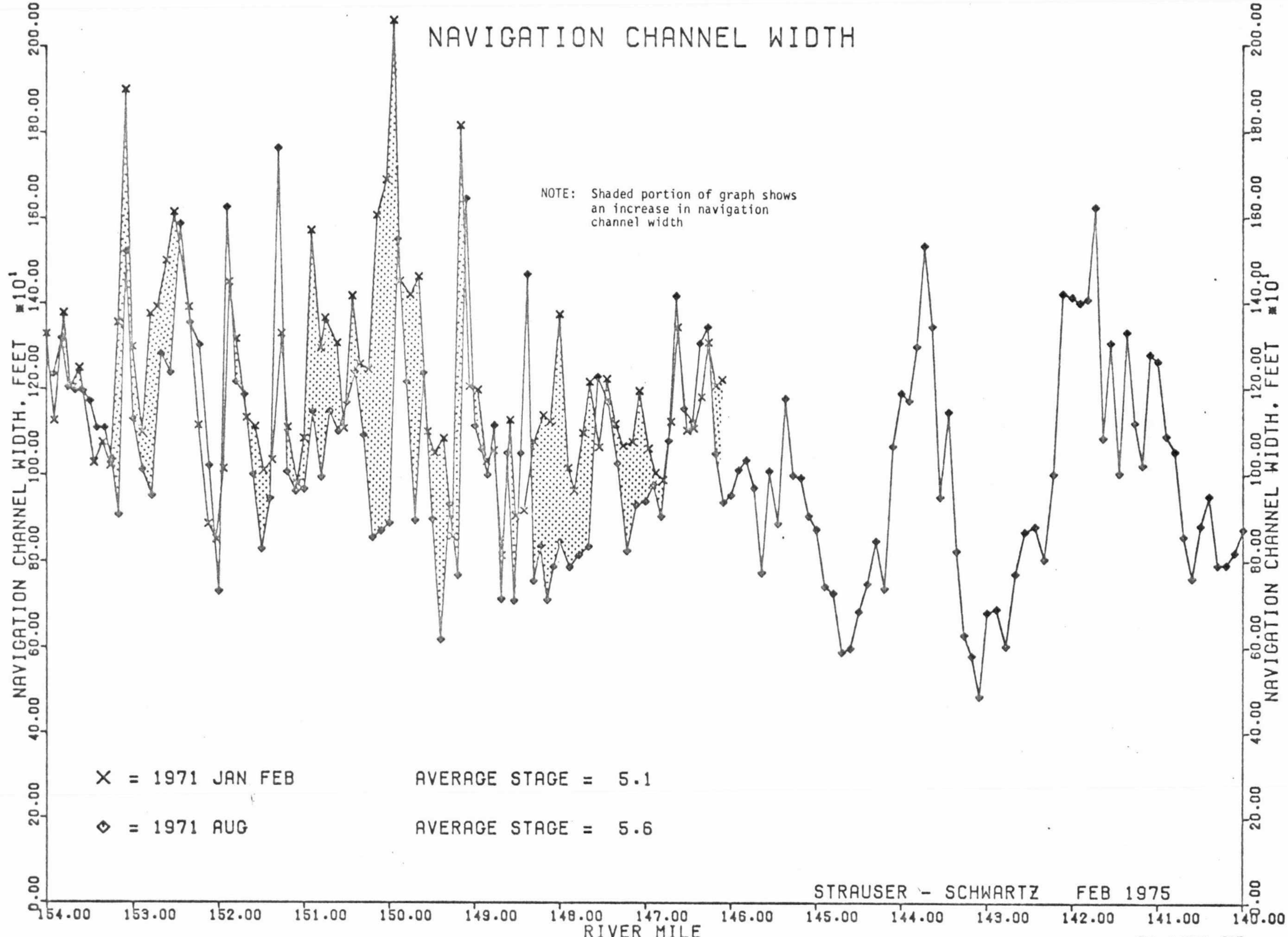

NAVIGATION CHANNEL WIDTH
NOTE: Shaded portion of graph shows an increase in navigation channel width
NAVIGATION CHANNEL WIDTH, FEET ×10¹
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
180.00
200.00
× = 1971 JAN FEB
AVERAGE STAGE = 5.1
◇ = 1971 AUG
AVERAGE STAGE = 5.6
STRAUSER - SCHWARTZ FEB 1975
154.00
153.00
152.00
151.00
150.00
149.00
148.00
147.00
146.00
145.00
144.00
143.00
142.00
141.00
140.00
RIVER MILE

PLATE 35

AVERAGE DEPTH BELOW LOW WATER REFERENCE PLANE

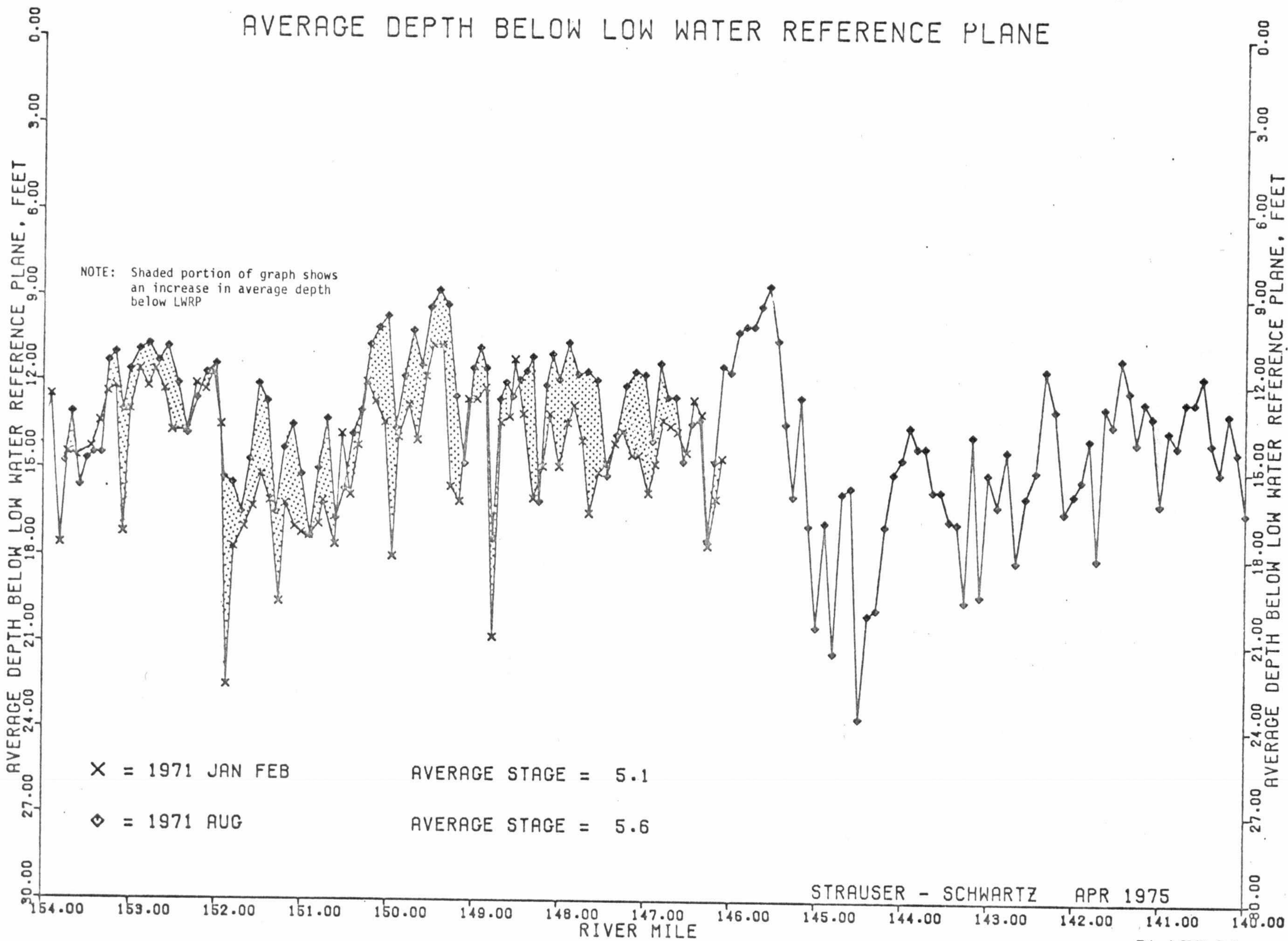
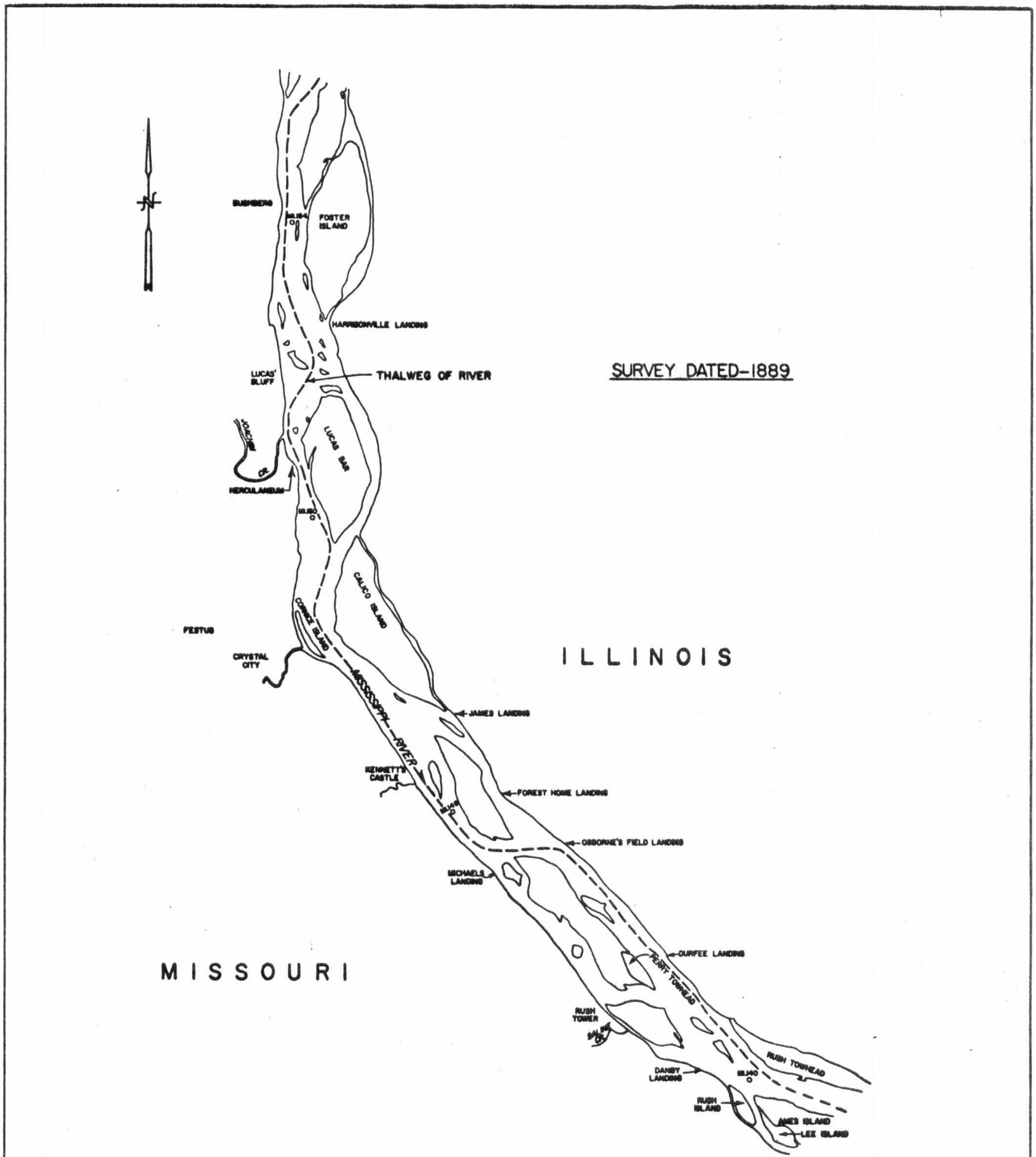


PLATE 36



MISSISSIPPI RIVER
PROTOTYPE REACH
(MILES 154.0 TO 140.0)

Improvement of Mississippi River between Illinois and Ohio Rivers.

Major O. H. Ernst,
Corps of Engineers, U.S. Army.
Officer in Charge.

Details of Hurdles.

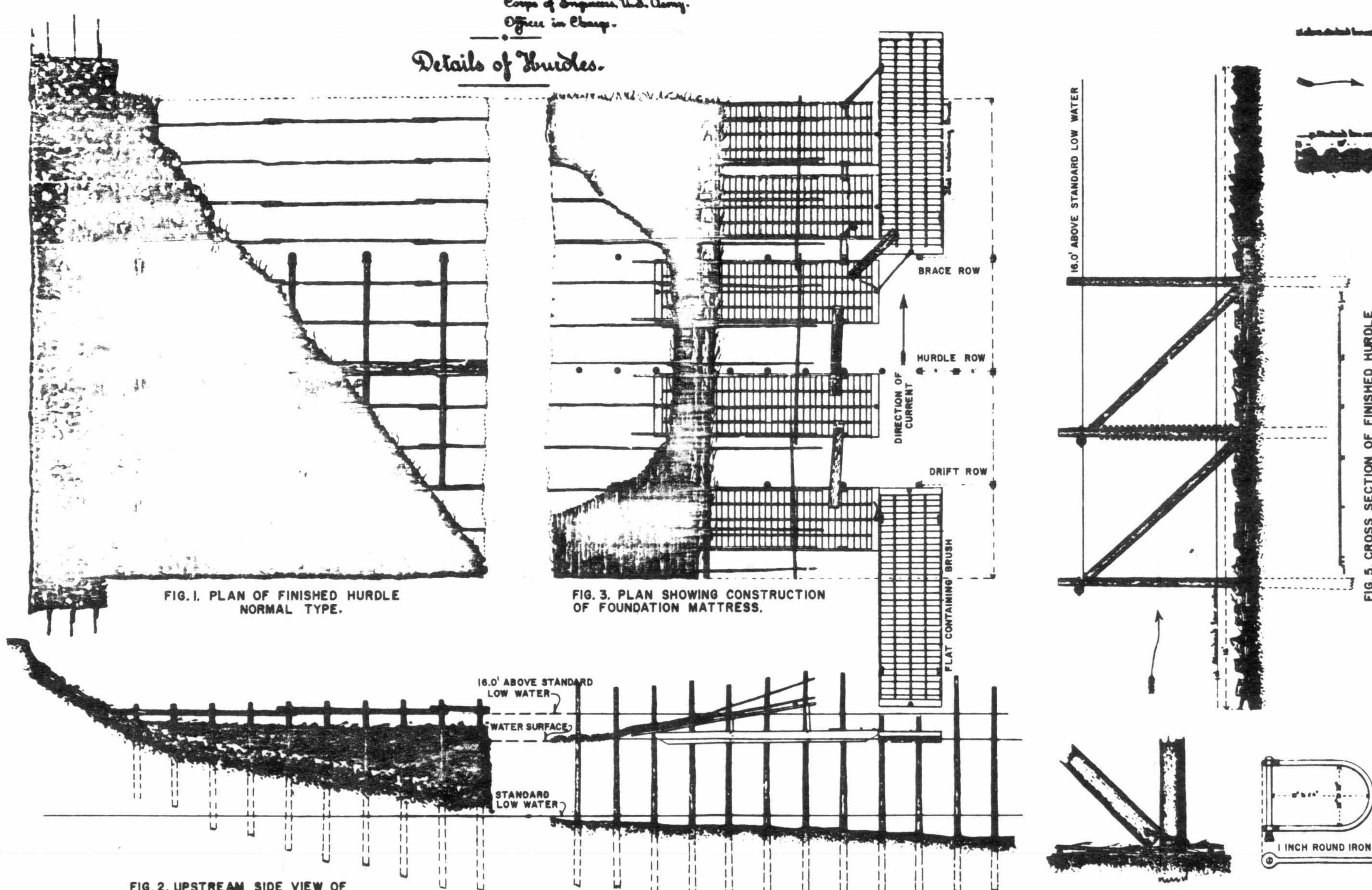


FIG. 1. PLAN OF FINISHED HURDLE NORMAL TYPE.

FIG. 3. PLAN SHOWING CONSTRUCTION OF FOUNDATION MATTRESS.

FIG. 2. UPSTREAM SIDE VIEW OF FINISHED HURDLE NORMAL TYPE

FIG. 4. UPSTREAM SIDE VIEW OF FOUNDATION MATTRESS UNDER CONSTRUCTION.

FIG. 5. CROSS SECTION OF FINISHED HURDLE NORMAL TYPE.

FIG. 8. CLEVIS FOR SECURING THE FOOT OF BRACE-PILES

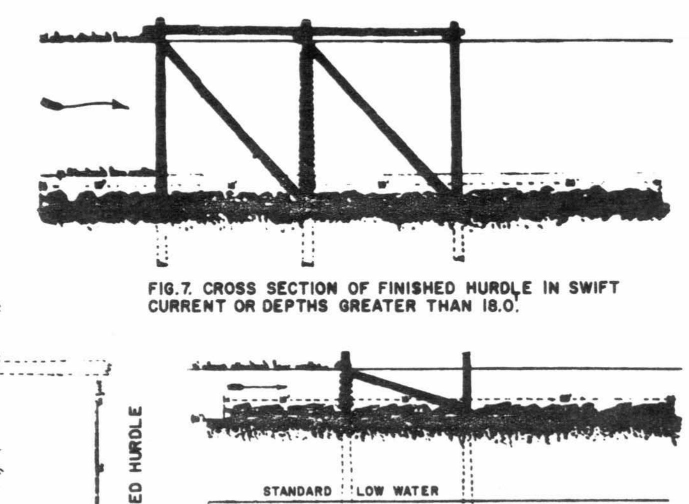


FIG. 7. CROSS SECTION OF FINISHED HURDLE IN SWIFT CURRENT OR DEPTHS GREATER THAN 18.0'.

FIG. 6. CROSS SECTION OF HURDLE IN DEPTH OF FROM 3.0' TO 6.0'.

NOTES

The hurdles are built to the surface of the water unless the latter be lower than the plane 16' above standard low water, in which case they are built to the uniform height of 16' above standard low water. Their forms of construction vary somewhat with the depth of water at the 16' standard stage.

Figures 1, 2 and 3 show the normal types.

For depths of 15' or more, the distance between the rows of piles is about equal to the depth of water. For example, in a depth of 15', the distance between rows is 15' as shown in drawings, for depths less than 15', the distance is constant and is kept at 15', except next the shore. In the latter case and in other cases of sudden and brief shoaling no change is made in the distance generally employed in that particular hurdle.

For depths of 3' to 6' only two rows of piles are used as shown in Fig. 6.

For depths of 3' or less only one row of piles is used.

For depths of 0', or over a dry bar, no piles are used, but the foundation mattress 38' wide is laid upon the bars surface and well ballasted with stone, except when the bar is already protected by a natural growth of willows.

For depths of over 18' or for less depths than where the current is very swift, cross stringers are used to brace together the tops of the piles in the three rows as shown in Fig. 7.

The foundation mattress is 35' wide where there are two rows of piles or less. Where there are three rows, the width of the mattress depends upon the distance between the rows, it extends 15' above the upstream row, and 25' below the downstream row, making its total width 76' in a depth of 18' as shown in drawings.

Wattling must be placed in horizontal layers. Depressions in the bottom are first filled, and then the wattling is carried up in horizontal courses extending from one end of the hurdle to the other.

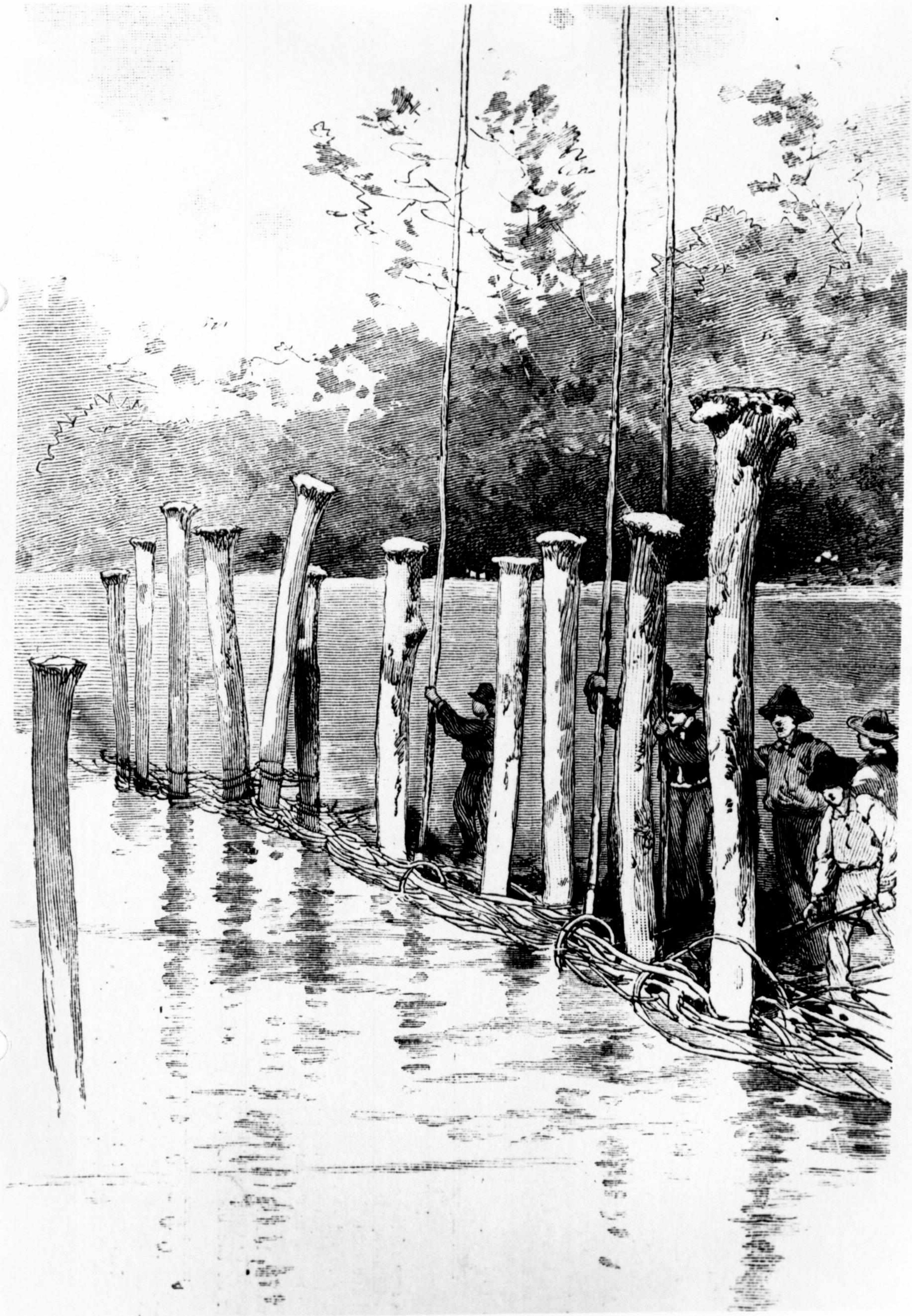
When a hurdle crosses a depth of over 15' the wattling will not at first be carried to the tops of the piles. It will be placed to a height about 8' above standard low water, and then be left until the hurdle shall be reinforced by deposits, after which it may be continued up to the full height.

The depth to which piles are driven should as a rule exceed the depth of water.

In most cases the bank near the shore end of a hurdle should be protected for a distance of about 100' above and 100' below the axis of the hurdle, the protection extending to the full height of the graded bank.

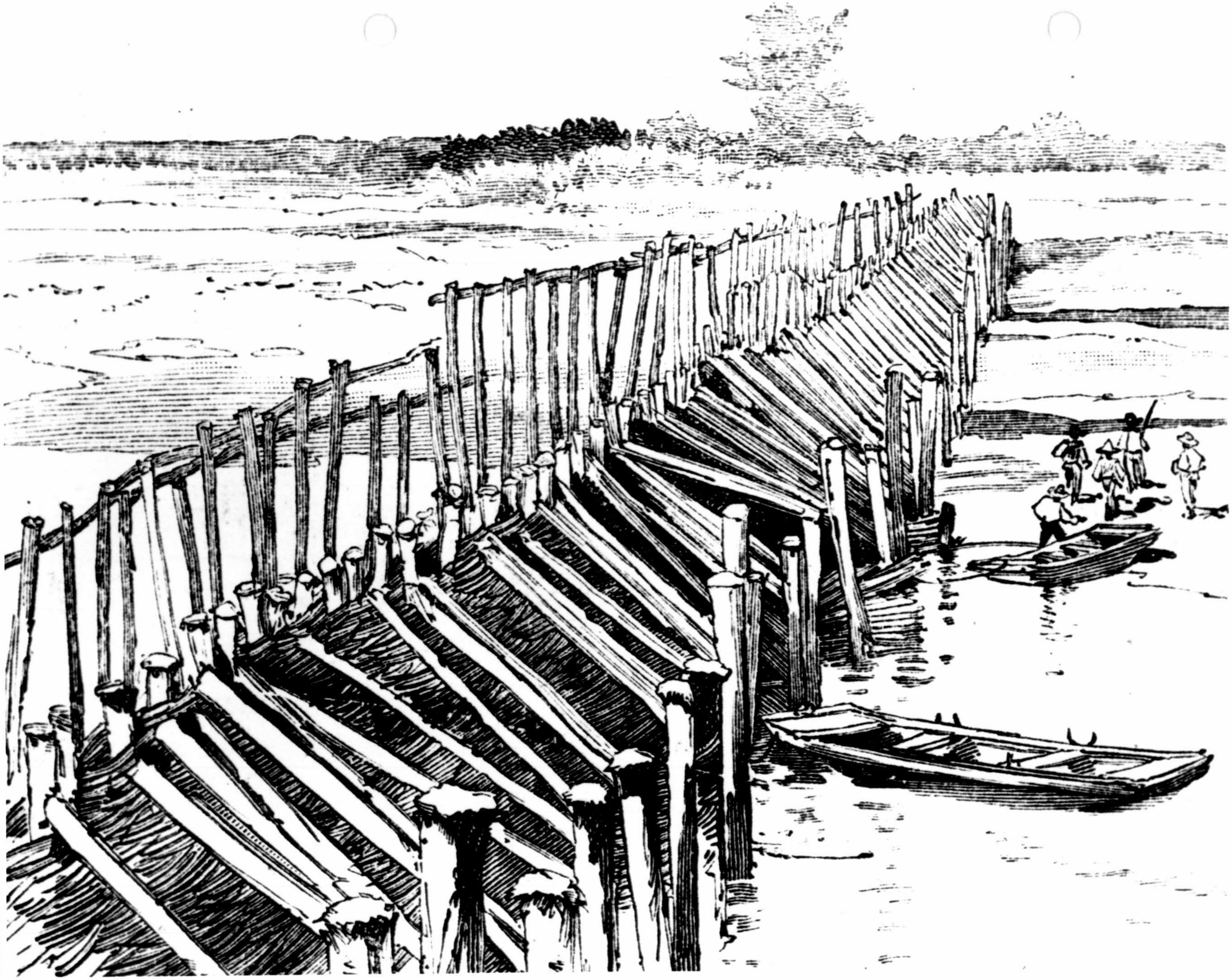
The construction of the hurdle should begin at the shore and progress continuously outward.

U.S. ENGINEER OFFICE, ST. LOUIS, MO. MARCH, 1885



Courtesy of: State Historical Society of Missouri

Plate 39



Courtesy of: State Historical Society of Missouri

Plate 40

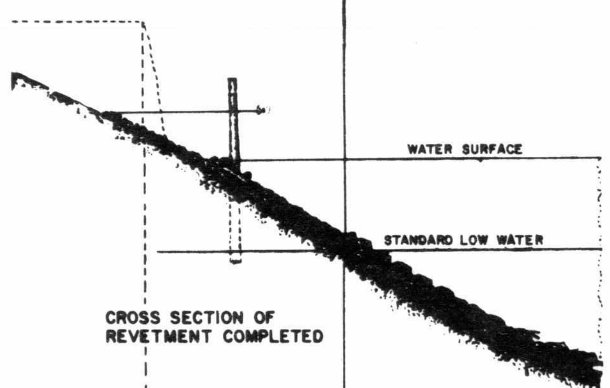
Improvement of Mississippi River between Illinois and Ohio Rivers.

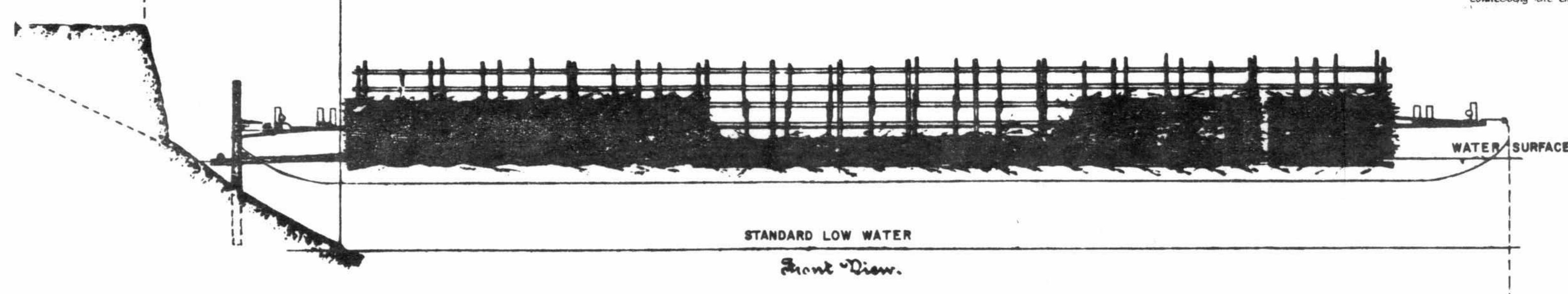
Major O. H. Ernst,
Corps of Engineers, U.S. Army.
Officer in Charge.

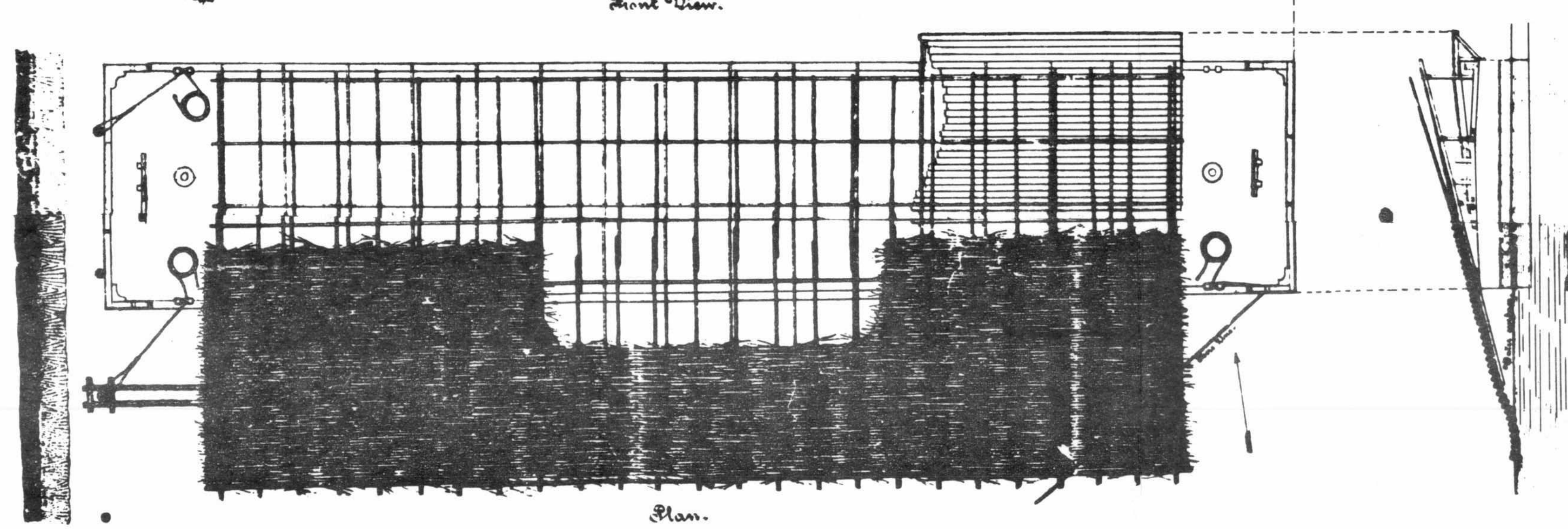
Bank Protection.

Below Missouri River.

U. S. Engineer Office, St. Louis, Mo. March 1883.







NOTES

Mattress to be 120' wide, woven upon 25 continuous poles 5' apart. Poles to be securely spliced with wire tightened by rack-sticks, the ends of poles overlapping about 4', with three 6" spikes driven through the overlap.

In moderate depths and velocities the mattress is launched and sunk progressively, and its length is unlimited. In great depths and velocities the length should not exceed 1000'.

Guide piles 15' apart to be driven upon a line distant 15' horizontally from standard low water mark. Standard low water is 4' above low water of 1863.

Shore edge of mattress after sinking should be about 15' outside of line of piles.

To hole it ready for this position poles acting both as spars and ties will extend from each guide pile and be secured to mattress. The upstream end of mattress during construction to be held above water surface by a raft or empty barge anchored at right angles to bank.

Stone sufficient to sink mattress and hold it securely in place to be scattered over it. In most cases, one cub. ft. of stone to 15 square feet of mattress is sufficient at which rate a barge load of 300 cu. yds. of stone should sink 1000 linear feet of mattress.

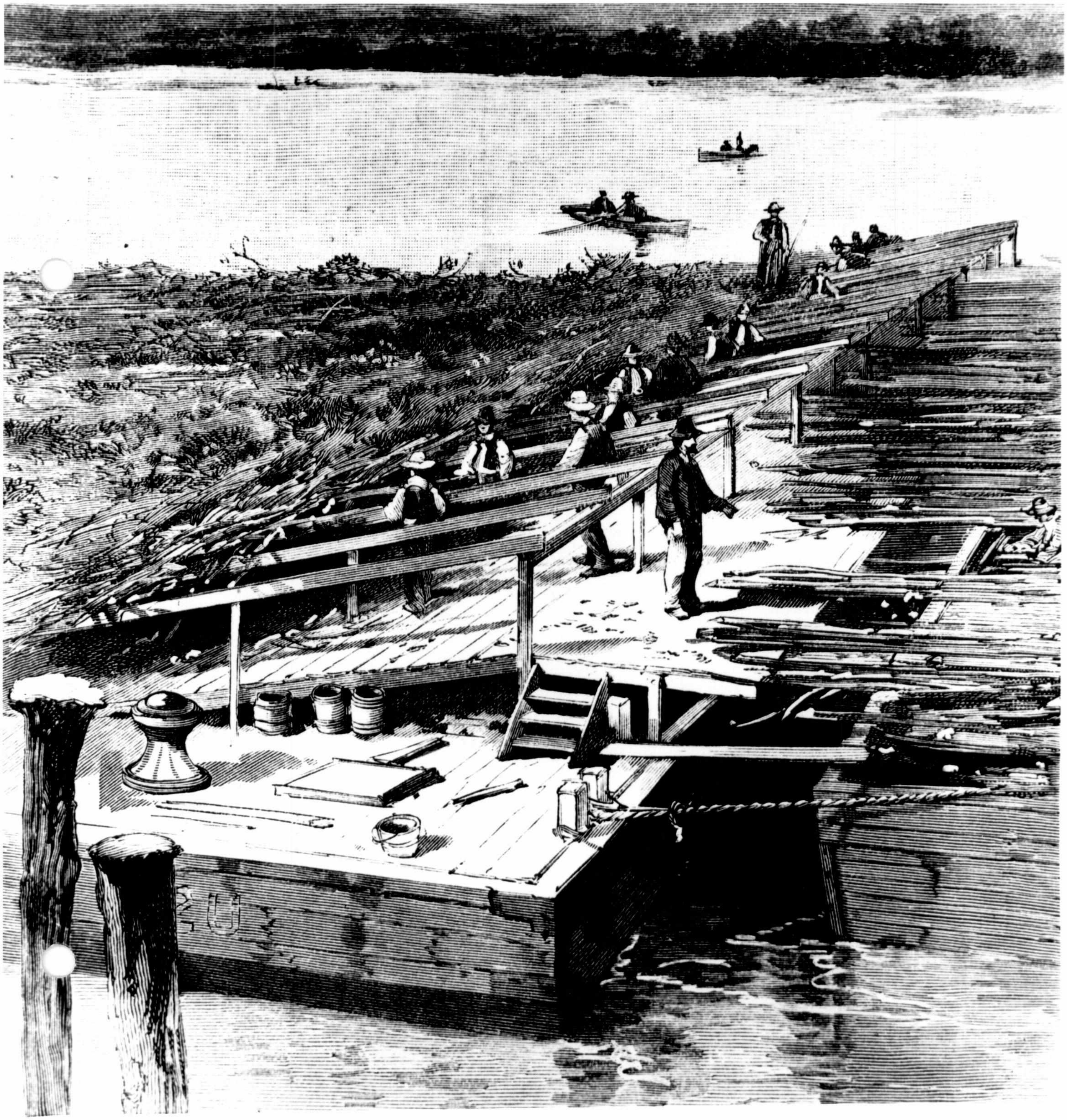
Interval between inner edge of mattress and water surface to be covered with a liberal supply of stone - say 18" thick.

Bank above water surface to be graded to a slope of ½ by hydraulic jet, or by natural action of the river; then to be covered to height of 16' above standard low water with a layer of stone 10" thick.

One mattress having been completed and sunk a new one will be begun overlapping the former by about 25'.

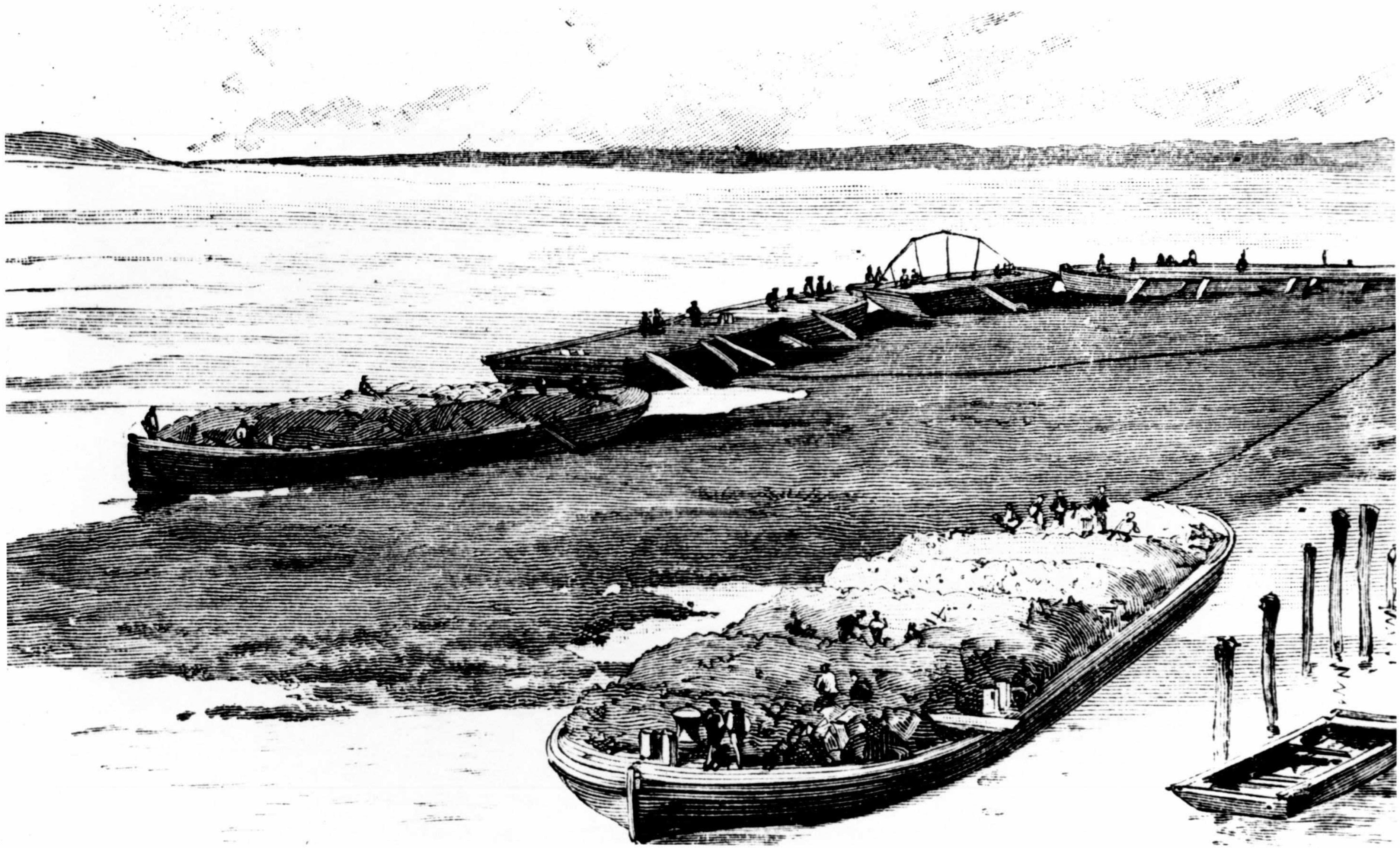
Wattling at beginning of mattress to be secured by two stringers connecting the ends of the poles as a clamp.

Plate 41



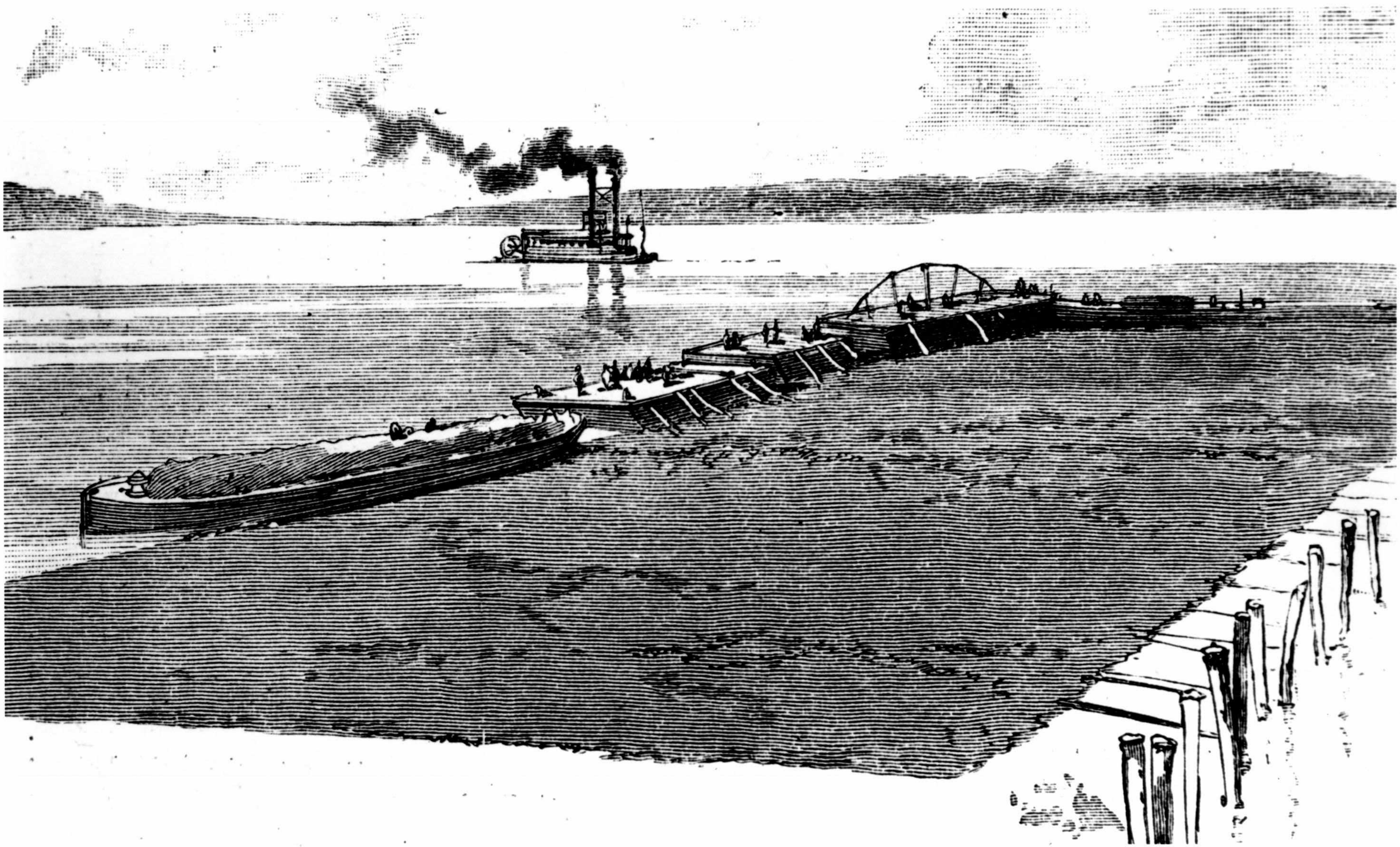
Courtesy of: State Historical Society of Missouri

Plate 42



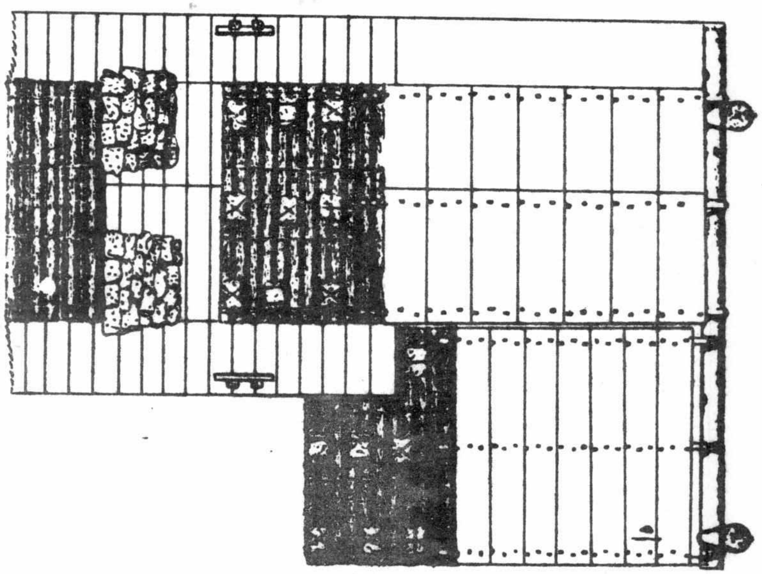
Courtesy of: State Historical Society of Missouri

Plate 43



Courtesy of: State Historical Society of Missouri

Improving Mississippi River between mouths of Ohio and Missouri Rivers.



Plan.

PORTABLE JETTY

used for

concentrating water upon shoals

and

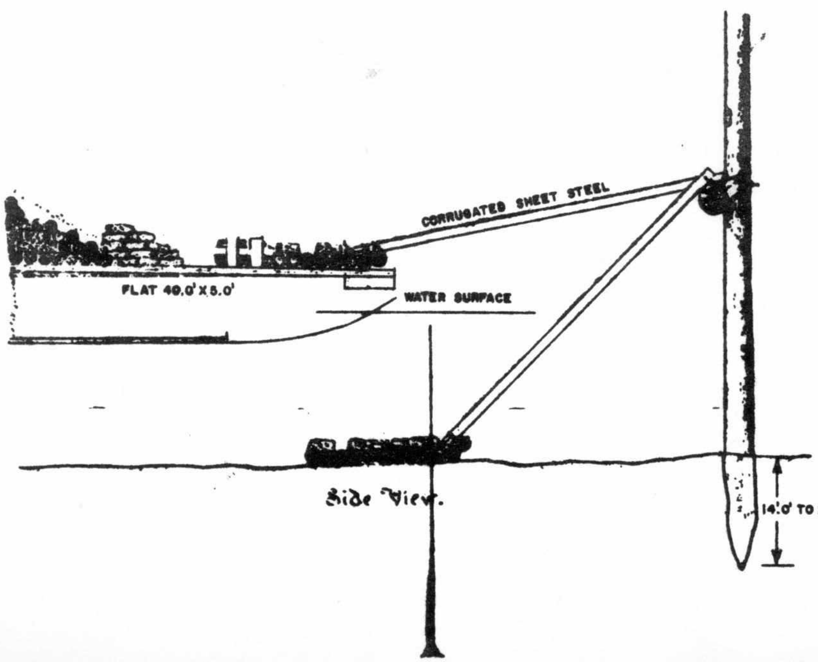
improving low water navigation.

The distance between piles varies from 10' to 20' depending upon depth of water and strength of current. In extreme cases piles may be driven in clumps of 3 each.

Material required for one portable jetty panel.

Medium size

3 - 5 in. I beams, 12.50# per ft. each 16 ft. long.
7 sheets No. 14 U.S. standard gauge corrugated sheet steel, corrugations 2⅔ in. between centers and ½ in. deep. Each 10 ft. x 25⅓ in. 73# per sheet.
63 rivets, 1¼ in. x 5/16 in. 63 washers 3 in. x 2 in. of corrugated No. 14 U.S. standard gauge sheet steel.
6 links of 3/4 round iron. Total weight 1150.



Side View.

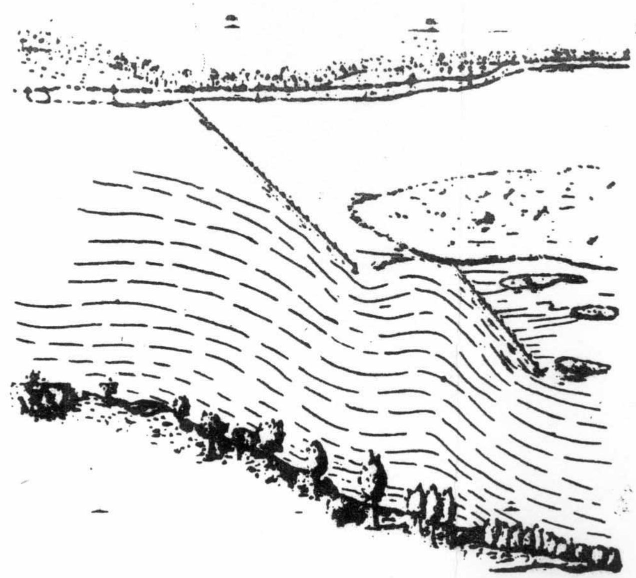


Plate 46

Plate 47

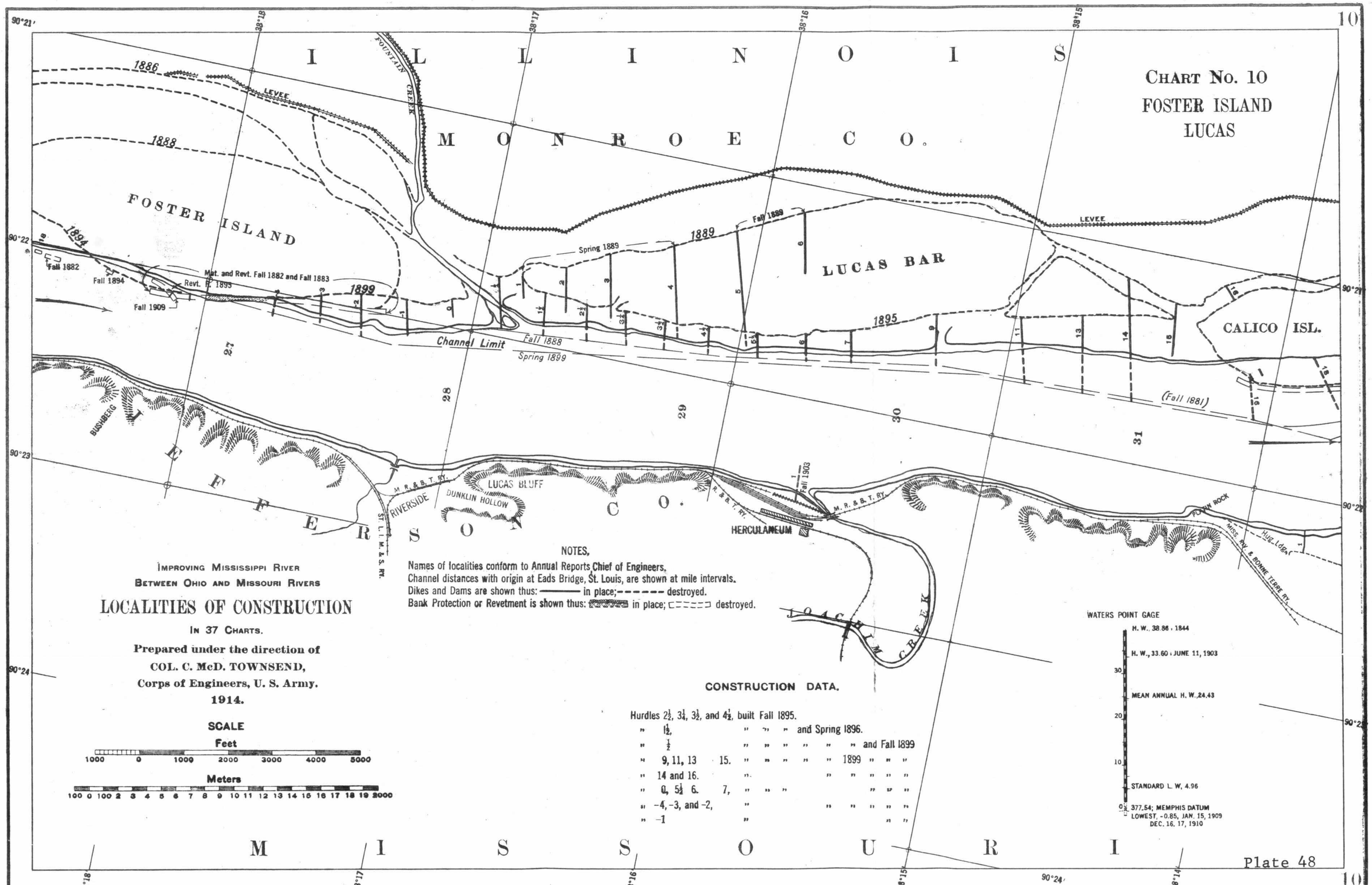


CHART No. 10
FOSTER ISLAND
LUCAS
ILLINOIS
MONROE CO.
FOSTER ISLAND
LUCAS BAR
CALICO ISL.
JEFFERSON CO.
MISSOURI
BUSHBERG
LUCAS BLUFF
DUNKLIN HOLLOW
RIVERSIDE
HERCULANEUM
JOACHIM CREEK
FOUNTAIN CREEK
LEVEE
Channel Limit
Fall 1888
Spring 1899
Spring 1889
Fall 1889
Fall 1881
Mat. and Revt. Fall 1882 and Fall 1883
Fall 1903
Improving Mississippi River
Between Ohio and Missouri Rivers
LOCALITIES OF CONSTRUCTION
In 37 Charts.
Prepared under the direction of
COL. C. McD. TOWNSEND,
Corps of Engineers, U. S. Army.
1914.
SCALE
Feet
Meters
NOTES.
Names of localities conform to Annual Reports Chief of Engineers.
Channel distances with origin at Eads Bridge, St. Louis, are shown at mile intervals.
Dikes and Dams are shown thus: in place; destroyed.
Bank Protection or Revetment is shown thus: in place; destroyed.
CONSTRUCTION DATA.
Hurdles 2½, 3¼, 3½, and 4½, built Fall 1895.
" 1½, " " " and Spring 1896.
" ½ " " " " " and Fall 1899
" 9, 11, 13 15. " " " " 1899 " " "
" 14 and 16. " " " " " "
" 0, 5½ 6. 7, " " " " " "
" -4, -3, and -2, " " " " " "
" -1 " " "
WATERS POINT GAGE
H. W. 38.86 - 1844
H. W., 33.60 - JUNE 11, 1903
MEAN ANNUAL H. W. 24.43
STANDARD L. W. 4.96
377.54; MEMPHIS DATUM
LOWEST, -0.85, JAN. 15, 1909
DEC. 16, 17, 1910
Plate 48

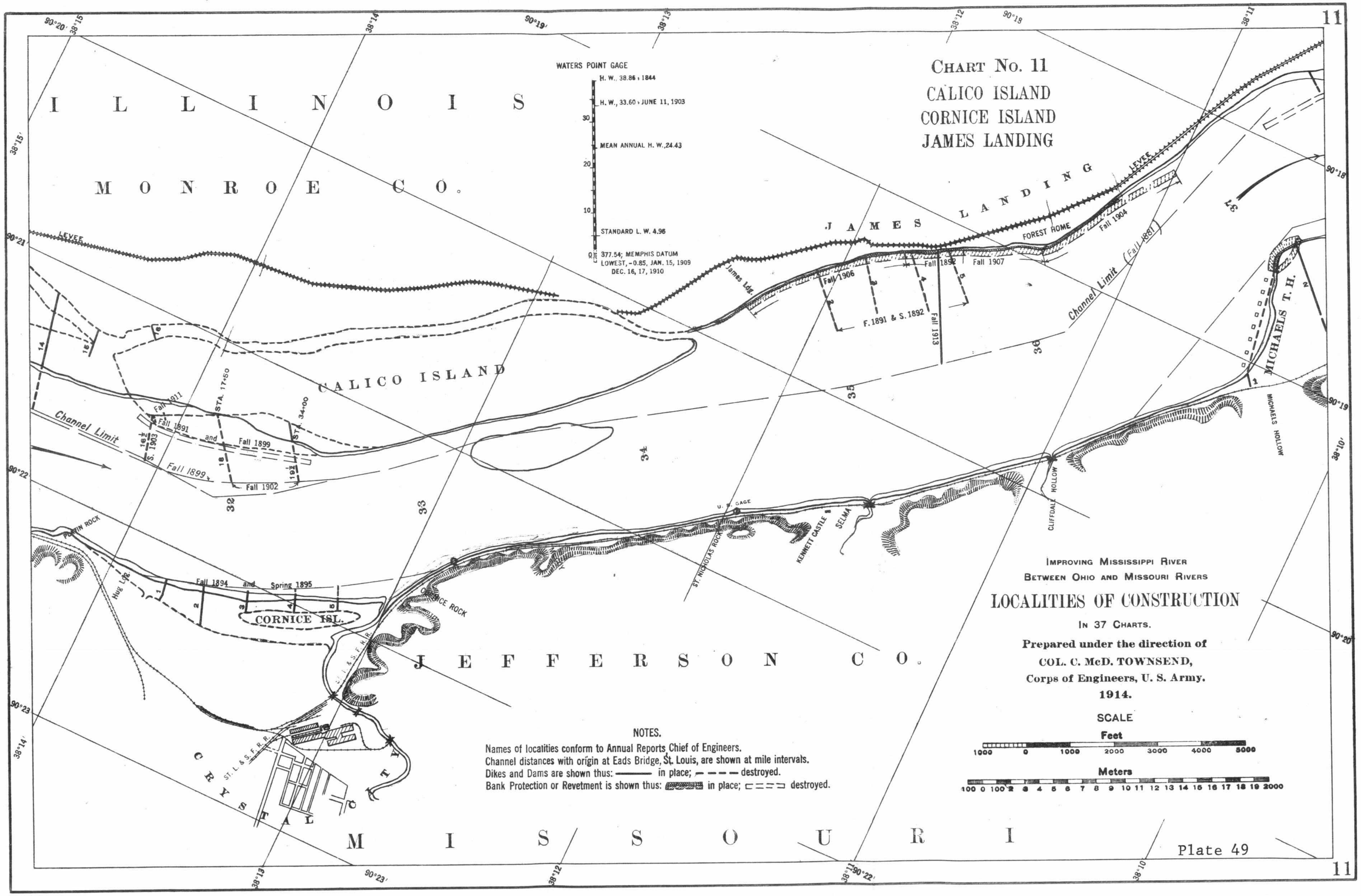


CHART No. 11
CALICO ISLAND
CORNICE ISLAND
JAMES LANDING
ILLINOIS
MONROE CO.
JEFFERSON CO.
MISSOURI
CRYSTAL CITY
CALICO ISLAND
CORNICE ISL.
JAMES LANDING
MICHAELS T.H.
MICHAELS HOLLOW
CLIFFDALE HOLLOW
SELMA
KENNETT CASTLE
ST. NICHOLAS ROCK
FOREST HOME
LEVEE
Channel Limit
WATERS POINT GAGE
H. W. 38.86 : 1844
H. W., 33.60 : JUNE 11, 1903
MEAN ANNUAL H. W. 24.43
STANDARD L. W. 4.96
377.54; MEMPHIS DATUM
LOWEST, -0.85, JAN. 15, 1909
DEC. 16, 17, 1910
IMPROVING MISSISSIPPI RIVER
BETWEEN OHIO AND MISSOURI RIVERS
LOCALITIES OF CONSTRUCTION
IN 37 CHARTS.
Prepared under the direction of
COL. C. McD. TOWNSEND,
Corps of Engineers, U. S. Army.
1914.
SCALE
Feet
Meters
NOTES.
Names of localities conform to Annual Reports Chief of Engineers.
Channel distances with origin at Eads Bridge, St. Louis, are shown at mile intervals.
Dikes and Dams are shown thus: ——— in place; — — — — destroyed.
Bank Protection or Revetment is shown thus: in place; destroyed.
Plate 49

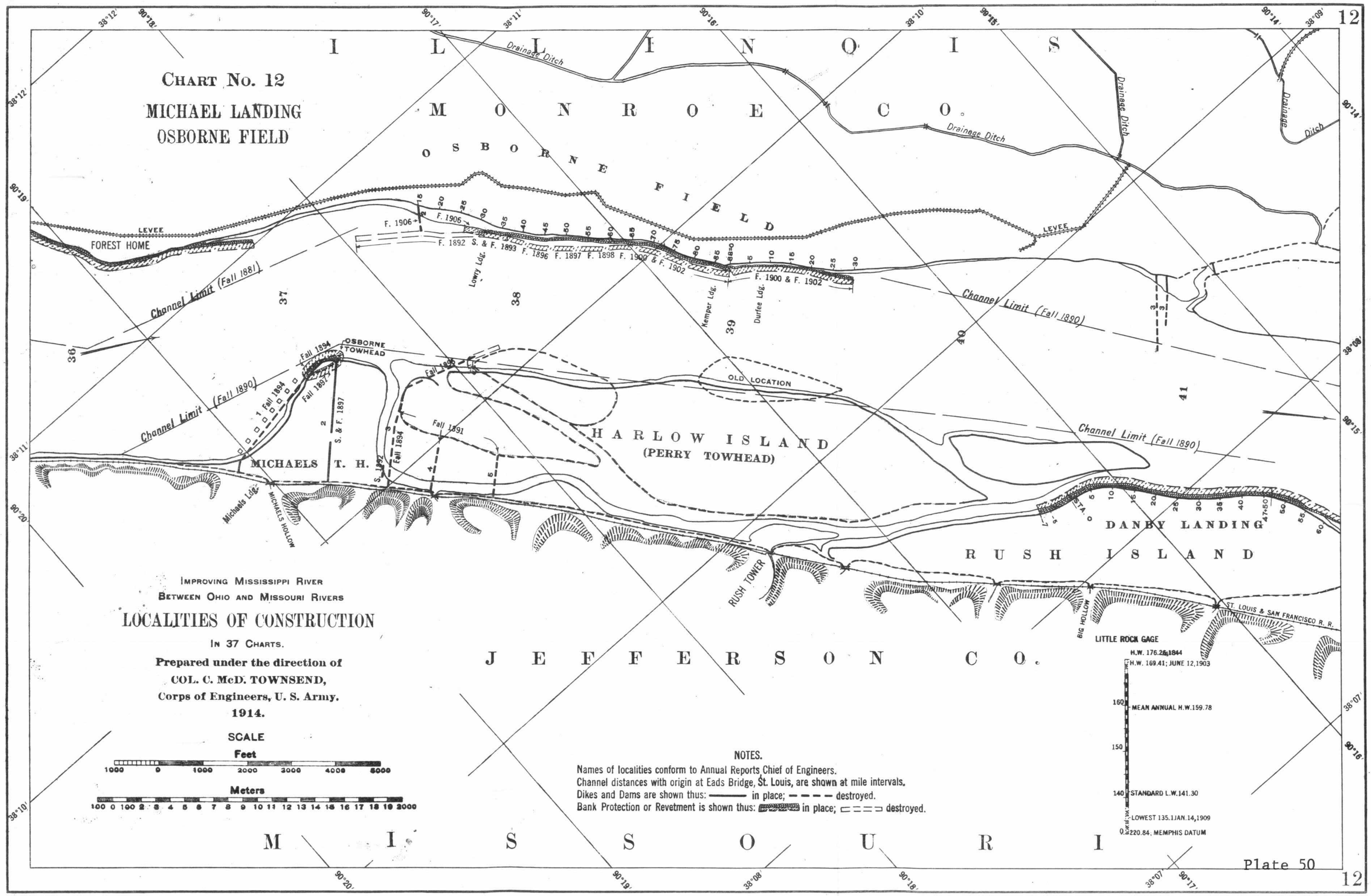
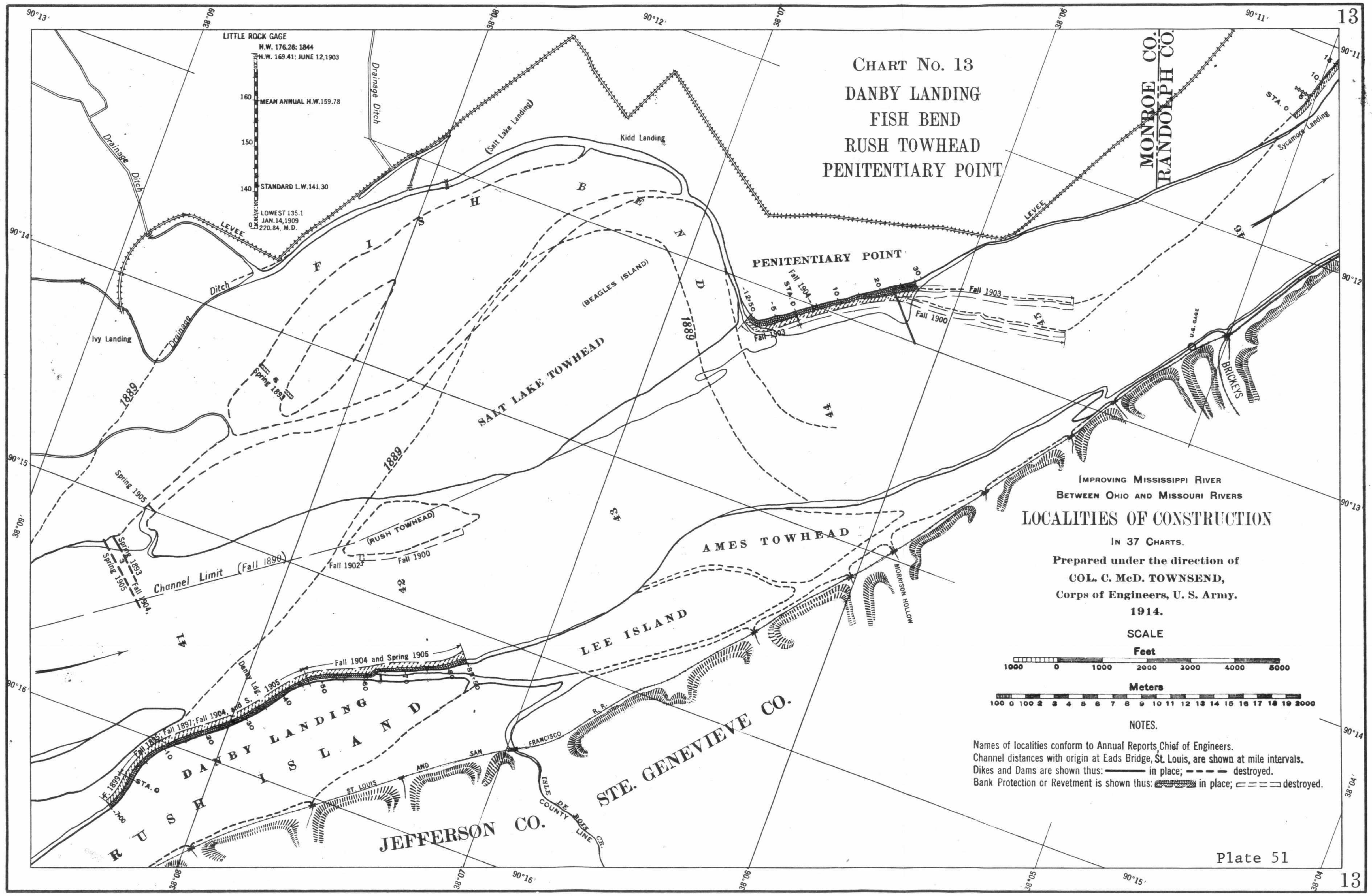


CHART No. 12
MICHAEL LANDING
OSBORNE FIELD
ILLINOIS
MONROE CO.
OSBORNE FIELD
Drainage Ditch
LEVEE
FOREST HOME
Channel Limit (Fall 1881)
Channel Limit (Fall 1890)
F. 1906
F. 1892 S. & F. 1893 F. 1896 F. 1897 F. 1898 F. 1900 & F. 1902
F. 1900 & F. 1902
Lowry Ldg.
Kemper Ldg.
Durfee Ldg.
36
37
38
39
40
41
OSBORNE TOWHEAD
Fall 1894
Fall 1897
S. & F. 1897
S. 1892
Fall 1891
Fall 1895
OLD LOCATION
HARLOW ISLAND
(PERRY TOWHEAD)
MICHAELS T. H.
Michaels Ldg.
MICHAELS HOLLOW
RUSH TOWER
RUSH ISLAND
DANBY LANDING
BIG HOLLOW
ST. LOUIS & SAN FRANCISCO R. R.
JEFFERSON CO.
MISSOURI
IMPROVING MISSISSIPPI RIVER
BETWEEN OHIO AND MISSOURI RIVERS
LOCALITIES OF CONSTRUCTION
IN 37 CHARTS.
Prepared under the direction of
COL. C. McD. TOWNSEND,
Corps of Engineers, U. S. Army.
1914.
SCALE
Feet
1000 0 1000 2000 3000 4000 5000
Meters
100 0 100 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 2000
NOTES.
Names of localities conform to Annual Reports Chief of Engineers.
Channel distances with origin at Eads Bridge, St. Louis, are shown at mile intervals.
Dikes and Dams are shown thus: in place; destroyed.
Bank Protection or Revetment is shown thus: in place; destroyed.
LITTLE ROCK GAGE
H.W. 176.26, 1844
H.W. 169.41; JUNE 12, 1903
MEAN ANNUAL H.W. 159.78
STANDARD L.W. 141.30
LOWEST 135.1 JAN. 14, 1909
220.84, MEMPHIS DATUM
Plate 50
12


13
CHART No. 13
DANBY LANDING
FISH BEND
RUSH TOWHEAD
PENITENTIARY POINT
MONROE CO.
RANDOLPH CO.
LITTLE ROCK GAGE
H.W. 176.26: 1844
H.W. 169.41: JUNE 12,1903
MEAN ANNUAL H.W.159.78
STANDARD L.W.141.30
LOWEST 135.1
JAN.14,1909
220.84, M.D.
Drainage Ditch
LEVEE
Ivy Landing
(Salt Lake Landing)
Kidd Landing
Sycamore Landing
F I S H B E N D
(BEAGLES ISLAND)
SALT LAKE TOWHEAD
(RUSH TOWHEAD)
PENITENTIARY POINT
AMES TOWHEAD
LEE ISLAND
DANBY LANDING
R U S H I S L A N D
STE. GENEVIEVE CO.
JEFFERSON CO.
ST. LOUIS AND SAN FRANCISCO R.R.
ISLE DE BOIS CR.
COUNTY LINE
MORRISON HOLLOW
BRICKEYS
U.S. GAGE
Channel Limit (Fall 1899)
1889
Fall 1904 and Spring 1905
Fall 1903
Fall 1900
Fall 1902
Spring 1905
Spring 1893
41
42
43
44
45
46
IMPROVING MISSISSIPPI RIVER
BETWEEN OHIO AND MISSOURI RIVERS
LOCALITIES OF CONSTRUCTION
IN 37 CHARTS.
Prepared under the direction of
COL. C. McD. TOWNSEND,
Corps of Engineers, U. S. Army.
1914.
SCALE
Feet
Meters
NOTES.
Names of localities conform to Annual Reports Chief of Engineers.
Channel distances with origin at Eads Bridge, St. Louis, are shown at mile intervals.
Dikes and Dams are shown thus: ——— in place; – – – – destroyed.
Bank Protection or Revetment is shown thus: in place; destroyed.
Plate 51

CLAUDE N. S...
CIVIL ENGINEER

PROTOTYPE POTAMOGRAPHY MIDDLE MISSISSIPPI RIVER

MILE 154 TO 140

PRESENTED AT

TWENTY-EIGHTH POTAMOLOGY CONFERENCE

U. S. ARMY, CORPS OF ENGINEERS
LOWER MISSISSIPPI VALLEY DIVISION

17 JUNE 1976

BY

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GARY W. SCHWARTZ

ENGINEERING DIVISION
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FOREWORD

This report was prepared by Mr. Claude N. Strauser, Potamologist and Mr. Gary W. Schwartz, Assistant Potamologist, River Stabilization Branch, Engineering Division.

Assistance was provided by Mrs. Joann M. Hutchinson, Chief Librarian, Mr. Lester Arms, Chief, Mapping Section, Survey Branch; Mrs. J. Bernice Thornton, Survey Branch; Mr. Harold Williams, Mapping Section, Survey Branch; Mrs. Helen Schleipman, Service Section; and Mrs. Lois J. King, Project Planning Branch.

This report was prepared under the direction of Mr. Norbert C. Long, Chief, River Stabilization Branch, and Mr. Jack R. Niemi, Chief, Engineering Division, St. Louis District.

Colonel Thorwald R. Peterson, CE, was District Engineer and LTC Richard W. Gell was Deputy District Engineer during the preparation of this report.

Authors' Preface

In dealing with the many parameters that affect the river, it is best to keep in mind that a permanent improvement should be designed in harmony with the natural laws of the river. This policy was established by Colonel J. H. Simpson in 1875.

"Nature overlooks nothing, and we may confidently assume that the position and direction of the river, at any time, is the resultant of all the forces, and consequently, is a concrete expression of the law of the stream, which we may modify and preserve, but may not safely destroy or radically change. To accept and follow nature is, in this case, the beginning and end of science."

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Middle Mississippi River

Miles 154.0 to 140.0

Report No. 3

PART I - INTRODUCTION

This is the third in a continuing series of reports pertaining to the reach of river now referred to as the "Prototype Reach." The first report was prepared by Norbert C. Long, Chief of the River Stabilization Branch, St. Louis District, Corps of Engineers (May 1971). The second report was prepared by Eugene A. Degenhardt, Potamologist, St. Louis District, Corps of Engineers (20 September 1972).

no

The first report compared various hydraulic parameters derived from the 1966 hydrographic survey and the 1970 hydrographic survey. The second report compared various hydraulic parameters derived from the 1966, 1970, winter 1971 and summer 1971 hydrographic surveys. This report will compare the 1959, 1966, 1967, 1970, winter 1971, summer 1971, 1972, winter 1975 and spring 1975 hydrographic surveys. (Due to various adverse field conditions and survey limitations, there were no hydrographic surveys made in this reach of river during 1973 and 1974.)

no

PART II - NAVIGATION PROJECT AUTHORIZATIONS (1910-1927-1930)

R&H Act of 26 June 1910	Provide a channel 8 feet deep and 200 feet wide between the Ohio and Missouri Rivers.

R&H Act of 21 Jan 1927	Provide a channel 9 feet deep and 300 feet wide from Ohio River to northern boundary of City of St. Louis.
R&H Act of 3 Jul 1930	Project between northern boundary of City of St. Louis and Grafton (mouth of Illinois River) modified to provide a channel 9 feet deep and generally 200 feet wide with additional width around bends.

The River & Harbor Act of 30 August 1935 extended the lower limits of the Mississippi River between the Missouri River and Minneapolis, Minnesota, project to the mouth of the Missouri River and authorized improvement by a system of locks and dams supplemented by dredging in accordance with plans recommended in House Document No. 137, 72d Congress, 1st Session. This, in essence, eliminated the reach of the Mississippi River from the mouth of the Illinois River to the mouth of the Missouri River from the Regulating Works project.

PART III - BACKGROUND INFORMATION

Start here after intro -

This 14-mile reach of the Mississippi River, ~~called the Prototype Reach,~~ contains the channel improvement problems most frequently encountered along the entire length of the Middle Mississippi River. Prior to the construction of improvements, extensive dredging was required to maintain the authorized navigation channel dimensions.

Dredging costs amounted to $624,000 between 1963 and 1968 to make a total of 37 dredge cuts. Since the completion of the river regulating improvements (March 1969), no dredging has been required to maintain the navigation channel.

~~The regulating~~ structures ~~in this reach include existing bank revetment and 51 newly constructed stone-fill dikes~~ (includes dike extension constructed on existing dikes). These ~~new structures~~ improvements contracted the low-water width of the river to 1200 feet. To reduce the cost of construction, dike elevations were built to slope downward from the high bank (or the ends of previously constructed dikes) so that the riverward ends of the new dikes were at an elevation equivalent to 5-foot on the St. Louis gage.

The Middle Mississippi River meanders within its banklines from one deep water pool on one side of the river to another deep water pool on the other side of the river. The areas located between successive deep water pools are called channel crossings. The critical depth of water available at any given channel crossing can, and often does, control the amount of depth available for navigation along the entire length of the Middle Mississippi River. There are six channel crossings in the reach of river from miles 154 to 140 which formerly required repetitive dredging to maintain minimum project dimensions. no

The design and construction of regulating structures has been the subject of considerable research and development studies in recent years. Many model studies have been conducted at the Waterways

Experiment Station in Vicksburg, Mississippi. The studies have been conducted in an effort to improve design criteria and reduce construction costs. The construction of regulating works between miles 154 and 140 is part of special prototype study program to learn what effect a 1,200-foot low water contraction would have upon navigation depths for the authorized 9-foot channel project.

No go on

While there are no reliable engineering formulas which can be used to determine the amount of contractive effort required to develop a navigation channel possessing a specified minimum depth and width, the construction of regulating structures between miles 154 and 140 has proven that the desired channel improvement objectives can be obtained provided available research and development data, existing dike field performance data, and engineering judgement are properly utilized during the planning stage. The reach of river between miles 154 and 140 now possesses an excellent 9-foot navigation channel.

This reach of the Middle Mississippi River has been converted through a period of approximately 100 years from a shallow, wild, meandering stream, unpredictable and hazardous to navigation, into a controlled channel of adequate depth and national importance over which millions of tons of bulk freight are handled annually.

The middle Mississippi was not, nor is now, a lazy stream. Its steep slope and the erodible character of the post-glacial deposit make it agressive in its attempt to change its course and cut off bends. It accomplished its purpose by caving banks ruthlessly and flowing over farmland in a highly destructive manner. On the authority of Mark Twain (the novelist, humorist and river pilot), the unlighted and uncharted river channel was never the same on any two successive trips. He also said the Mississippi River was remarkable for its ability to cut through narrow necks thereby shortening its overall length by as much as 30 miles with a single cutoff. His early observations concerning the ability of the Mississippi River to create new channels via cutoffs is borne out by the fact that three segments of the state of Illinois are located on the Missouri side of the river while two segments of Missouri are located on the Illinois side. Now, due to the construction of regulating structures similar to those constructed between miles 154 and 140, the banklines have been stabilized and a dependable navigation channel has been developed.

On 30 September 1971, it was announced that the Chief of Engineers had selected the Prototype Reach for an Award of Merit. This award is given for efficient, economical and sound engineering designs. See Plates 1 thru 3.

III - CHANNEL ANALYSIS (1959-1975)

The methods used, in this report, to analyze data obtained from hydrographic surveys of the Prototype Reach are essentially the same as were used in the two previous reports.

It has been the opinion of the River Stabilization Branch that an analysis of the hydrographic surveys should be associated with the Low-Water Reference Plane (LWRP). This theoretical plane is based upon a discharge of 54,000 cfs. There are advantages in making comparisons with regard to the LWRP, one of which is the elimination of the problem associated with deposition and the related "masking" of the channel geometry. Although this approach was thought to be original, a search of old records revealed that this idea was formulated before the turn of the century. The following quotation was taken from the Annual Report of the Chief of Engineers, in the year 1880:

"In examining (river cross sections), it is to be borne in mind that the works are built to a height (several feet) above the low water, and that the portion of the river bed lying below that level is mainly to be considered as to their effect."

Some reports recently published by private individuals and universities have taken river data and attempted to make a comparative analysis of river conditions, at various times, without considering the changes in stage, discharge, etc. that were present when the surveys were taken. This common error has led to many conclusions that can not, upon closer examination, be substantiated. For instance, one report compared river bed elevations in different years and did not make any attempt to explain that the river conditions were not similar. Comparisons should be made only when similar conditions exist. Even though this was realized by experienced river engineers many years ago, there are still individuals that are unaware of this basic rule. In Senate Document No. 204, 63d Congress, 1st Session, dated 16 May 1913, it is simply stated as follows:

"... the only way to determine whether the river ~~bid~~ bed is rising or being scoured out is by comparing corresponding low waters with each other, or corresponding high waters."

Even in 1880 this problem was realized and was addressed as follows:

"It is no easy matter in the case of a silt-bearing stream to show definitely upon paper the effect of the works of improvement upon the channel. A statement that a certain depth existed before the execution of the works and another depth existed afterwards might be strictly true, but at the same time might be misleading and unfair. The channel is constantly shifting its position and the bottom fills or scours with the rise or fall of the water surface."

There are three hydrographic surveys used in this report which were made before the Prototype Reach was constructed and six hydrographic surveys which were made after the Prototype Reach was constructed. These are the surveys that will be used in this report for the comparative analysis. See Table No. 1.

Table No. 1

Listing of Hydrographic Surveys Used in This Report

Date	Average Stage Above LWRP	Miles Covered	
1959 Feb. - Mar.	15.2	140 to 154	
1966 Oct. - Nov.	3.9	140 to 154	
1967 Oct.	9.8	140 to 154	Before Prototype Const.
1970 May - Jun.	23.3	140 to 154	After Prototype Const.
1971 Jan. - Feb.	5.1	146 to 154	
1971 Aug.	5.6	140 to 154	
1972 Jul, Aug, Sep.	15.6	141 to 154	
1975 Feb.	20.9	148 to 154	
1975 May	26.5	148 to 154	

*Note: Similar stages are not always accompanied by similar discharges

The only significant construction activity that has taken place in the Prototype Reach since its completion has been the rehabilitation of three breached dikes. These dikes were mentioned in the previous prototype report. The rehabilitated dikes are:

Mile	Bank	Date of Repair
150.0 L	left	28 November 1973
149.2 L	left	6 December 1973
148.1 L	left	10 December 1973

The dike at river mile 142.3 R has not been repaired and is therefore, still inoperative.

a. Navigation Channel Width

Width is one of the channel dimensions that can be most easily influenced by the works of man. The topic of river width has been discussed by river engineers for years. One of the earliest published discussions is found in the Annual Report to the Chief of Engineers, in the year 1880. The following account is reproduced here because of the importance of this early discussion.

"One of the most important developments of this survey is the evidence which the present position of the shore line affords, that the stability of the banks has decreased with the settlement of the country and the clearing away of the forests. Weakened banks permit more rapid erosions, give the river greater width, and therefore less depth, and the navigation is injured. The fact that the river has materially widened within the last 60 years (since 1820) is generally acknowledged by those best informed, but all evidence that can be procured in support of it is useful in resisting claims for damages, by establishing the position that our works of improvement are works of conservancy. And if this widening process is still going on it is evident that the navigation is still further deteriorating. An examination of the shore line shows that in every case where cleared fields along a caving bank are interrupted by a patch of woods, the latter projects out into the river. It is easy to believe that the binding quality of the roots, and the protection formed by the fallen trees at the foot of the bank should have this effect. Wooded banks yield finally, of course, but the rate of erosion is so slow that the river has time to build up on the opposite side, and there is no increase in width.

"The facts lead to the belief not only that the navigation has been deteriorating in the past, but that the process is still going on, and will increase in rapidity as further clearings are made, and that, unless energetic measures are adopted to replace the guards established by nature and removed by man, the day will come when the navigability of the river for vessels that now use it will be destroyed."

This widening of the river from the 1820's to the 1880's was recently reported in a study sponsored by the U.S. Army Engineer District in St. Louis, Missouri (July 1974). This report, "Geomorphology of the Middle Mississippi River", states that the average river width in 1821 was 3600 ft., in 1888 it was 5300 ft. and in 1968, the average river width was 3200 ft.

Since the river widths of 1821 and 1968 are approximately the same, it shows that much of the work performed on the river during the last 100 years has been a work of conservancy.

With the above background information on the total river width in mind, an examination of the change in the average navigation widths throughout the Prototype Reach may be better understood.

To determine the change in navigation width, it was first necessary to define the term. Navigation width will be used in this report as the distance between the contour lines on the hydrographic surveys that are located 10 feet below the LWRP (project depth is 9 feet below the LWRP; however, the -10 contour was chosen for simplicity).

One way to evaluate the effectiveness of the Prototype Reach contraction is to compare conditions that existed "before" and "after" its construction. The 1959 hydrographic survey and the 1972 hydrographic survey were taken at approximately the same average stage so they were chosen for the first comparison. The average stages of these surveys were 15.2 ft. and 15.9 ft. above the LWRP, respectively. The average navigation width in 1959 was 876 feet compared to the average navigation width in 1972 of 976 feet. See Plate 4. As in previous reports, it can be seen that where there were breached dikes or excessive spacing between dikes, the navigation widths did not improve as desired.

explain first graph only

The 1966 and 1971 hydrographic surveys were taken at average stages of 3.9 ft. and 5.6 ft. above the LWRP, respectively. Since these were relatively similar, comparisons between these two surveys were made. The average navigation width in 1966 was 850 feet and in 1971 was 1,045 feet. See Plate 5.

To see what impact the dikes have on navigation widths at high river stages, two partial surveys of the prototype reach were made in 1975. The surveys were limited to miles 154 to 148 because this is the only area where the horizontal survey control points are still available at high water. These surveys were compared with the 1970 survey that was made using only that part of the 1970 survey between miles 154 to 148.

no

The average stage of the 1970 survey was 23.3 ft. above the LWRP. The February 1975 average stage was 20.9 ft. above the LWRP and the May 1975 average stage was 26.5 ft. above the LWRP. The navigation width was 1,082 feet, 1,375 feet and 1,435 feet, respectively. See Plate 6.

Table No. 2

Average Navigation Widths

Low Stages	
1966 (before construction)	850 feet
1971 (after construction)	1,045 feet (22% increase)
Medium Stages	
1959 (before construction)	876 feet
1972 (after construction)	976 feet (11% increase)
High Stages (there were no high water surveys made before the Prototype Reach was constructed)	
1970 (after construction)	1,082 feet
February 1975 (after construction)	1,375 feet
May 1975 (after construction)	1,435 feet

An examination of this data indicates that at the lower stages, when channel dimensions are the most important, the dikes have improved the navigation widths substantially. As the stage increases above the dike contraction elevation, some reduction in width is observed; however, when the stage increases towards the bankfull elevation, the navigation widths, once again, begin to increase.

b. Average Depth Below the LWRP

The navigation depth is of primary importance to the river engineer. Once again, in order to place this topic in its proper perspective, reference is made to the Annual Report of the Chief of Engineers, dated 1880. The following is an extract pertaining to navigation depths:

"The shoals in the Mississippi are constantly shifting their position, and there are very few spots now occupied by them where there has not been deep water within a recent period. It is pretty well established that there was in former years a depth of water throughout the navigable channel at the lowest stage at least equal to what we shall endeavor to obtain by our works."

The river in 1880 had deteriorated to such an extent that it was almost impossible to navigate. The goal of the 1881 project was to return the river to a condition that had previously existed under natural conditions (early 1820's).

The 1966 and the August 1971 hydrographic surveys were selected to compare "before" and "after" conditions of the navigation depth within the Prototype Reach at low stages. The navigation depth, for this report, is defined as the average depth below the LWRP. It is calculated by dividing the area below the LWRP by the width at the LWRP.

The average depth in 1966 was 10.4 feet and the average depth in August 1971 was 13.8 feet. See Plate 7.

The 1959 hydrographic survey and the 1972 hydrographic survey were selected for "before" and "after" conditions at medium stages. The 1959 average depth below the LWRP was 11.5 feet and in 1972 it was 12.9 feet. See Plate 8.

For high flows the 1970, February 1975, and the May 1975 hydrographic surveys were compared. The average depth in 1970 was 12.4 feet, in February 1975 it was 14.0 and in May 1975 it was 15.0. (Only that portion of the 1970 survey was used in these calculations that matched the partial surveys that were taken in 1975, i.e., miles 154 to 148.) See Plate 9.

Table No. 3

Average Depth Below the LWRP

Low Stages		
	1966 (before construction)	10.4 feet
	Aug. 1971 (after construction)	13.8 feet (33% increase)
Medium Stages		
	1959 (before construction)	11.5 feet
	1972 (after construction)	12.9 feet (12% increase)
High Stages		
	1970 (after construction)	12.4 feet
	Feb. 1975 (after construction)	14.0 feet
	May 1975 (after construction)	15.0 feet

It appears that around mid-bank stages there is a small decrease in navigation depths and as the stages increase more towards bankfull, the depths below the LWRP begin to increase. The dikes become less effective as the stages increase to about mid-bank and then it appears that increased flows begin to compensate for the loss of contraction.

c. Average Area Below the Low Water Reference Plane

As can be expected, similar results should be obtained when you combine width and depth and investigate the area below the LWRP.

The 1966 and the August 1971 hydrographic surveys were selected for the low water comparisons. The 1966 average area below the LWRP was 17,608 sq. ft. and the average area below the LWRP in August 1971 was 19,668 sq. ft. See Plate 10.

For the medium stages, the 1959 and the 1972 hydrographic surveys were selected. In 1959, the area below the LWRP was 18,122 sq. ft. and in 1972 it was 17,849 sq. ft. See Plate 11.

For the high stages, the 1970, February 1975 and May 1975 hydrographic surveys were selected. The area below the LWRP in 1970 was 19,744 sq. ft. and in February 1975 it was 25,813 sq. ft., and in May 1975, it was 28,287 sq. ft. (Only the portion of the 1970 survey was used that coincided with the partial surveys made in 1975.) See Plate 12.

Table No. 4

Average Area Below the Low Water Reference Plane

Low Stages	
1966 (before construction)	17,608 sq. ft.
Aug. 1971 (after construction)	19,668 sq. ft. (12% increase)
Medium Stages	
1959 (before construction)	18,122 sq. ft.
1972 (after construction)	17,849 sq. ft. (1% decrease)
High Stages	
1970 (after construction)	19,744 sq. ft.
Feb. 1975 (after construction)	25,813 sq. ft.
May 1975 (after construction)	28,287 sq. ft.

d. Prototype "Pause"

The observance of a hesitance in the river channel geometry to improve at stages near mid-bank, led to a closer examination of this phenomena. For lack of a better name, this hesitance was called the "Prototype Pause".

It was decided to recombine the variables already used and plot "stage vs area below the LWRP" and "discharge vs area below the LWRP". This approach proved to be very interesting.

In order to fully utilize the partial surveys that were made during high water in 1975, only the survey miles between 148 and 154 were used.

Comparisons were made at each mile using hydrographic survey ranges that most nearly approximated the same location. The surveys were plotted in two groups, "before" and "after" the construction of the Prototype Reach.

Once again it was evident that the "Prototype Pause" was present. See Plates 13 thru 22 for "before" and Plates 23 thru 33 for "after". There was an insufficient number and variety of points among the "before" surveys to state unequivocally that the "Prototype Pause" was not present before construction; however, it does appear after the Prototype Reach was constructed.

e. Analysis

The riverward ends of the dikes in the Prototype Reach are constructed to an elevation equivalent to a stage of 5 ft. on the St. Louis gage. When the river stages are equivalent to 5 ft. St. Louis, or lower, there is a 1200-ft. contraction available. As the stages increase, the amount of contraction decreases continuously until the stages are above the elevations of the dikes and the width of the water surface extends from bankline to bankline.

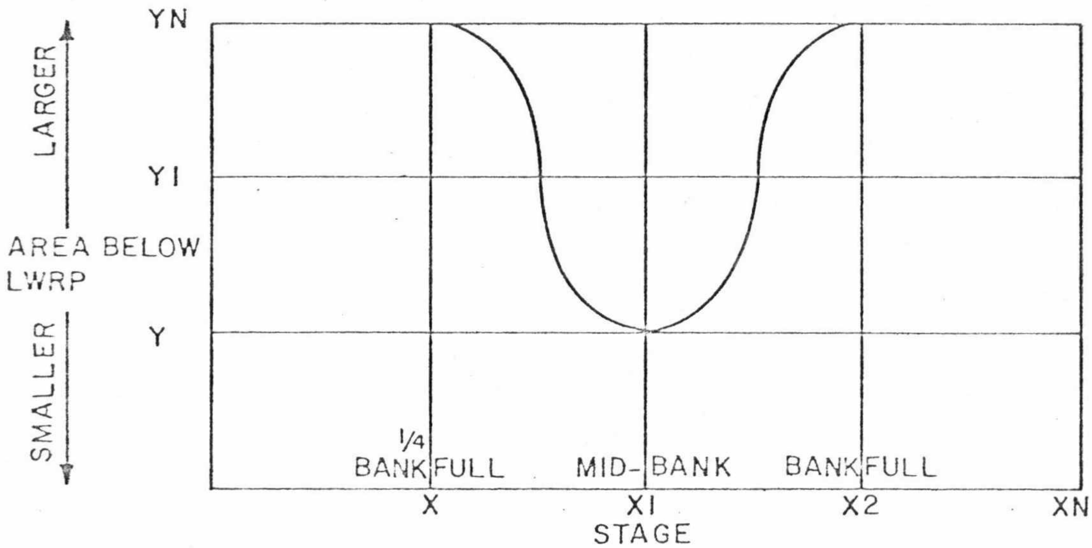
When stages begin to rise, the contraction in the Prototype Reach begins to lose its effectiveness before the increased flows can compensate for this loss of contractive effort. If this had occurred in a reach of river when the contractive effort had been less than 1200 ft. (at low flows), there would most probably have been a less than adequate depth available in portions of the navigation channel.

As Colonel J. H. Simpson stated in 1875, "... the dikes should be of such height as to produce action upon the bed when the river is first approaching the low stage, so as to prepare the channel, in some degree, for the less powerful effect of the diminished low-water volume." He goes on further to say, "... the works erected should begin to act as some intermediate stage. This should be before the want of depth is felt ... ."

As the stages begin to decrease in the Prototype Reach, the diminishing volume of water loses some of its power before the effect of the low-water contraction can be fully developed and then as the stages approach a stage equivalent to 5-ft. on the St. Louis gage, the contraction becomes great enough to permit the channel dimensions to "catch-up" and to continue their improvement.

To more fully understand the best combination of dike height and amount of contractive effort, another test reach has been designed and is presently being constructed. This test reach is located between Mississippi River, miles 87.0 to 93.0. This test reach is being constructed with a 1500-ft. contraction (instead of the 1200-ft. contraction used in this study) and the riverward end of the dikes are being built to an elevation equivalent to 5-ft. on the St. Louis gage. This test reach has been named by the Chief, River Stabilization Branch as "Prototype 76." The old community of Seventy-Six, Missouri, at mile 90.3 R, the year of construction of this test reach and the Bicentennial celebration all combined, indicate that this name is appropriate for the above mentioned reasons.

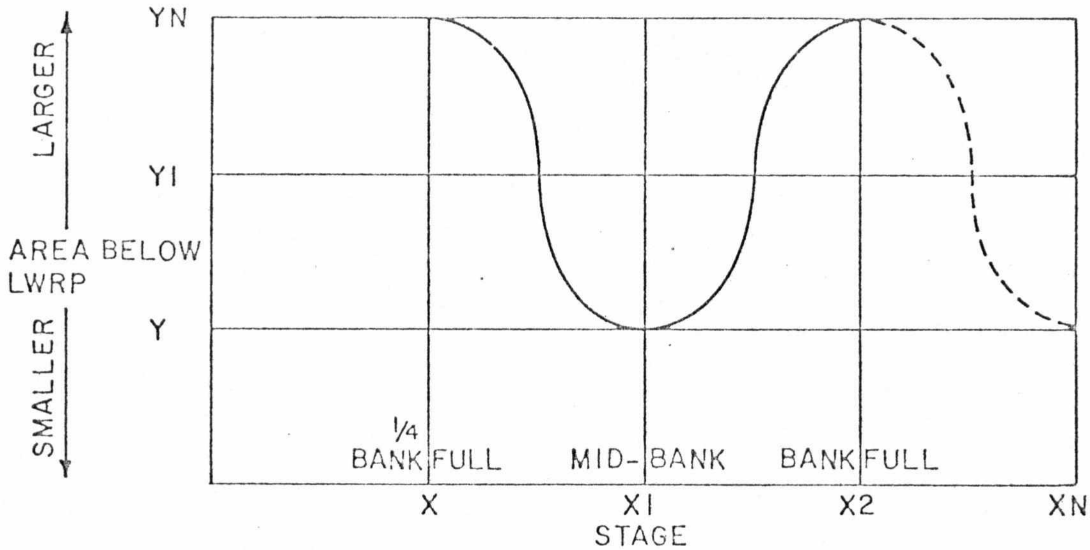
The "Prototype Pause," if properly used, can be a "yardstick" by which the river engineer can measure the effectiveness of his design criteria.



tell page number

The above graph shows a theoretical "Prototype Pause." At low stages, there is sufficient area below the LWRP; at mid-bank stages, the area decreases; and as the stages continue to increase, the area once again begins to improve.

Although there were no hydrographic surveys made above bankfull stages, field observations have indicated that the area below the LWRP decreases during flood stages (above bankfull).



In developing the optimum design criteria for regulating works, it is desired that adequate width and depth dimensions be available at low river stages. These dimensions must begin to develop before they are needed (while the river stages are decreasing).

As can be seen, at some stage above bankfull, XN, the navigation channel is being filled with deposition; at bankfull stages, X2, the dimensions have improved; at mid-bank stages, X1, the dimensions resemble conditions at XN and at low stages, X, the dikes have created a condition resembling conditions at X2.

It is important for the river engineer to realize that similar channel geometry may exist for different stages and must keep this in mind when analyzing his data. The desired area below the LWRP, YN, occurs at X and X2 and a smaller area below the LWRP occurs at X1 and XN.

This knowledge could be valuable in analyzing dredge surveys. For example, assume that a dredge survey was made at X1 when Y conditions were present. It would appear from this survey that in order for traffic to navigate this area, extensive dredging would be required; however, as stages decrease to X, the river will develop YN conditions and no dredging is necessary.

This information could decrease preventive maintenance dredging done at the higher stages and reduce overall channel maintenance costs.

Of course, the goal of the river engineer is to try to keep Y as large as possible in the most economical manner. If Y becomes too small at X1, the river has to work harder to achieve YN at X. There are several ways to increase Y at XI, one is to increase the contractive effort, another is to increase the height of the dikes. As explained, the Prototype Reach was designed with a 1200-ft. contraction at a stage equivalent to 5-ft. on the St. Louis gage. This produced YN at X.

The Jan.-Feb. 1971 and the August 1971 hydrographic surveys have been chosen to see how temperature affects channel dimensions at low stages in the Prototype Reach. The average stages were 5.1 ft. and 5.6 ft. above the LWRP, respectively.

The average water temperature for the winter survey was 35° F and the average water temperature for the summer 1971 survey was 81° F, a difference of 46° F. The following results were observed: See plates 34 → 36

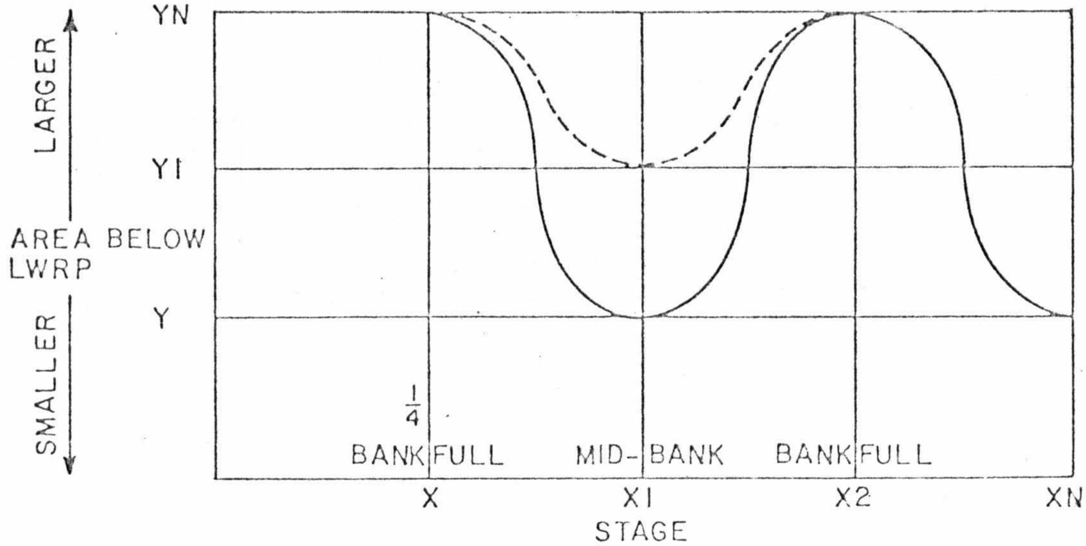
TABLE NO. 5*

	Area Below LWRP, ft.	Width at -10 LWRP, ft.	Ave. Depth Below LWRP, ft.
Winter 1971	22,136	1216	14.5
Summer 1971	19,309	1069	12.7

The winter 1971 channel dimensions were larger than the summer 1971 channels dimensions. The area below the LWRP was 15% larger, the average width at 10 ft. below the LWRP was 14% greater and the average depth below the LWRP was 14% deeper.

There is insufficient data available in this report to determine just what the mechanisms are that improved the channel geometry; however, it is apparent that temperature is a factor that should not be overlooked in the analysis of river mechanisms. See Plates 34 thru 36.

* Note: Only the miles between 146 to 153 were considered in this table. The winter survey was not completed because of heavy ice conditions on the river.



If Y can be increased to Y1 at X1, perhaps a smaller contractive effort would be required. This might be achieved by raising the riverward elevation of the dikes. Based on field experience and observations, it appears at this time that a 1500-ft. contraction, constructed to mid-bank elevations will be the most efficient way to achieve this goal. Future studies will examine this theory.

f. Water Temperature

From data developed for use in this report, it was decided to see if any surveys could be used to evaluate the effects of water temperature on channel dimensions. A paper written in April 1965 by Pearl Pierce Burke of the U.S. Army Engineer District, New Orleans, Louisiana, entitled, "Effect of Water Temperature on Discharge and Bed Configuration," states the following:

"... it is concluded that water temperature has a significant effect on riverbed configuration and an influence on the gage stage - discharge relationship."

g. Conclusions

The design criteria that was used to construct the Prototype Reach has proven successful. A dependable navigation channel, with adequate dimensions, has been developed.

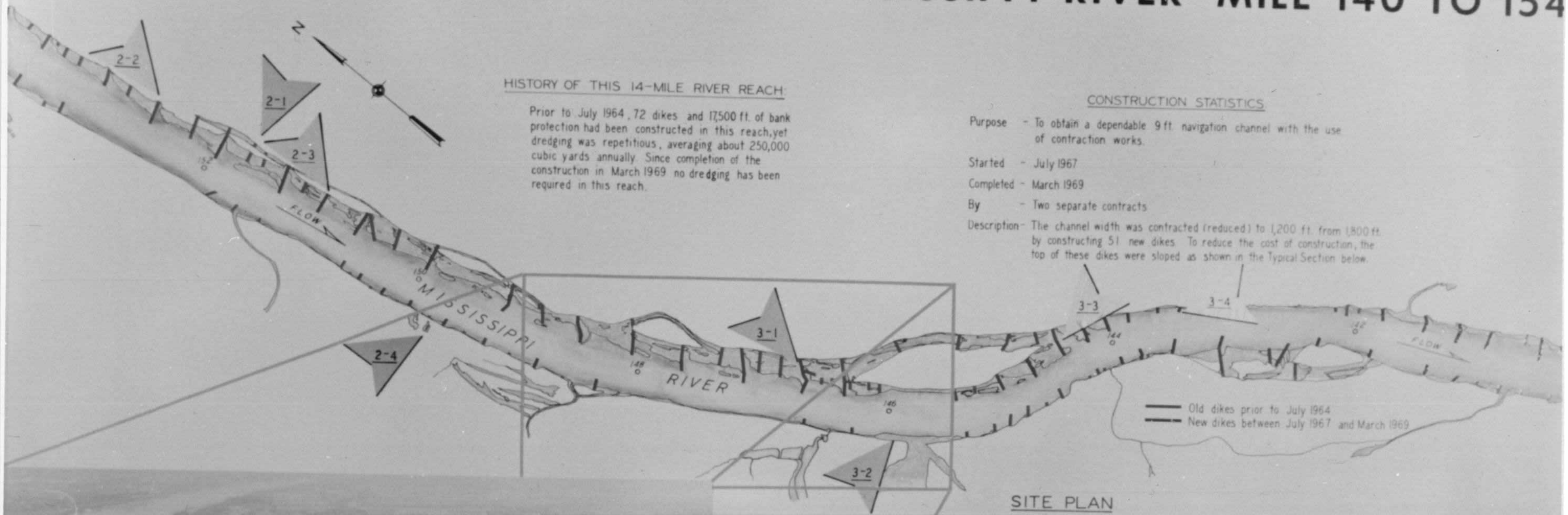
The goal of future potamology studies will be to investigate other design criteria to see if channel dimensions can be achieved in a more economical and efficient manner.

Mr. Chairman - this concludes the report of the St. Louis District on PRP-10.

Thank You

APPENDIX

REGULATING STRUCTURES - MIDDLE MISSISSIPPI RIVER - MILE 140 TO 154



HISTORY OF THIS 14-MILE RIVER REACH:

Prior to July 1964, 72 dikes and 17,500 ft. of bank protection had been constructed in this reach, yet dredging was repetitious, averaging about 250,000 cubic yards annually. Since completion of the construction in March 1969 no dredging has been required in this reach.

CONSTRUCTION STATISTICS

Purpose - To obtain a dependable 9 ft. navigation channel with the use of contraction works.

Started - July 1967

Completed - March 1969

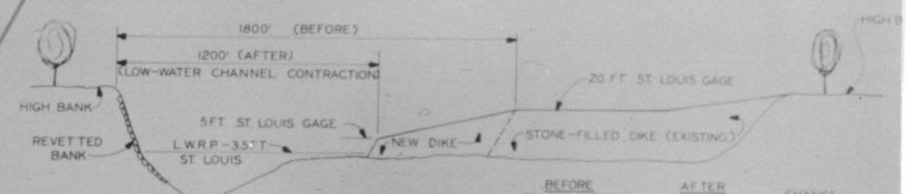
By - Two separate contracts

Description - The channel width was contracted (reduced) to 1,200 ft. from 1,800 ft. by constructing 51 new dikes. To reduce the cost of construction, the top of these dikes were sloped as shown in the Typical Section below.

SITE PLAN
SCALE: 1" = 2,400'

Aerial view - Looking upstream (approx. mile 146.0) showing dike fields, barge loading facilities, towboat moving upstream, which typifies the improvements made to date through the construction of regulating structures. Current estimate of annual benefits contributable to construction of regulating structures on the Middle Mississippi River derived from savings in transportation costs exceed 24 million dollars annually. Current B/C ratio is 5.3 to 1.

TYPICAL SECTION FOR STONE FILLED DIKE



	BEFORE CONSTRUCTION	AFTER CONSTRUCTION	CHANGE
AVERAGE WIDTH OF RIVER MEASURED AT THE ELEVATION OF THE L.W.R.P.*	1835 FT.	1530 FT.	-305 FT.
AVERAGE DEPTH OF WATER BELOW THE ELEVATION OF THE L.W.R.P.*	9.60 FT.	12.60 FT.	+3.00 FT.
AVERAGE AREA OF RIVER CROSS SECTION BELOW THE ELEVATION OF THE L.W.R.P.*	17,300 FT²	19,250 FT²	+1,950 FT²

*LOW WATER REFERENCE PLANE BASED UPON A DISCHARGE OF 54,000 C.F.S.

TYPICAL RIVER CROSS-SECTION

Plate 1

2-1 Aerial view - looking west showing extensive accretion of material downstream of dike No.152.0 L.
(River stage was approx. 8.0 feet on the St. Louis gage when these aerial photos were taken.)

2-2 Aerial view - looking southwest approx mile 151.0 showing accretion of materials in newly constructed dike fields.

2-3 Aerial view - looking south approx mile 150.0 showing accretion of materials in newly constructed dike fields.

2-4 Photo from high riverbank showing upbound tow with bulk commodities, e.g., sand, gravel, pipe, etc.

Plate 2

3-1 Aerial view - approx. mile 146.3 showing how dike fields are constructed to improve the navigation channel and yet not impair the operation of existing dock facilities.

3-2 Aerial view - approx. mile 146.0 showing that new stone dike construction is more effective in trapping materials than pile dike construction. Pile dike is shown in upper left portion of photo.

3-3 Aerial view - approx. mile 145.0 showing how dikes are used to train the direction of current and develop the navigation channel.

3-4 Aerial view - approx. mile 144.0 showing chute closure built to a low elevation to confine low flows to the navigation channel. The low elevation of the chute closure permits flow during high river stages and provides excellent fish habitat during low river stages.

Plate 3

NAVIGATION CHANNEL WIDTH

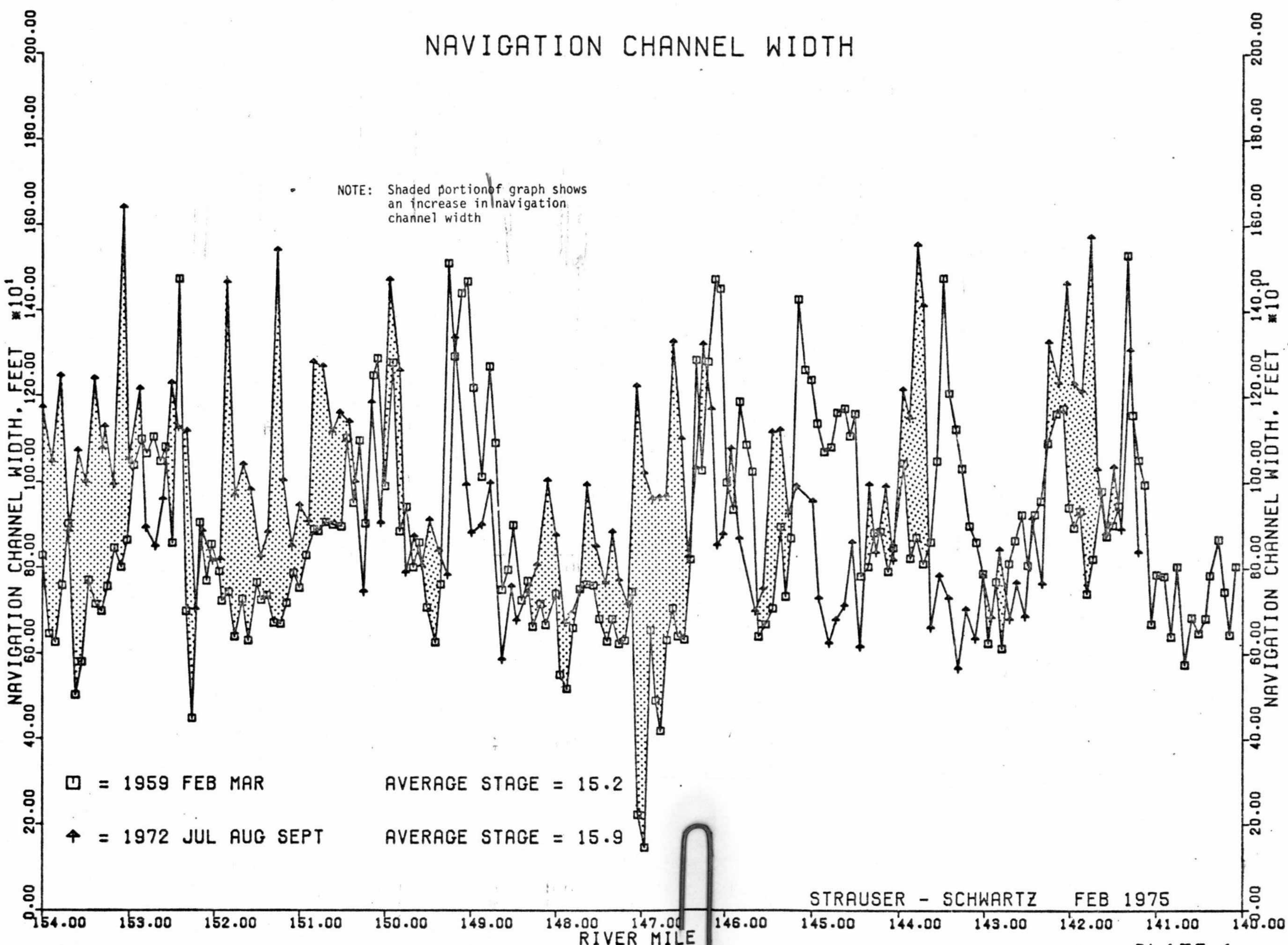
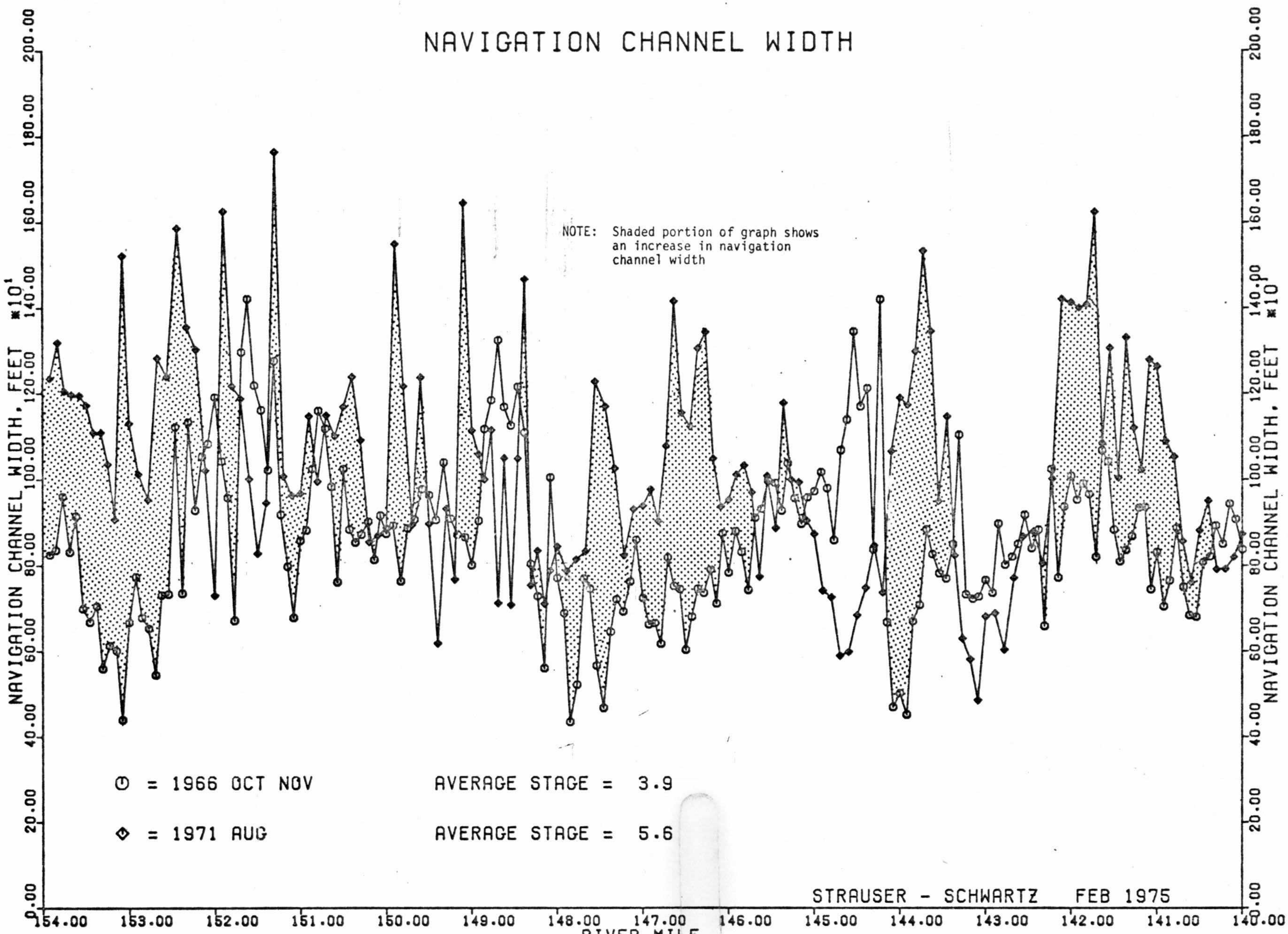
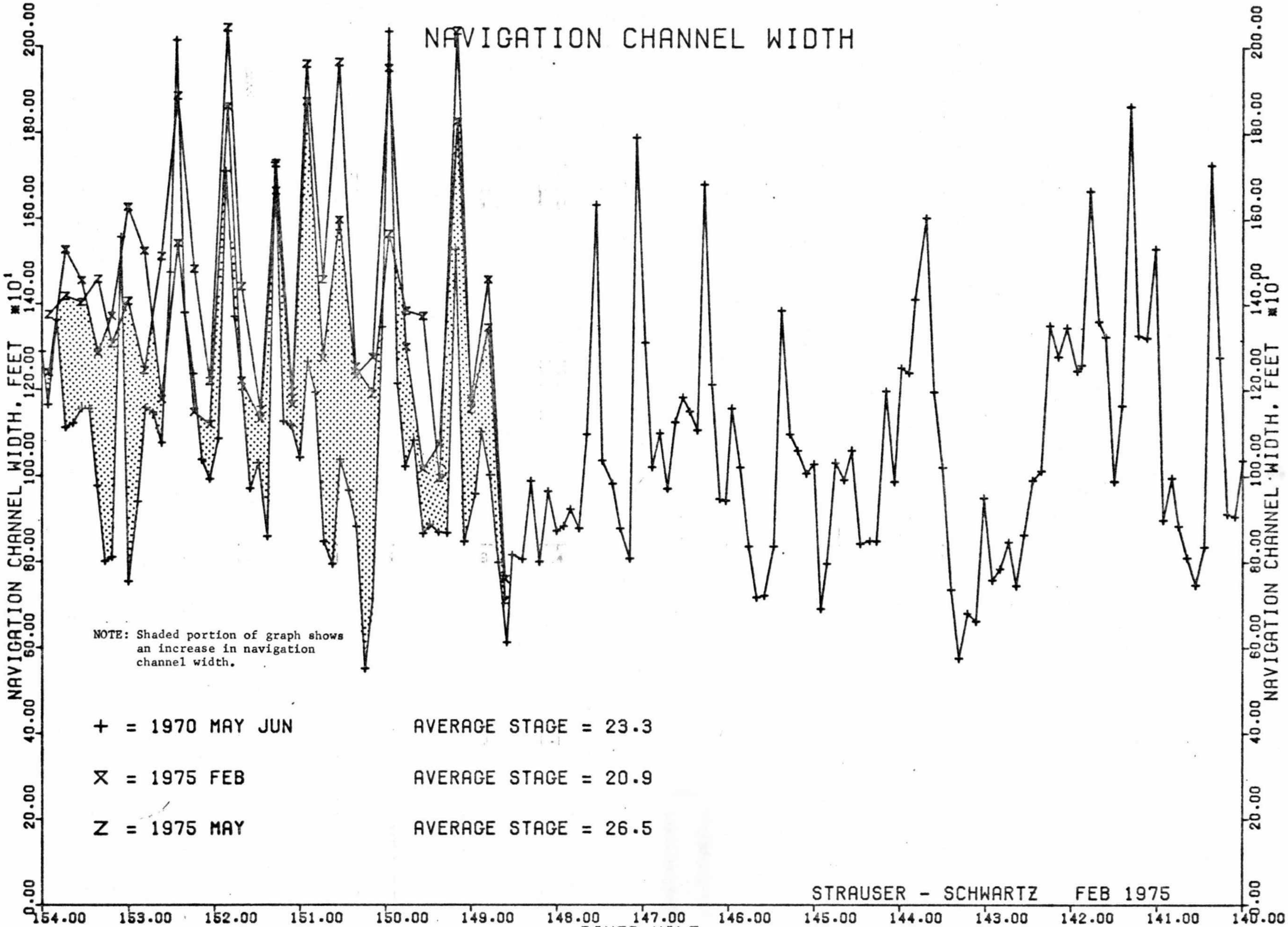


PLATE 4



NAVIGATION CHANNEL WIDTH
NOTE: Shaded portion of graph shows an increase in navigation channel width
NAVIGATION CHANNEL WIDTH, FEET ✱10[1]
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
180.00
200.00
154.00
153.00
152.00
151.00
150.00
149.00
148.00
147.00
146.00
145.00
144.00
143.00
142.00
141.00
140.00
RIVER MILE
⦶ = 1966 OCT NOV
◇ = 1971 AUG
AVERAGE STAGE = 3.9
AVERAGE STAGE = 5.6
STRAUSER - SCHWARTZ FEB 1975

PLATE 5



NAVIGATION CHANNEL WIDTH
NAVIGATION CHANNEL WIDTH, FEET *10¹
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
180.00
200.00
NOTE: Shaded portion of graph shows an increase in navigation channel width.
+ = 1970 MAY JUN
AVERAGE STAGE = 23.3
X = 1975 FEB
AVERAGE STAGE = 20.9
Z = 1975 MAY
AVERAGE STAGE = 26.5
STRAUSER - SCHWARTZ FEB 1975
154.00
153.00
152.00
151.00
150.00
149.00
148.00
147.00
146.00
145.00
144.00
143.00
142.00
141.00
140.00
RIVER MILE

PLATE 6

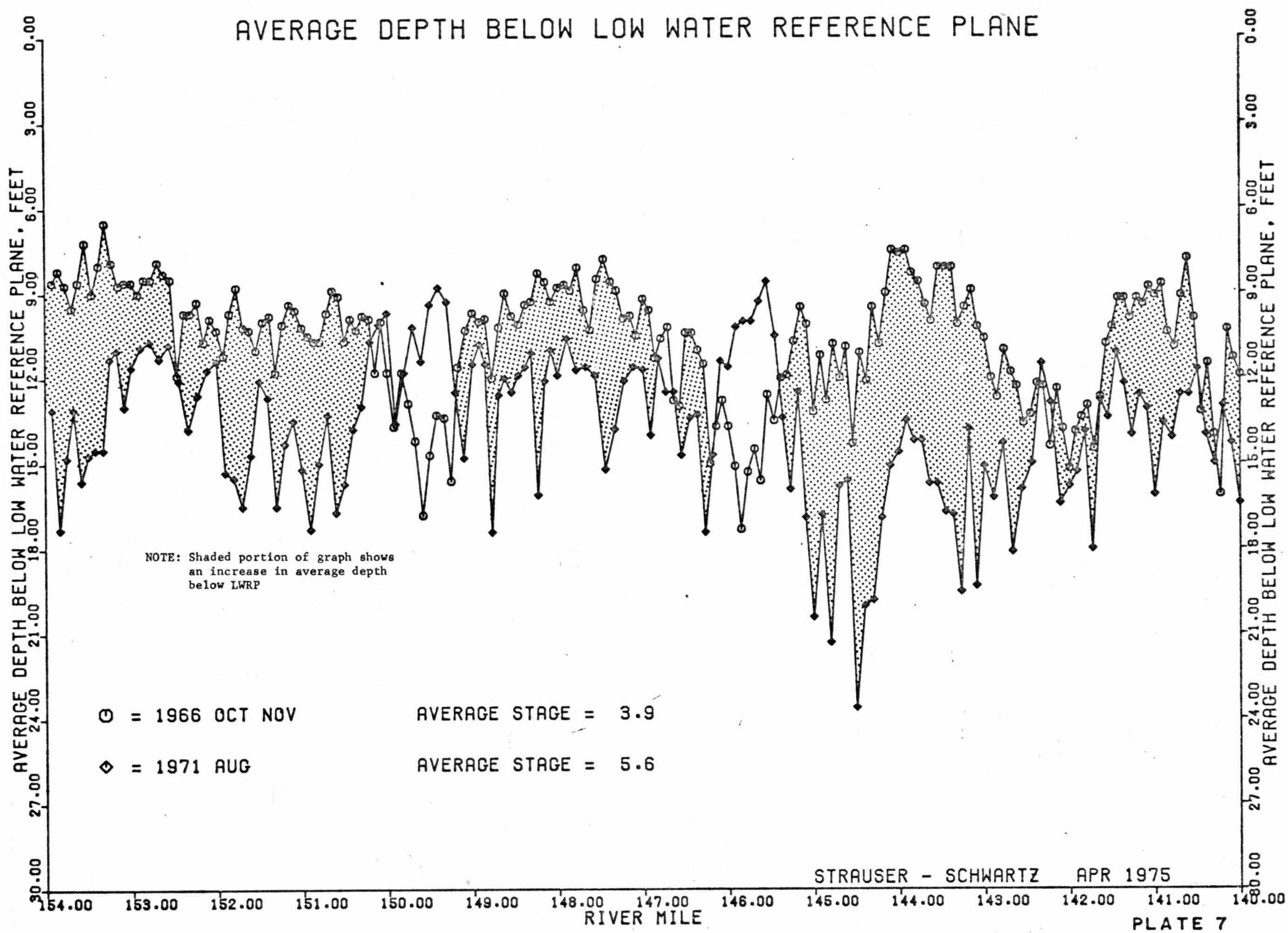

AVERAGE DEPTH BELOW LOW WATER REFERENCE PLANE
AVERAGE DEPTH BELOW LOW WATER REFERENCE PLANE, FEET
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00
30.00
NOTE: Shaded portion of graph shows an increase in average depth below LWRP
⊙ = 1966 OCT NOV
AVERAGE STAGE = 3.9
◇ = 1971 AUG
AVERAGE STAGE = 5.6
STRAUSER - SCHWARTZ APR 1975
154.00
153.00
152.00
151.00
150.00
149.00
148.00
147.00
146.00
145.00
144.00
143.00
142.00
141.00
140.00
RIVER MILE

PLATE 7

AVERAGE DEPTH BELOW LOW WATER REFERENCE PLANE

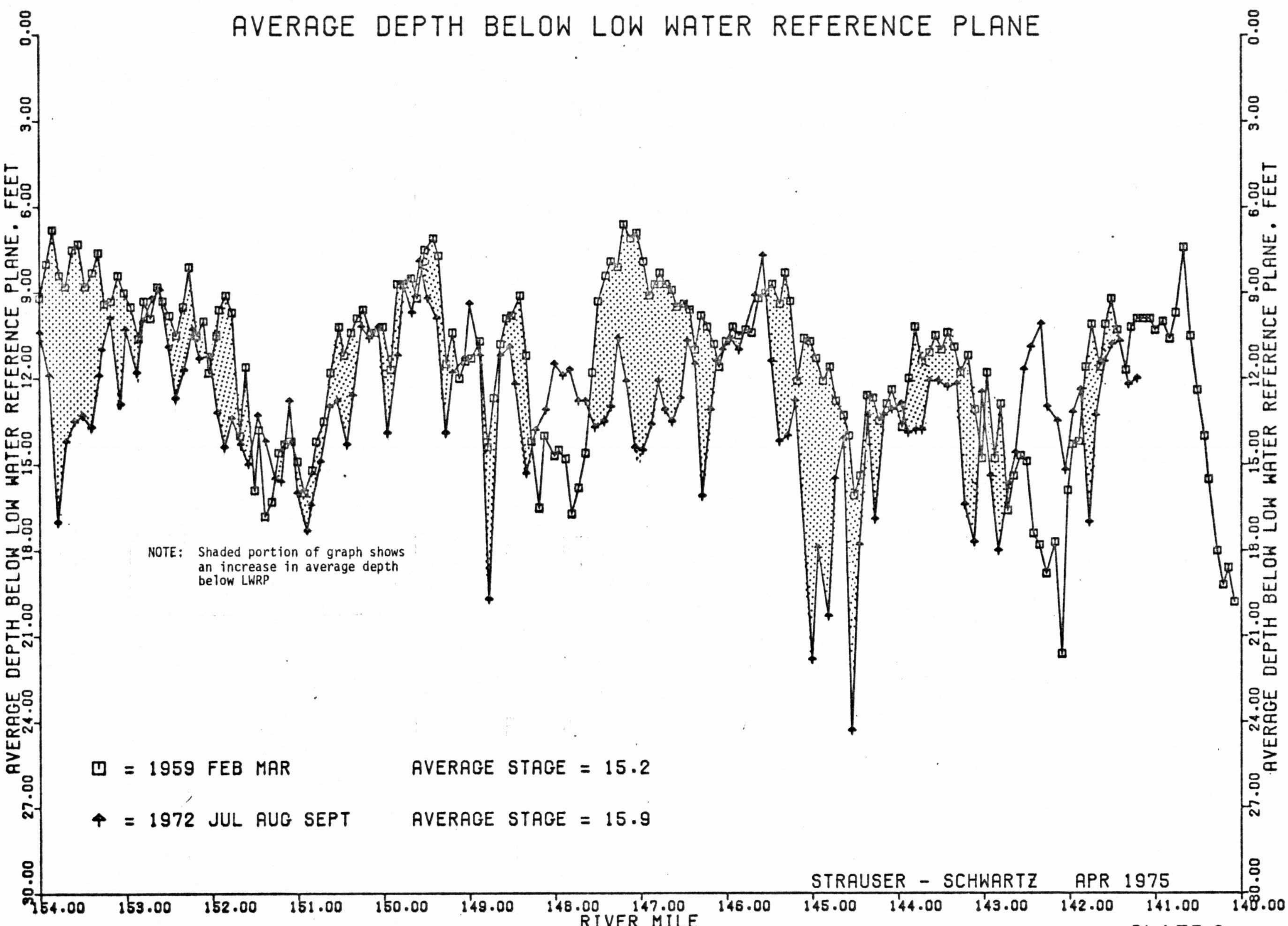


PLATE 8

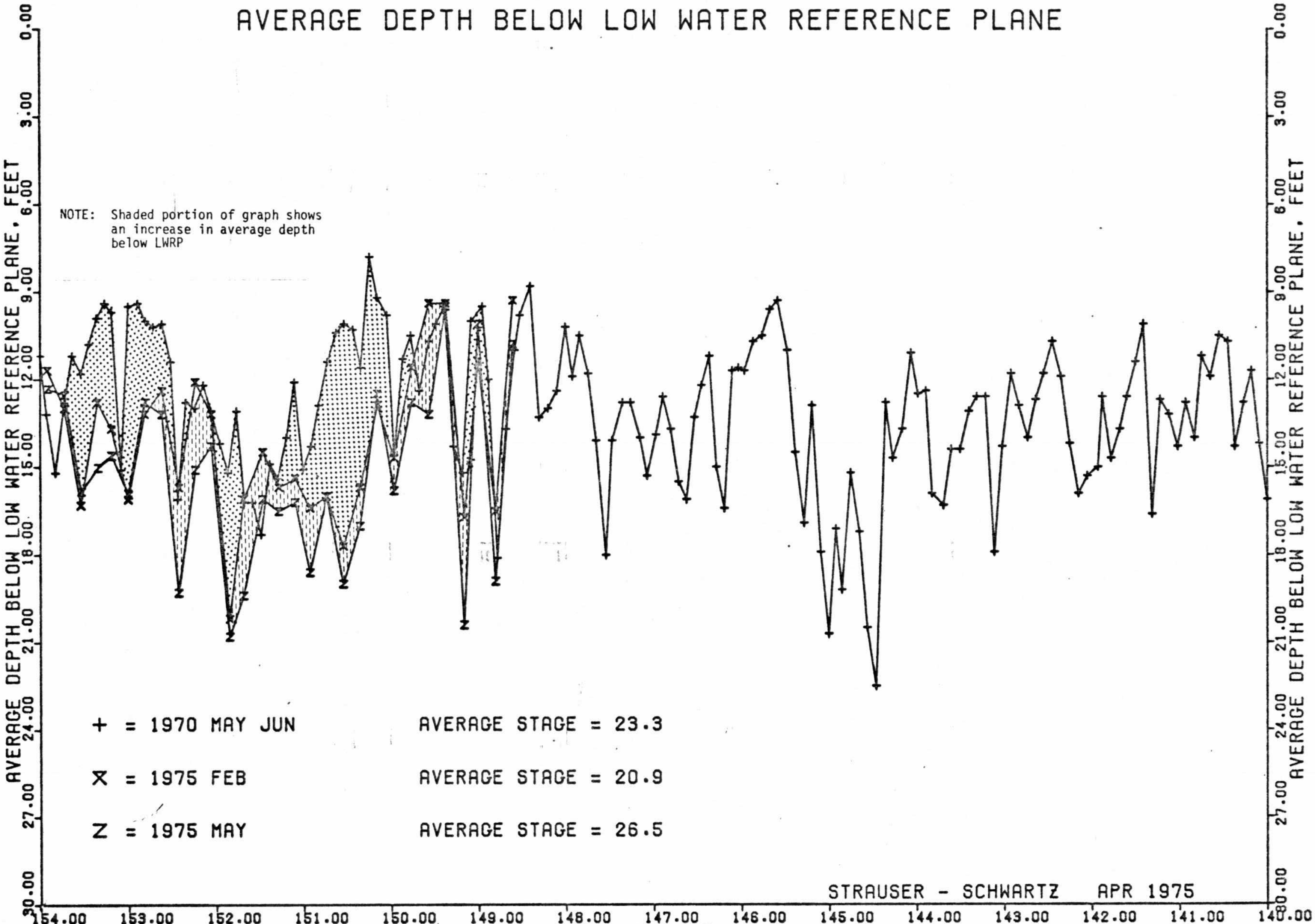

AVERAGE DEPTH BELOW LOW WATER REFERENCE PLANE
NOTE: Shaded portion of graph shows an increase in average depth below LWRP
+ = 1970 MAY JUN
AVERAGE STAGE = 23.3
X = 1975 FEB
AVERAGE STAGE = 20.9
Z = 1975 MAY
AVERAGE STAGE = 26.5
AVERAGE DEPTH BELOW LOW WATER REFERENCE PLANE, FEET
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00
30.00
154.00
153.00
152.00
151.00
150.00
149.00
148.00
147.00
146.00
145.00
144.00
143.00
142.00
141.00
140.00
RIVER MILE
STRAUSER - SCHWARTZ APR 1975

PLATE 9

AREA BELOW LOW WATER REFERENCE PLANE

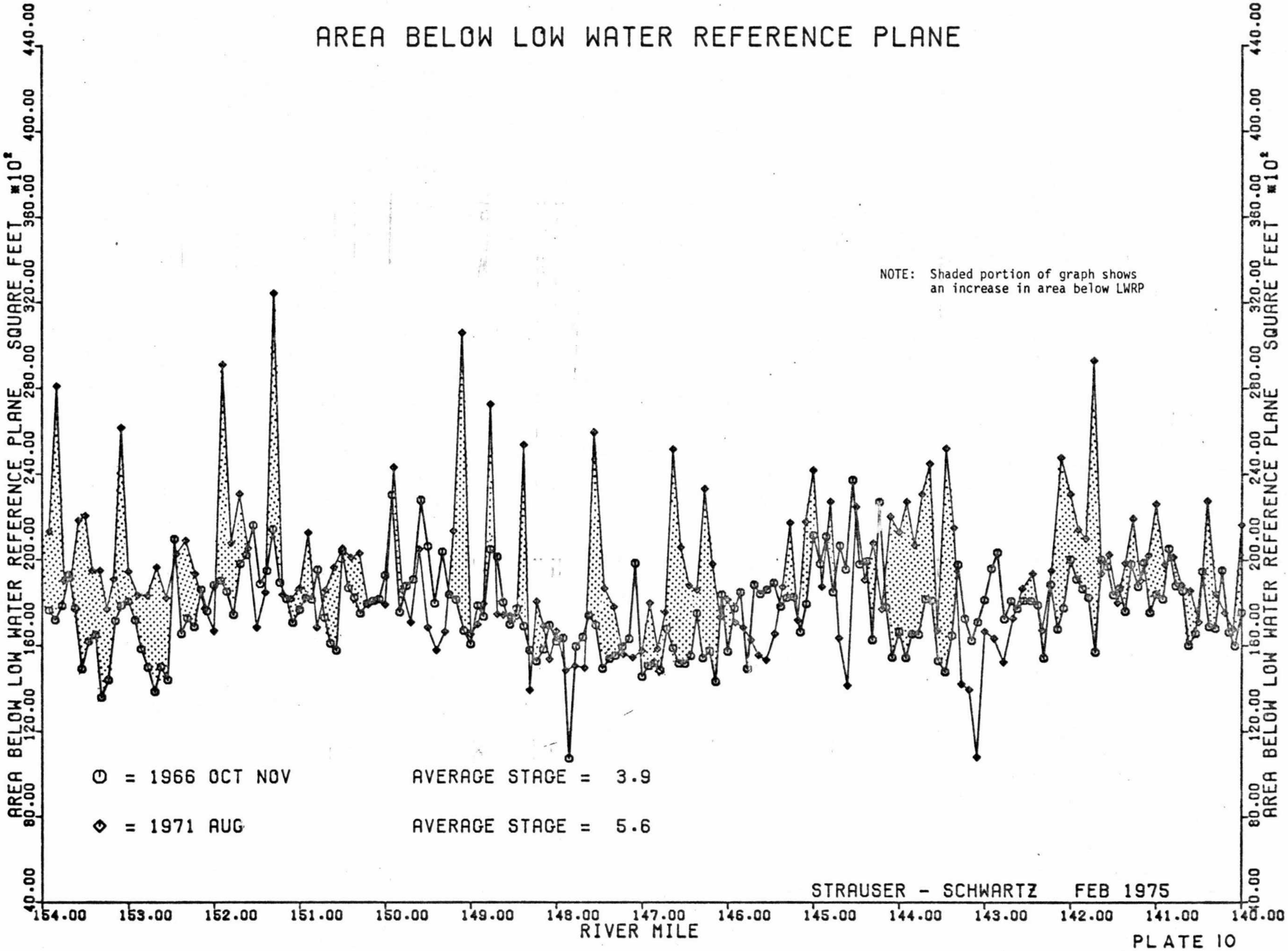


PLATE 10

AREA BELOW LOW WATER REFERENCE PLANE

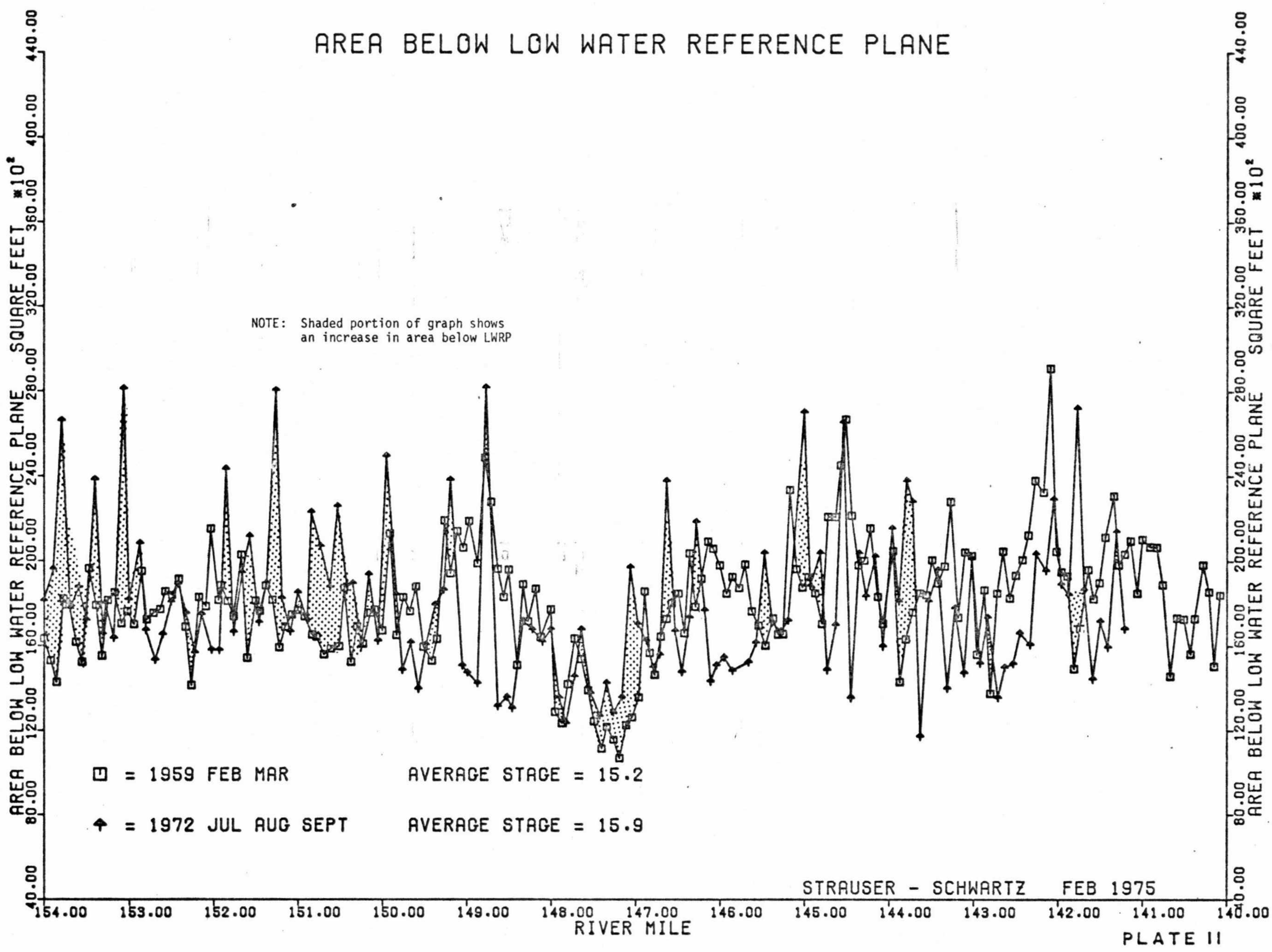


PLATE II

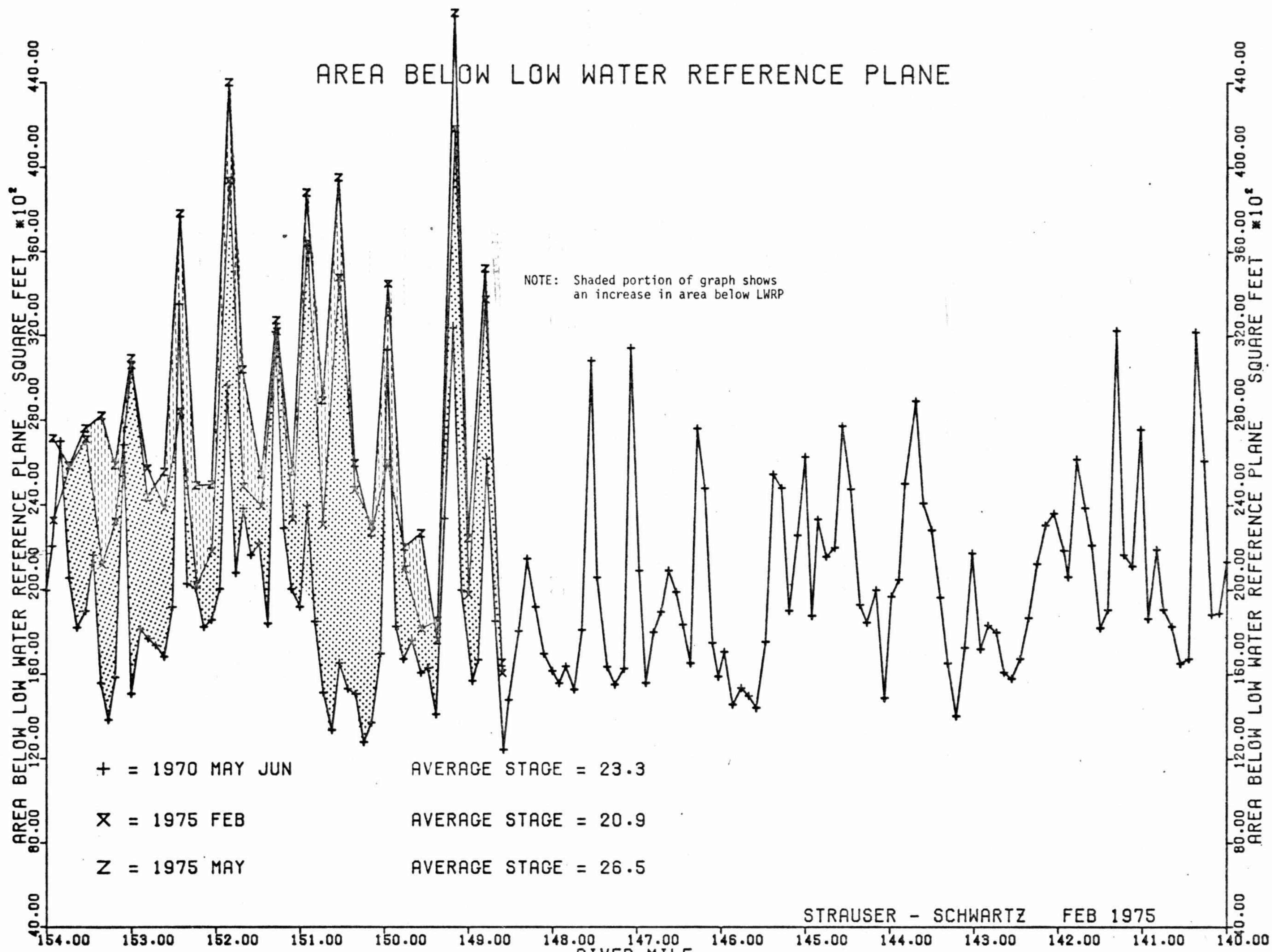
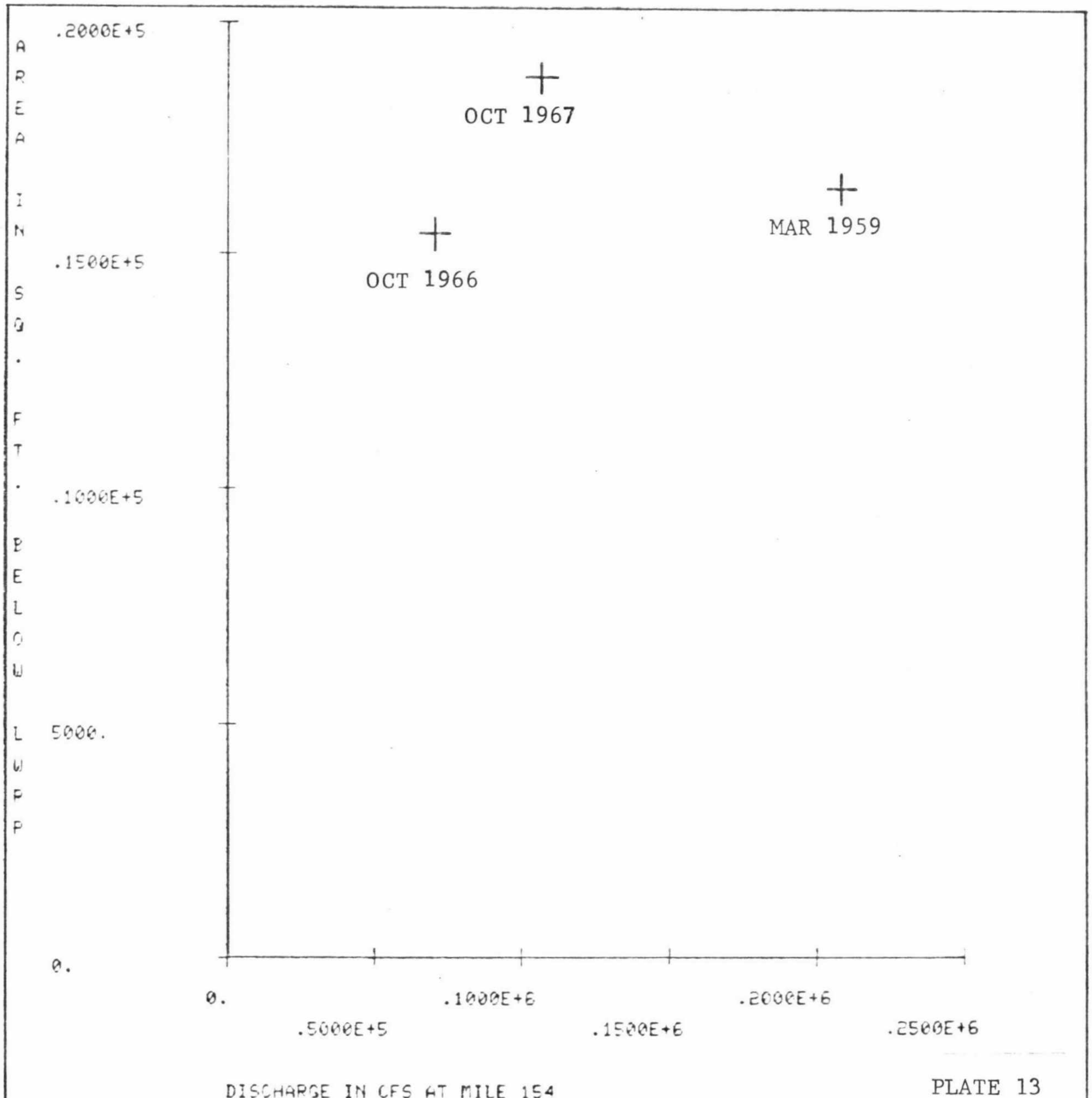

AREA BELOW LOW WATER REFERENCE PLANE
NOTE: Shaded portion of graph shows an increase in area below LWRP
AREA BELOW LOW WATER REFERENCE PLANE SQUARE FEET *10²
40.00
80.00
120.00
160.00
200.00
240.00
280.00
320.00
360.00
400.00
440.00
+ = 1970 MAY JUN
AVERAGE STAGE = 23.3
X = 1975 FEB
AVERAGE STAGE = 20.9
Z = 1975 MAY
AVERAGE STAGE = 26.5
STRAUSER - SCHWARTZ FEB 1975
154.00
153.00
152.00
151.00
150.00
149.00
148.00
147.00
146.00
145.00
144.00
143.00
142.00
141.00
140.00
RIVER MILE

PLATE 12



AREA IN SQ. FT. BELOW LWPP
.2000E+5
.1500E+5
.1000E+5
5000.
0.
OCT 1967
MAR 1959
OCT 1966
0.
.5000E+5
.1000E+6
.1500E+6
.2000E+6
.2500E+6
DISCHARGE IN CFS AT MILE 154

PLATE 13

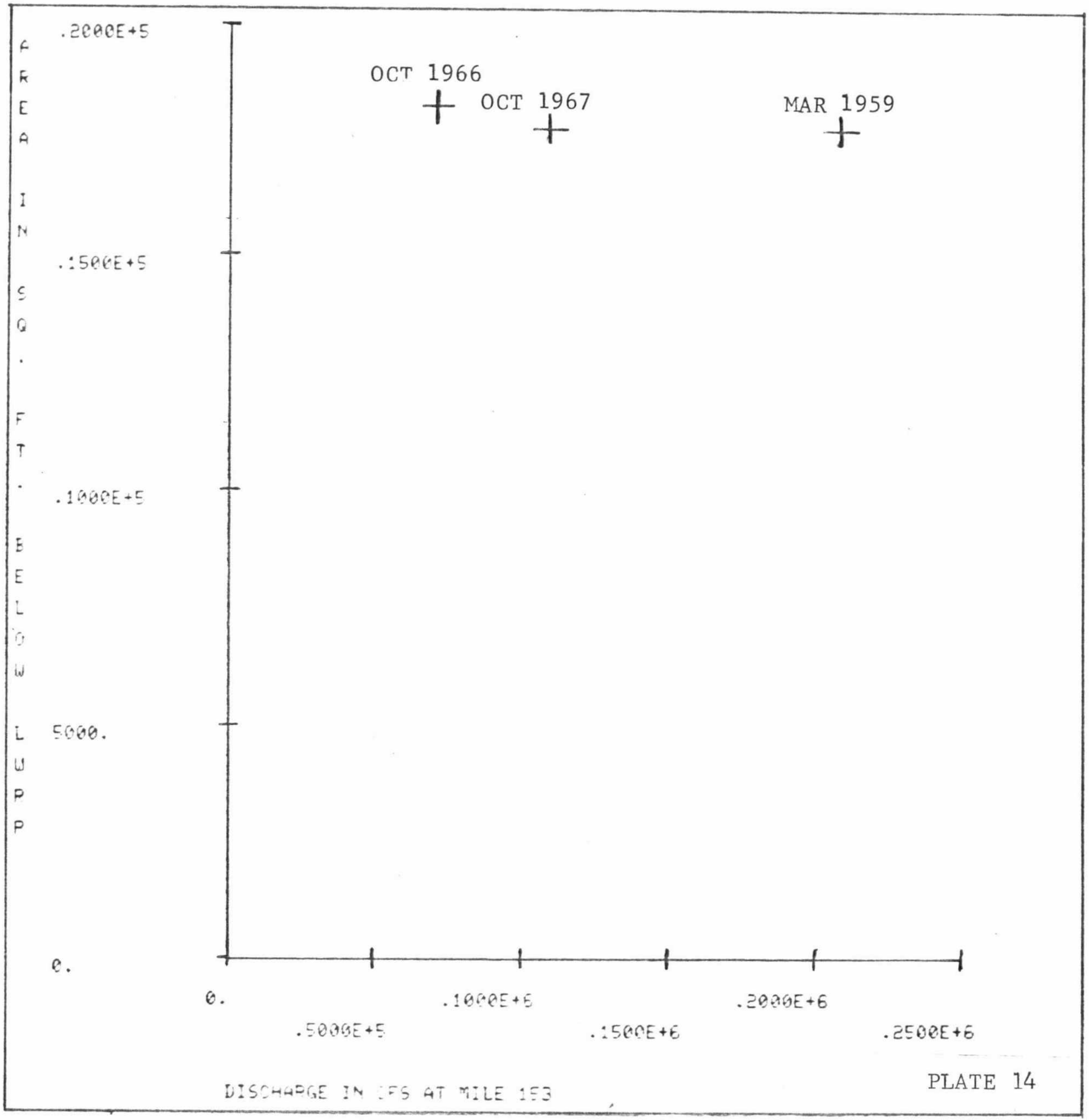
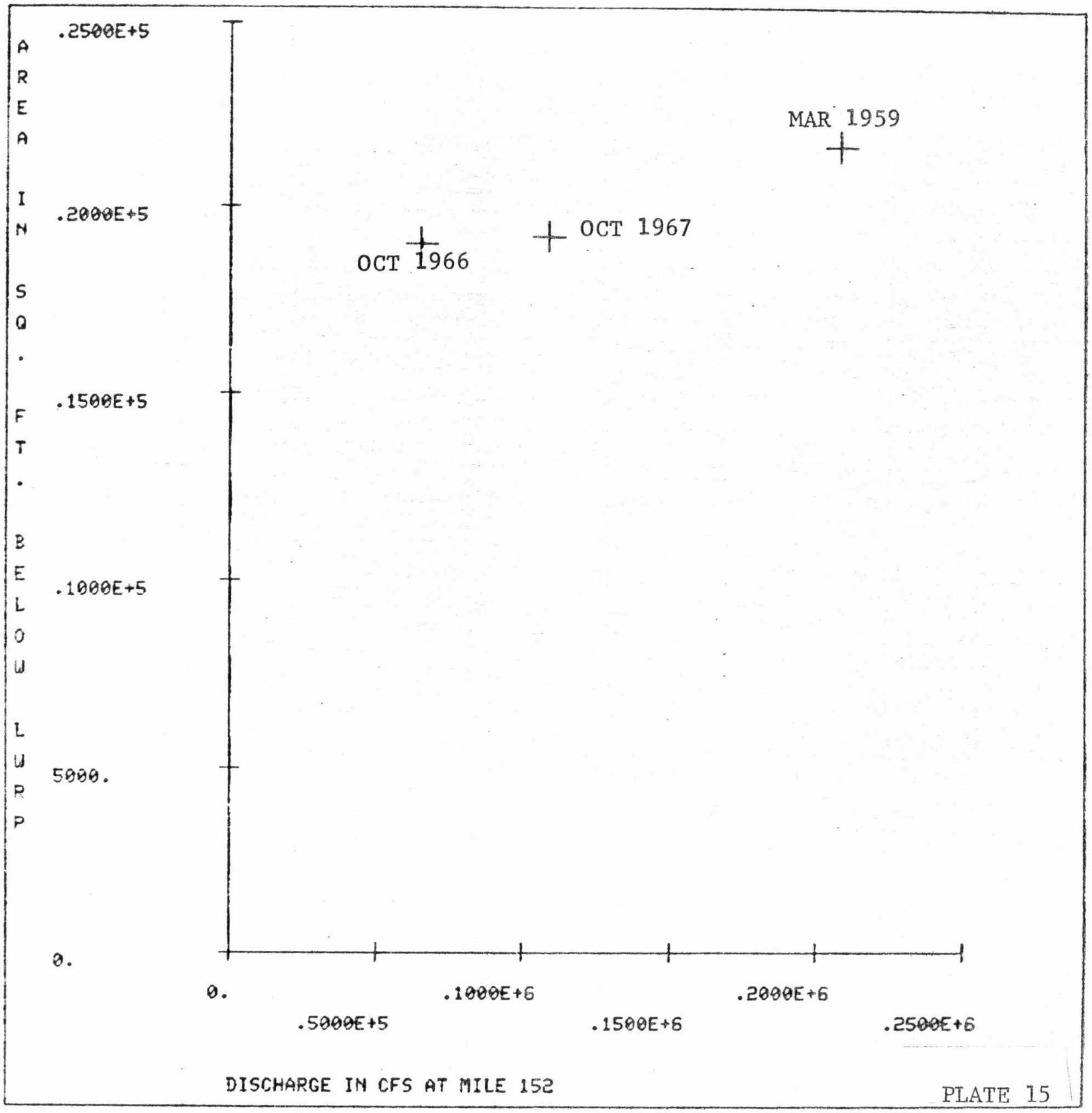

AREA IN SQ. FT. BELOW LWPP
.2000E+5
.1500E+5
.1000E+5
5000.
0.
OCT 1966
OCT 1967
MAR 1959
0.
.5000E+5
.1000E+6
.1500E+6
.2000E+6
.2500E+6
DISCHARGE IN CFS AT MILE 153

PLATE 14



AREA IN SQ. FT. BELOW LWRP
.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
MAR 1959
OCT 1967
OCT 1966
0.
.5000E+5
.1000E+6
.1500E+6
.2000E+6
.2500E+6
DISCHARGE IN CFS AT MILE 152

PLATE 15

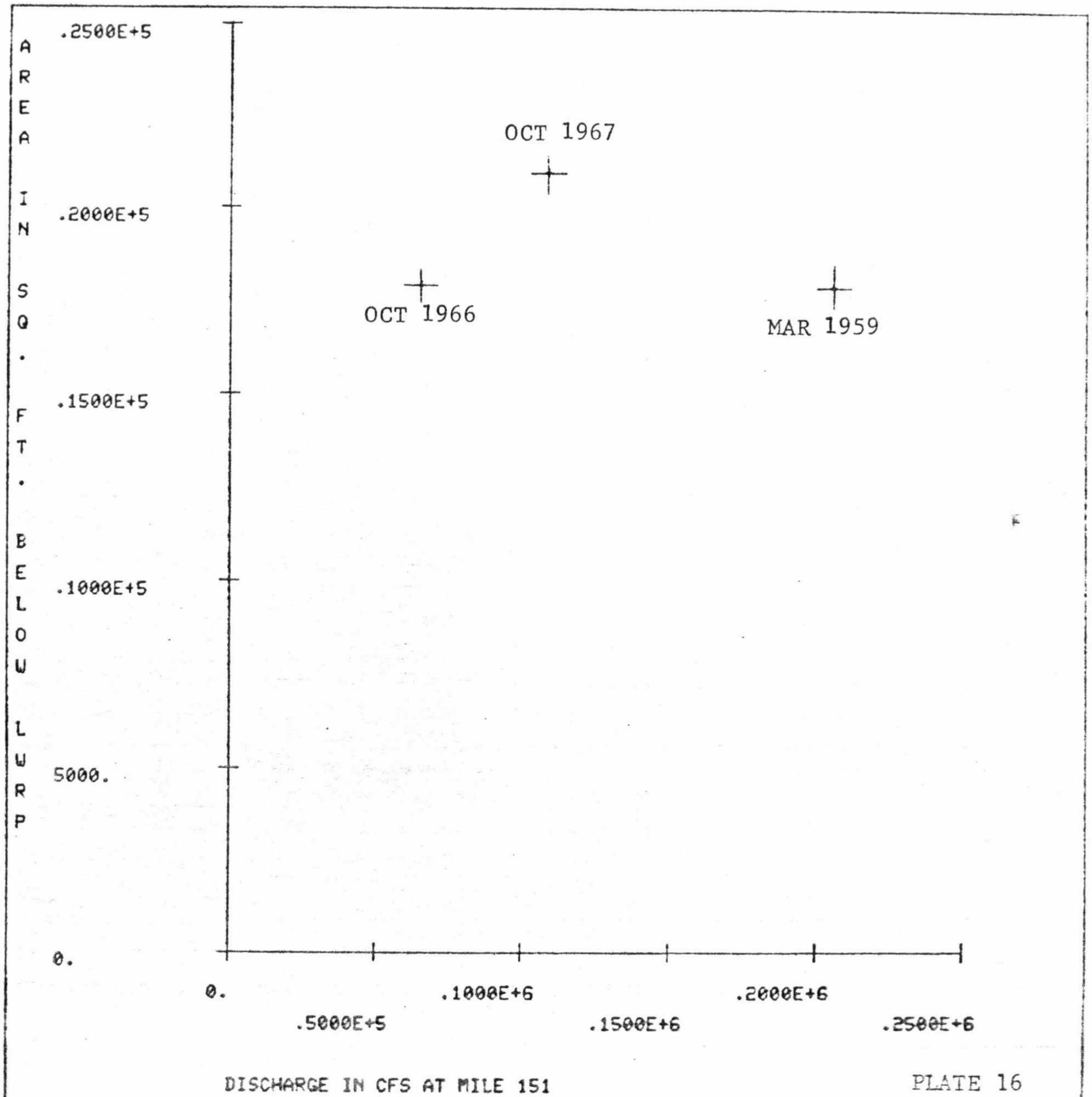
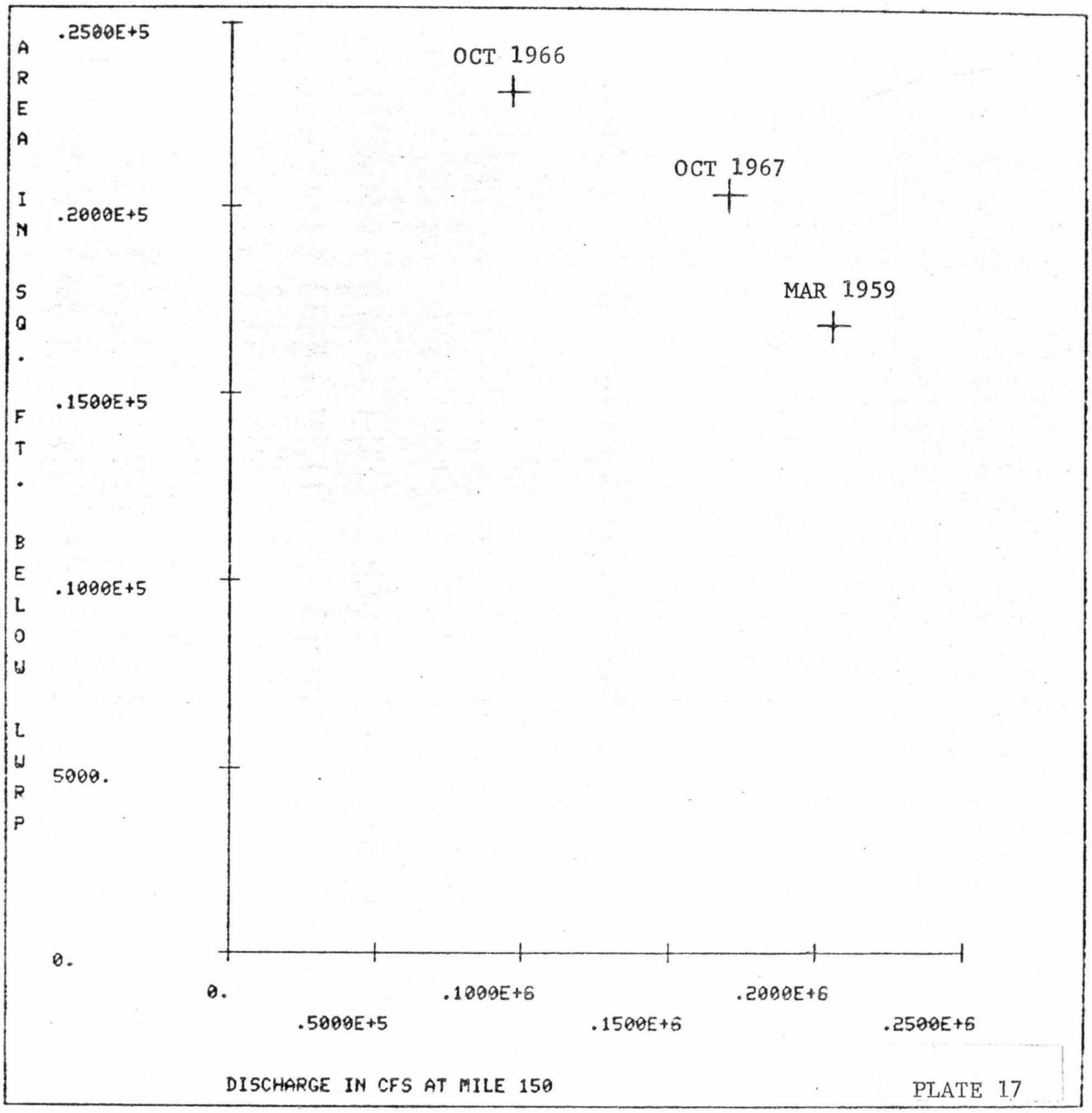

.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
AREA IN SQ. FT. BELOW LWRP
OCT 1967
OCT 1966
MAR 1959
0.
.5000E+5
.1000E+6
.1500E+6
.2000E+6
.2500E+6
DISCHARGE IN CFS AT MILE 151

PLATE 16



AREA IN SQ. FT. BELOW LWRP
.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
OCT 1966
OCT 1967
MAR 1959
0.
.5000E+5
.1000E+6
.1500E+6
.2000E+6
.2500E+6
DISCHARGE IN CFS AT MILE 150

PLATE 17

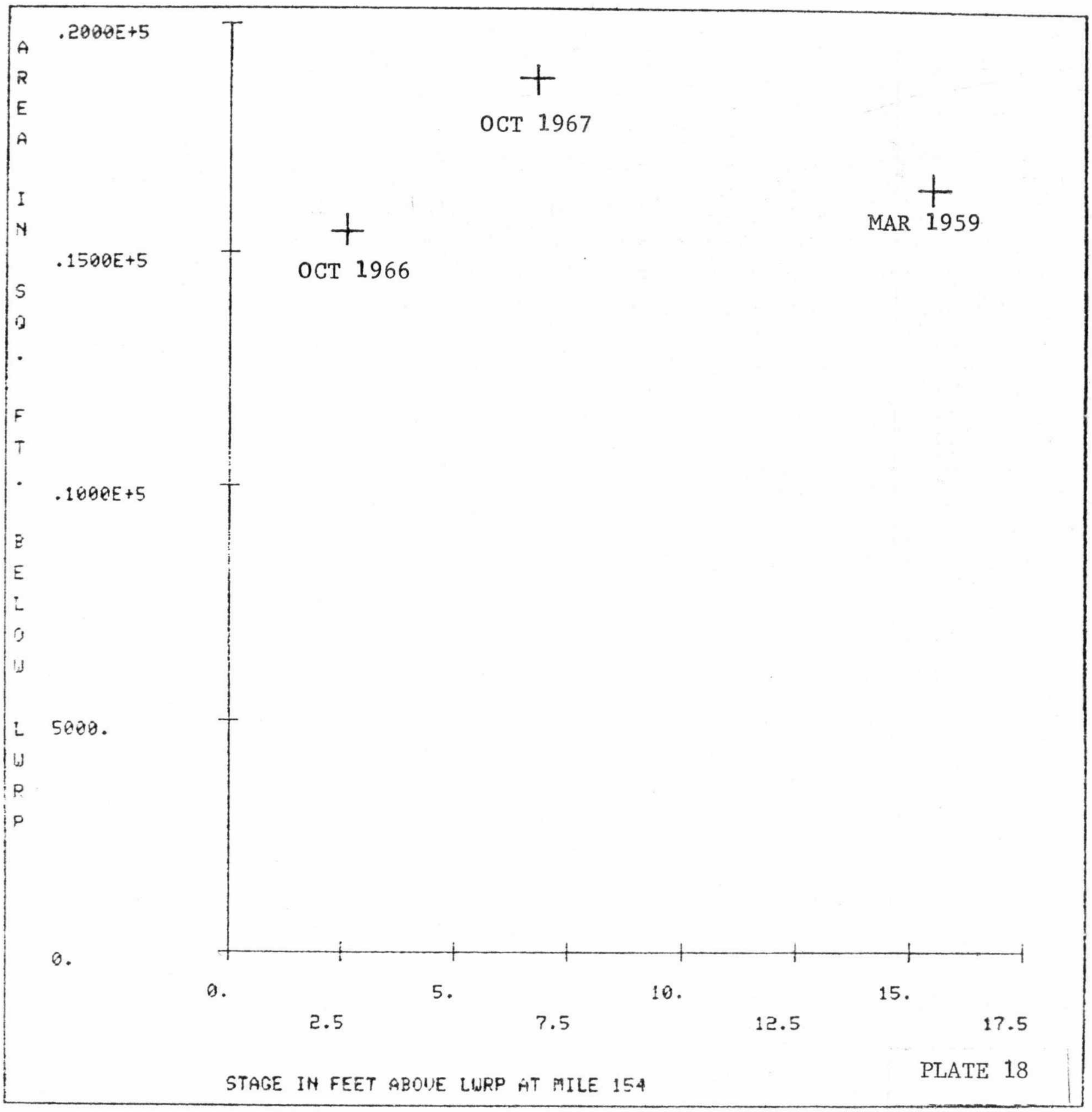

.2000E+5
.1500E+5
.1000E+5
5000.
0.
AREA IN SQ. FT. BELOW LWRP
OCT 1967
MAR 1959
OCT 1966
0.
5.
10.
15.
2.5
7.5
12.5
17.5
STAGE IN FEET ABOVE LWRP AT MILE 154

PLATE 18

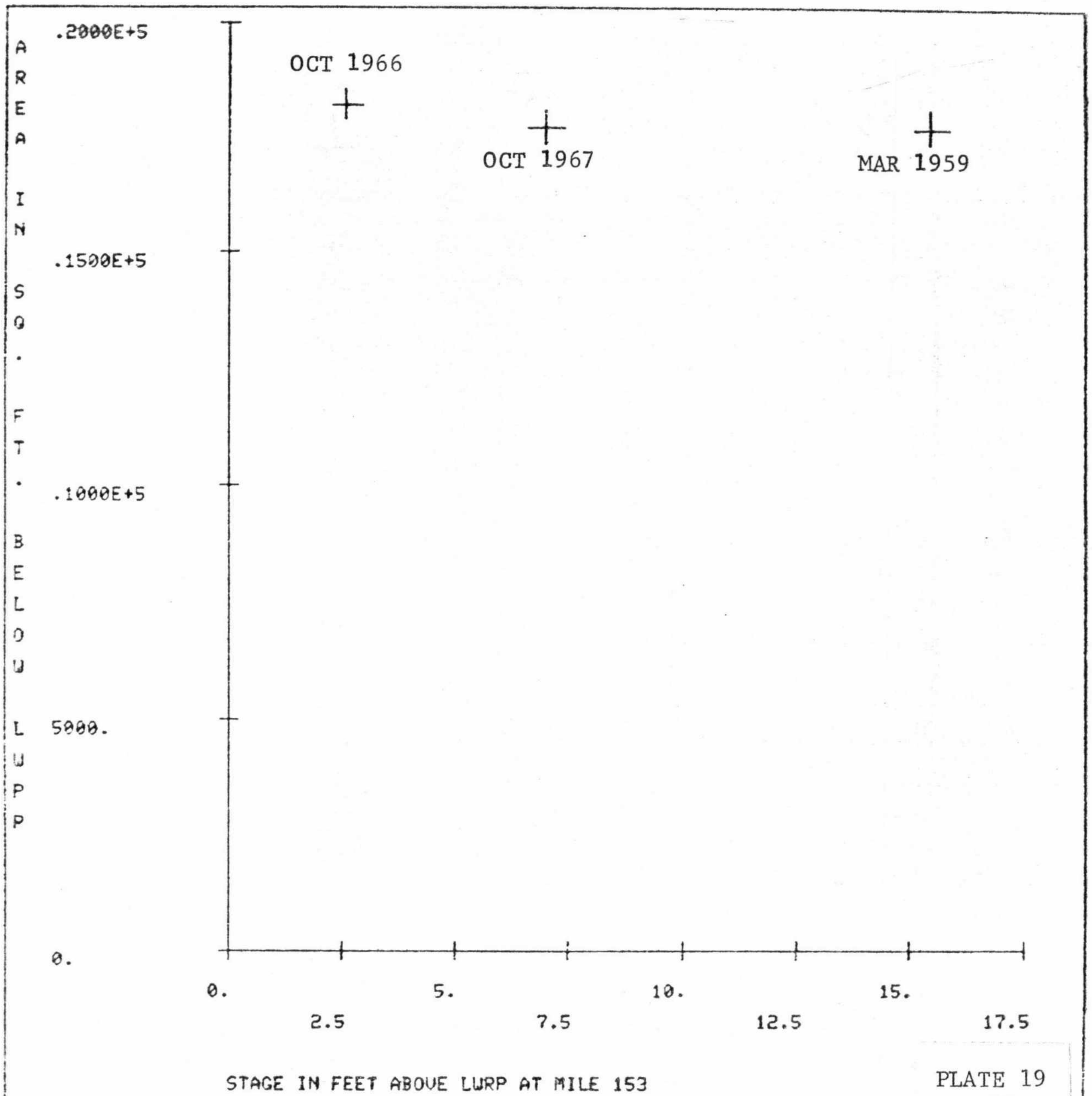

AREA IN SQ. FT. BELOW LWPP
.2000E+5
.1500E+5
.1000E+5
5000.
0.
OCT 1966
OCT 1967
MAR 1959
0.
5.
10.
15.
2.5
7.5
12.5
17.5
STAGE IN FEET ABOVE LWRP AT MILE 153

PLATE 19

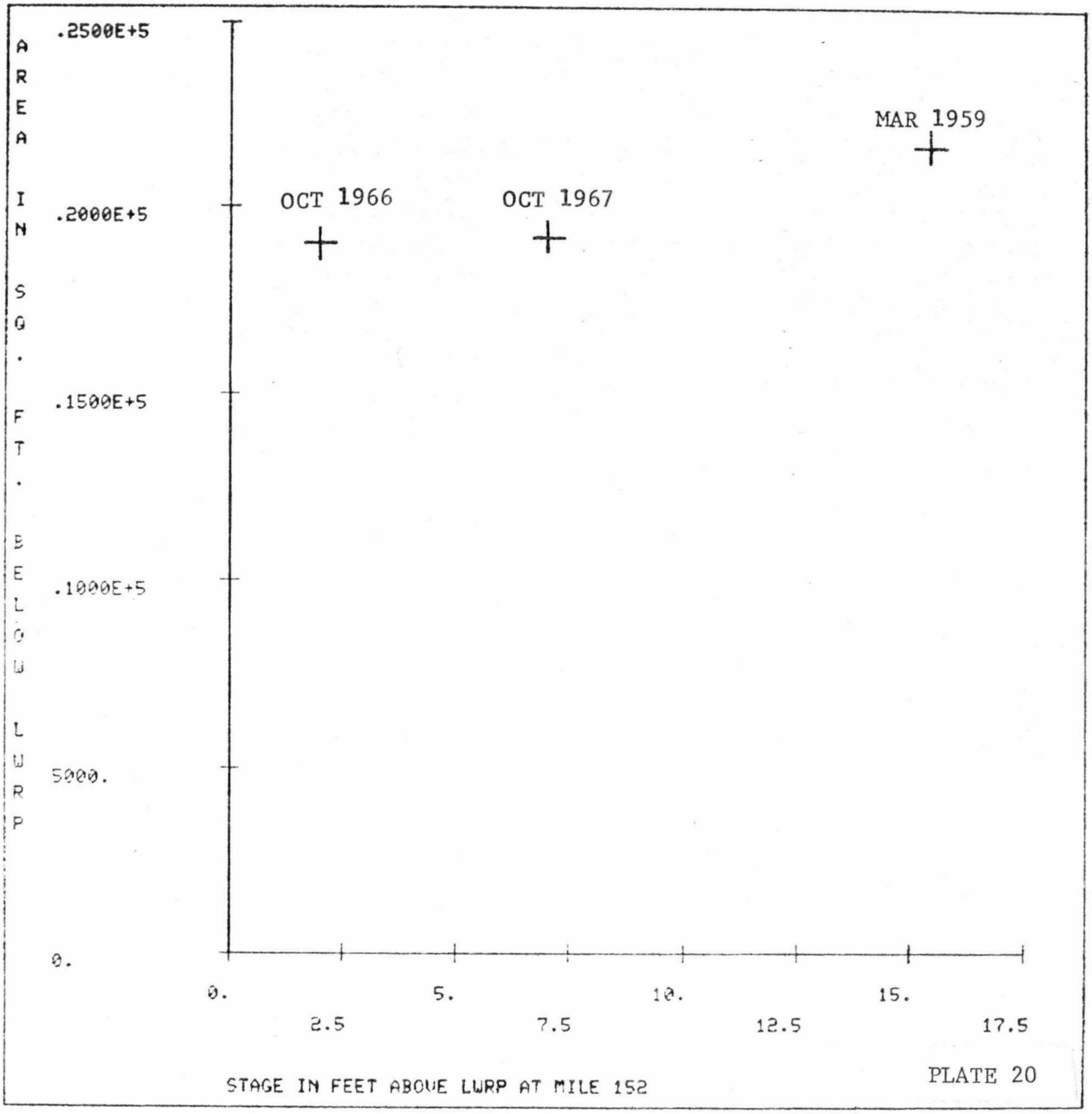

AREA IN SQ. FT. BELOW LWRP
.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
OCT 1966
OCT 1967
MAR 1959
0.
2.5
5.
7.5
10.
12.5
15.
17.5
STAGE IN FEET ABOVE LWRP AT MILE 152

PLATE 20

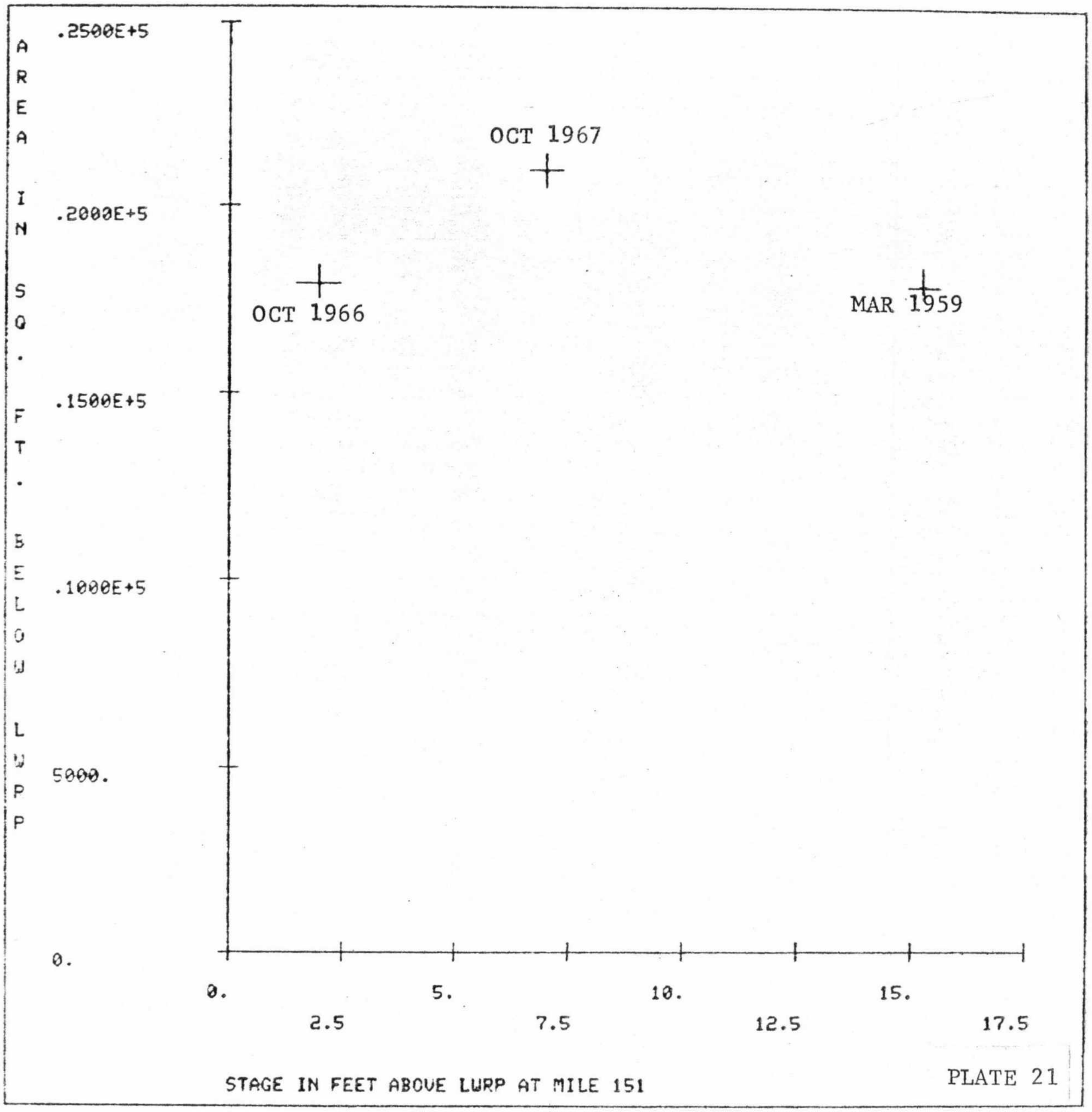
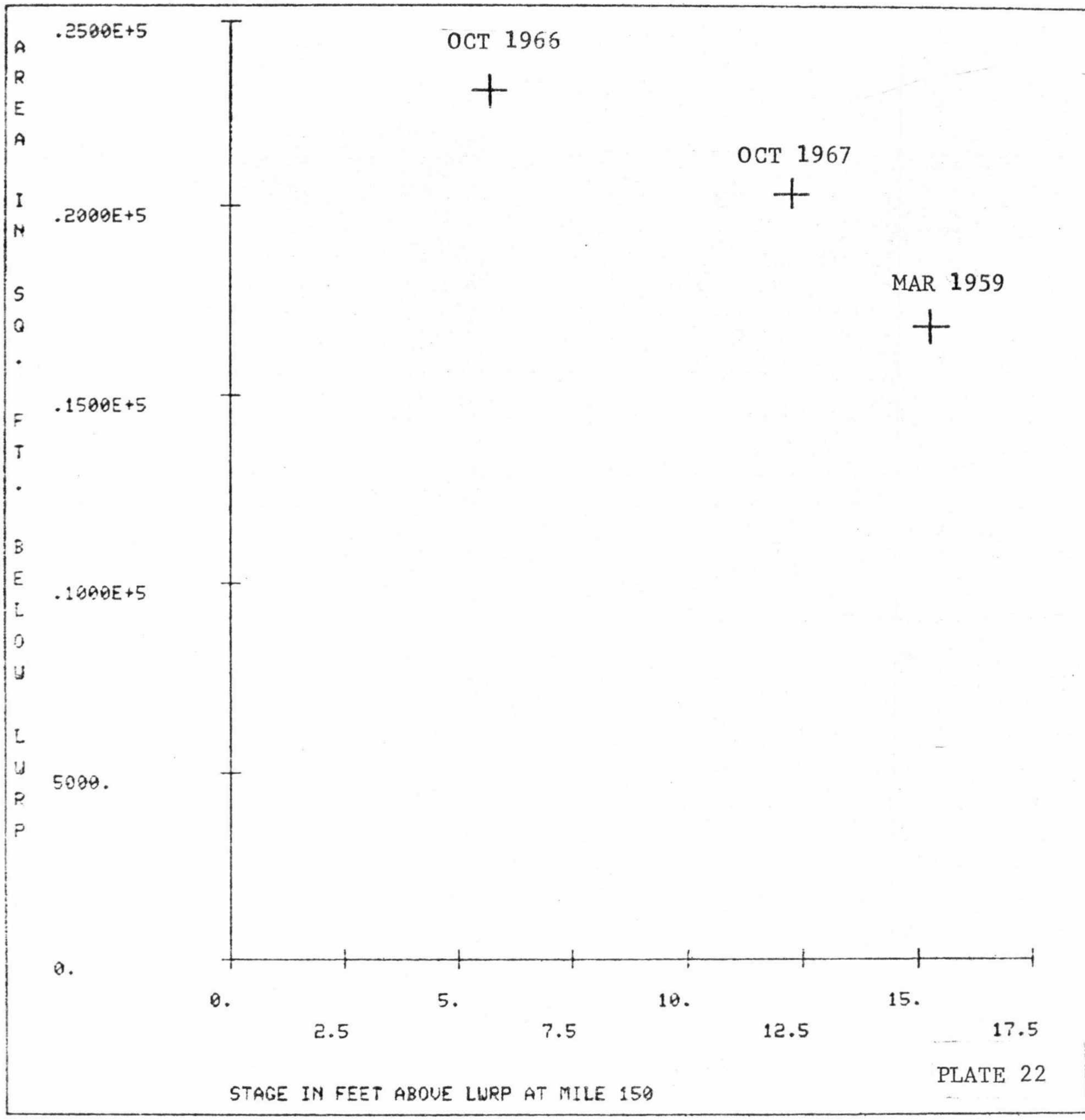

AREA IN SQ. FT. BELOW LWPP
.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
OCT 1967
OCT 1966
MAR 1959
0.
2.5
5.
7.5
10.
12.5
15.
17.5
STAGE IN FEET ABOVE LWRP AT MILE 151

PLATE 21



AREA IN SQ. FT. BELOW LWRP
.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
OCT 1966
OCT 1967
MAR 1959
0.
5.
10.
15.
2.5
7.5
12.5
17.5
STAGE IN FEET ABOVE LWRP AT MILE 150

PLATE 22

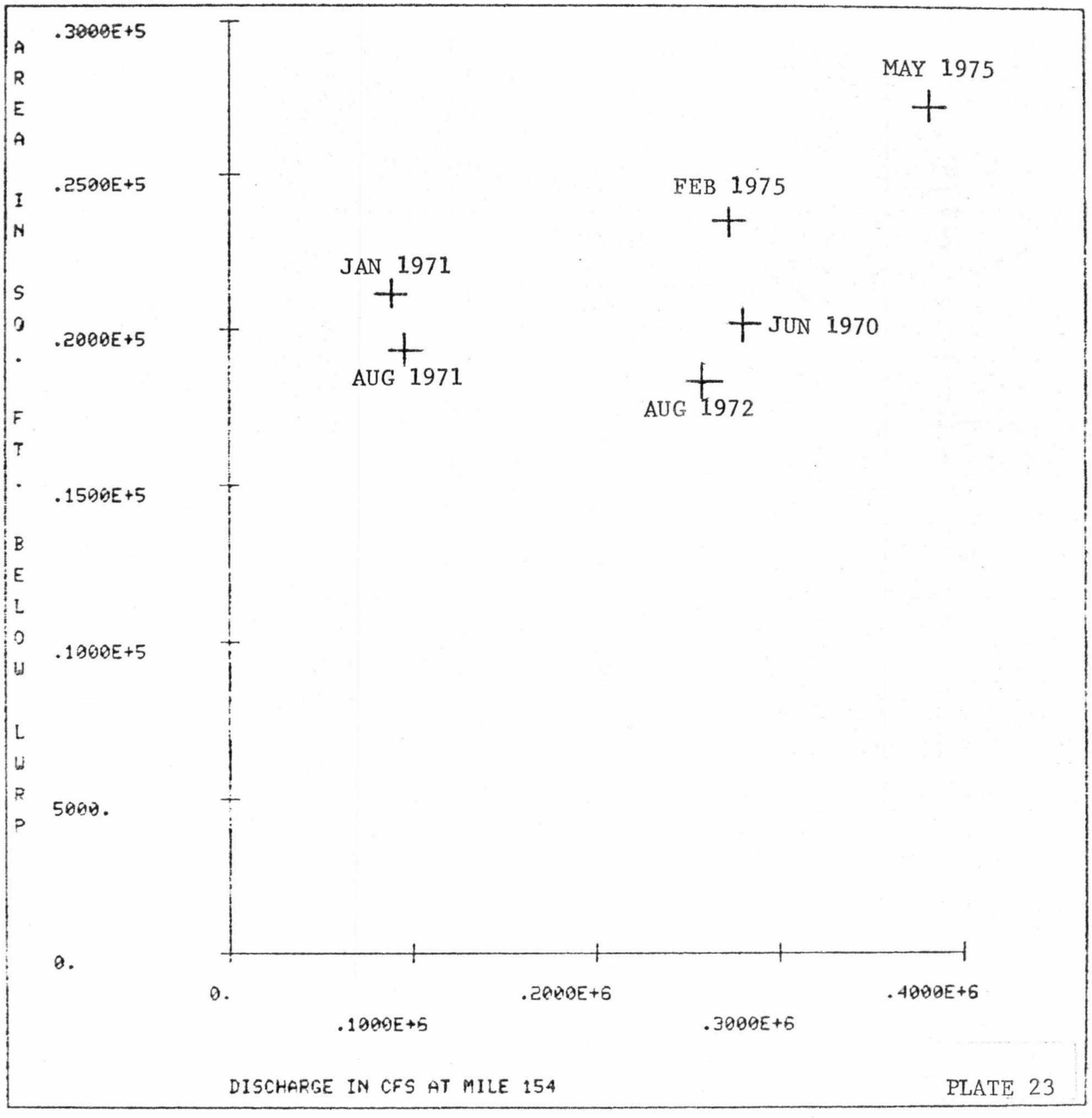
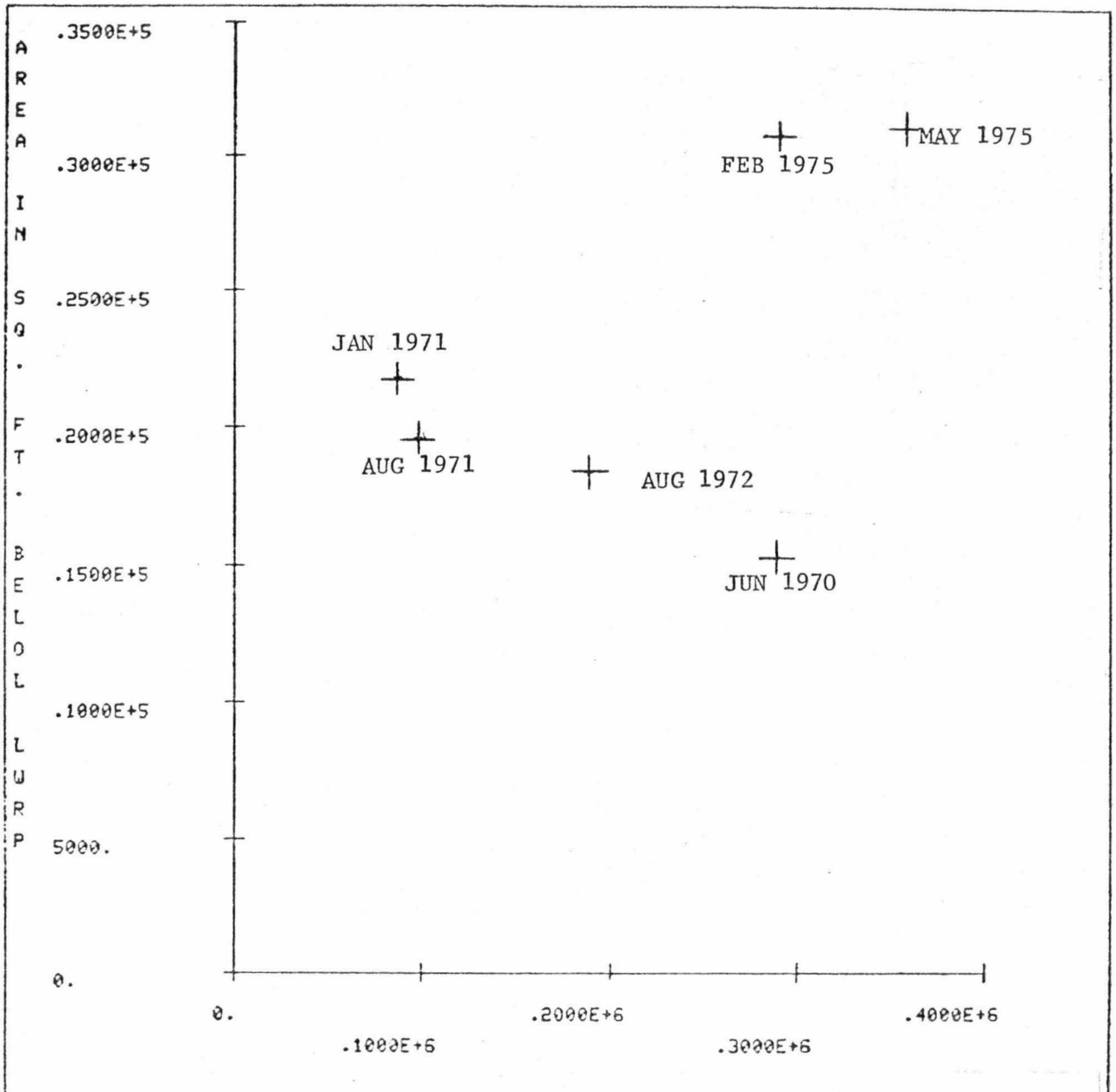

AREA IN SQ. FT. BELOW LWRP
.3000E+5
.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
MAY 1975
FEB 1975
JAN 1971
JUN 1970
AUG 1971
AUG 1972
0.
.1000E+6
.2000E+6
.3000E+6
.4000E+6
DISCHARGE IN CFS AT MILE 154

PLATE 23



AREA IN SQ. FT. BELOL LWRP
.3500E+5
.3000E+5
.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
JAN 1971
AUG 1971
AUG 1972
JUN 1970
FEB 1975
MAY 1975
0.
.1000E+6
.2000E+6
.3000E+6
.4000E+6
DISCHARGE IN CFS AT MILE 153

PLATE 24

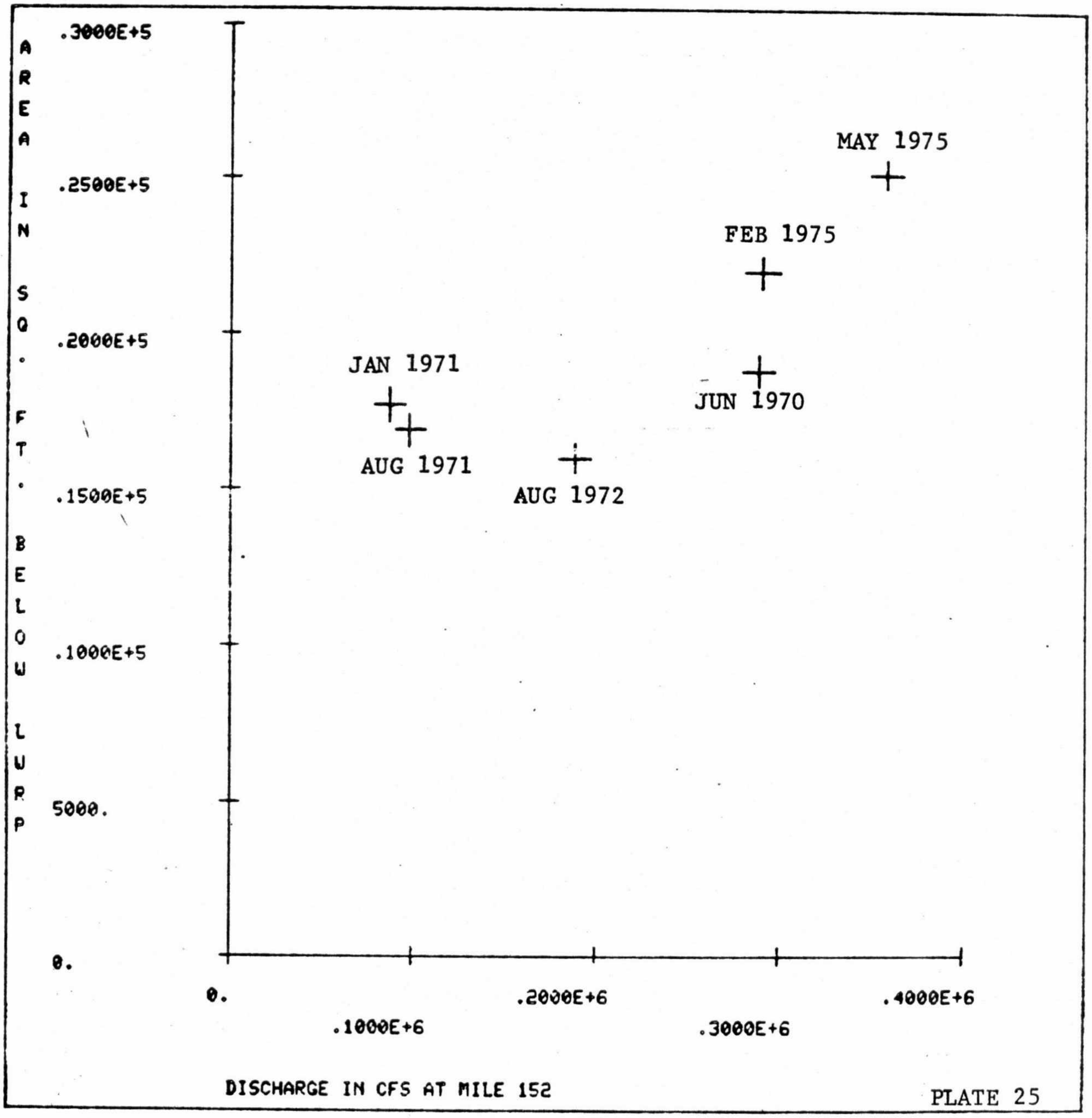

AREA IN SQ. FT. BELOW LURP
.3000E+5
.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
MAY 1975
FEB 1975
JAN 1971
JUN 1970
AUG 1971
AUG 1972
0.
.1000E+6
.2000E+6
.3000E+6
.4000E+6
DISCHARGE IN CFS AT MILE 152

PLATE 25

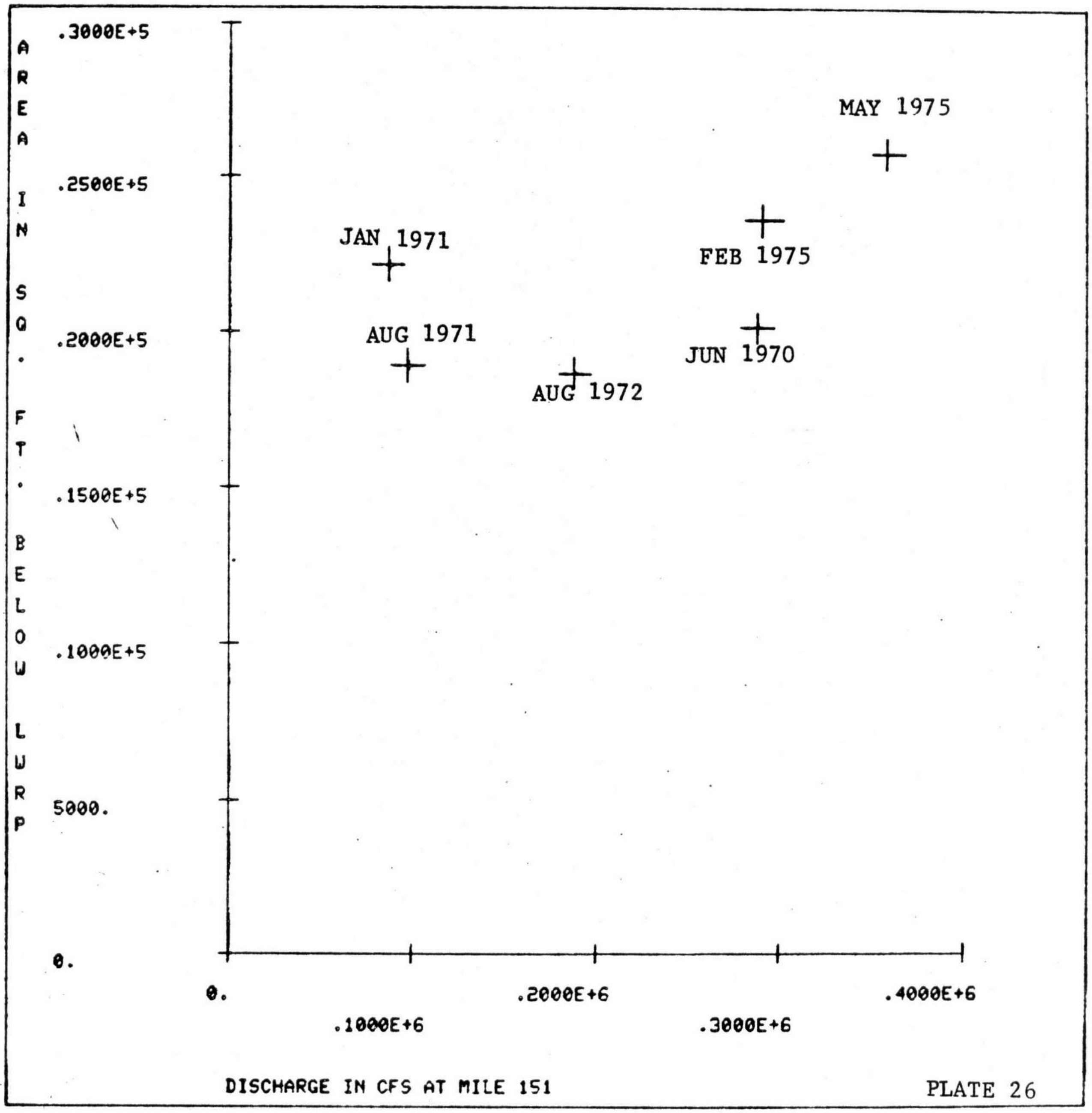

AREA IN SQ. FT. BELOW LWRP
.3000E+5
.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
MAY 1975
JAN 1971
FEB 1975
AUG 1971
JUN 1970
AUG 1972
0.
.1000E+6
.2000E+6
.3000E+6
.4000E+6
DISCHARGE IN CFS AT MILE 151

PLATE 26

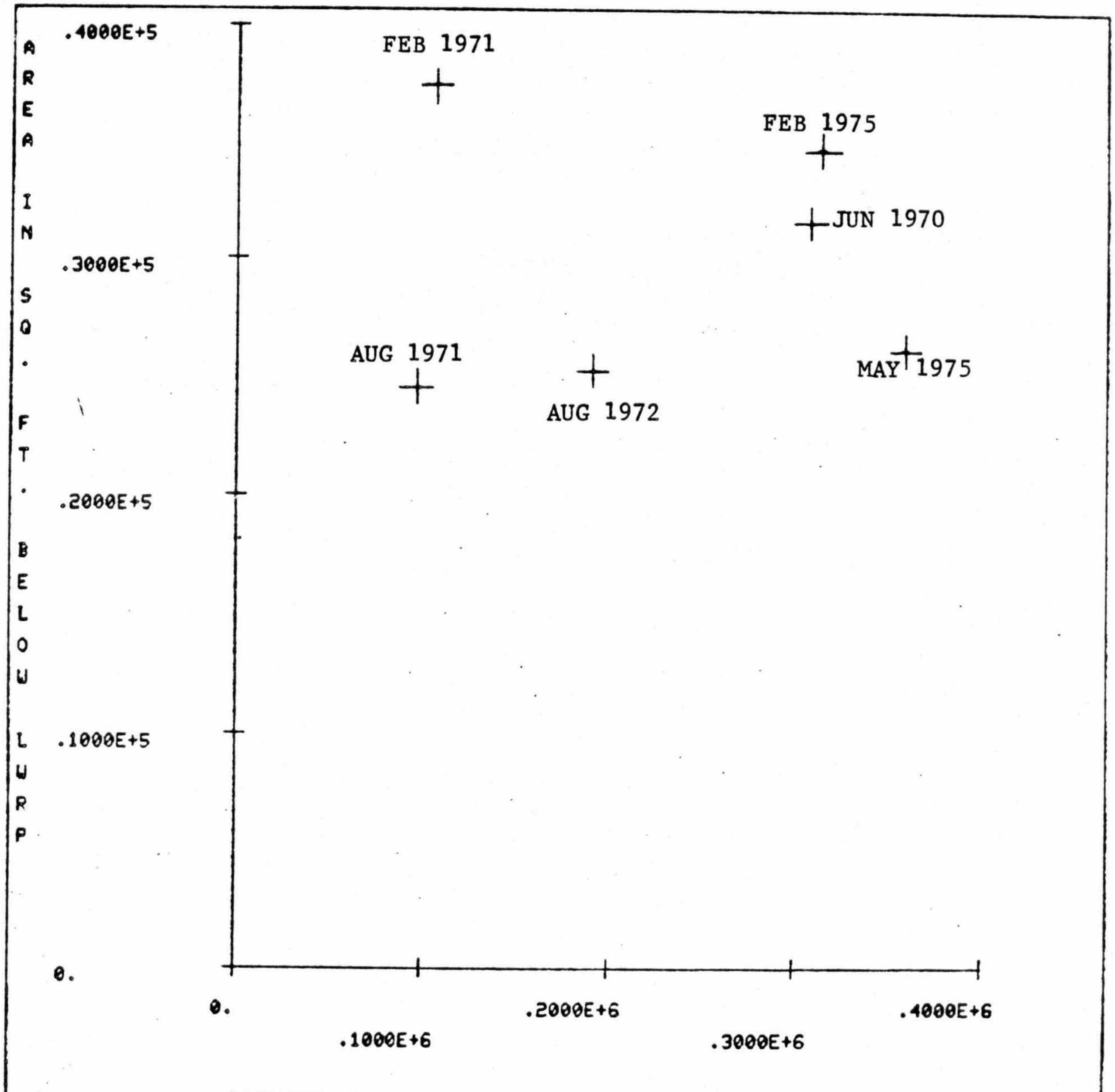
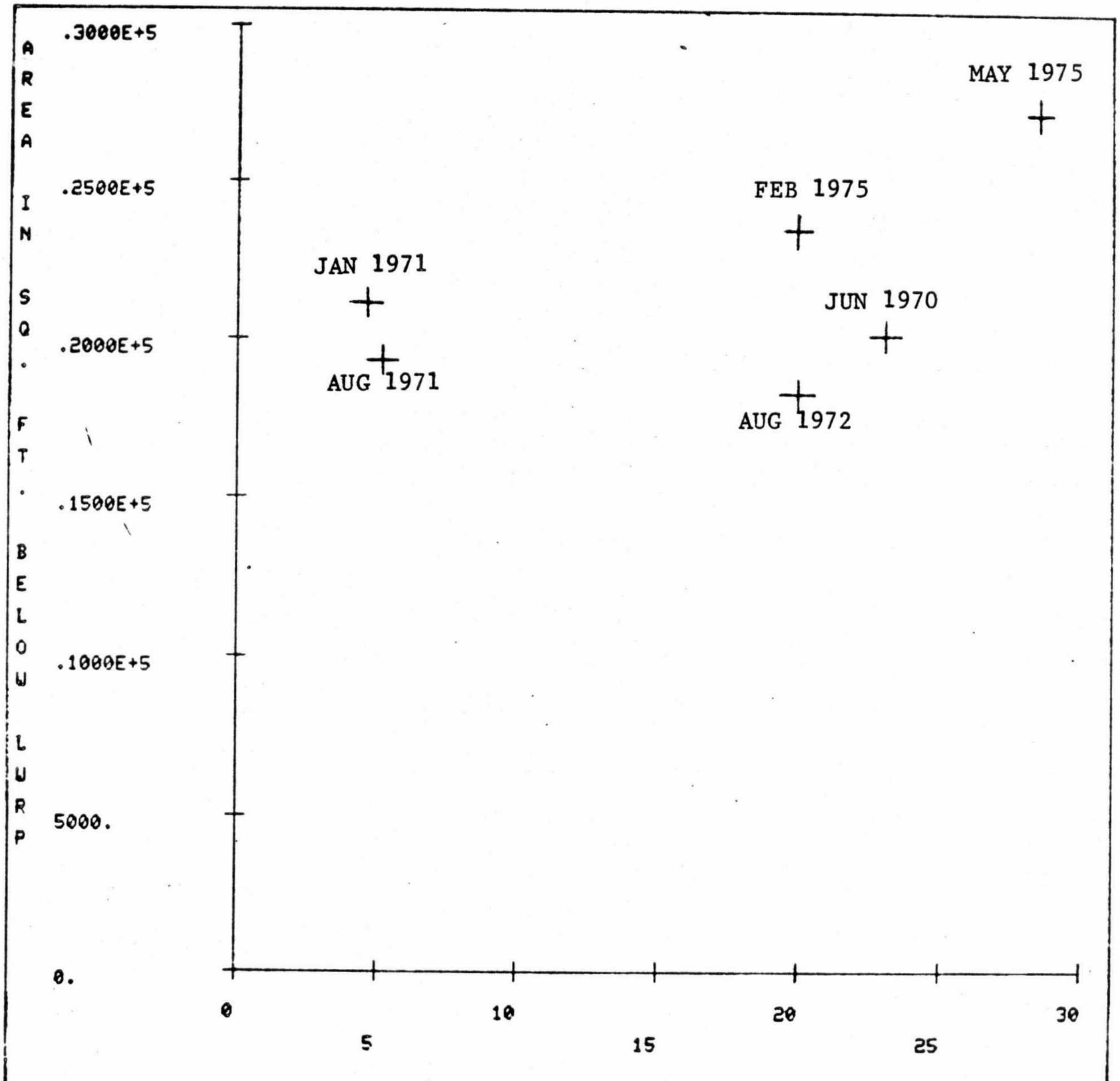

AREA IN SQ. FT. BELOW LWRP
.4000E+5
.3000E+5
.2000E+5
.1000E+5
0.
FEB 1971
FEB 1975
JUN 1970
AUG 1971
AUG 1972
MAY 1975
0.
.1000E+6
.2000E+6
.3000E+6
.4000E+6
DISCHARGE IN CFS AT MILE 150

PLATE 27



AREA IN SQ. FT. BELOW LWRP
.3000E+5
.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
MAY 1975
FEB 1975
JAN 1971
JUN 1970
AUG 1971
AUG 1972
0
5
10
15
20
25
30
STAGE IN FEET ABOVE LWRP AT MILE 154

PLATE 28

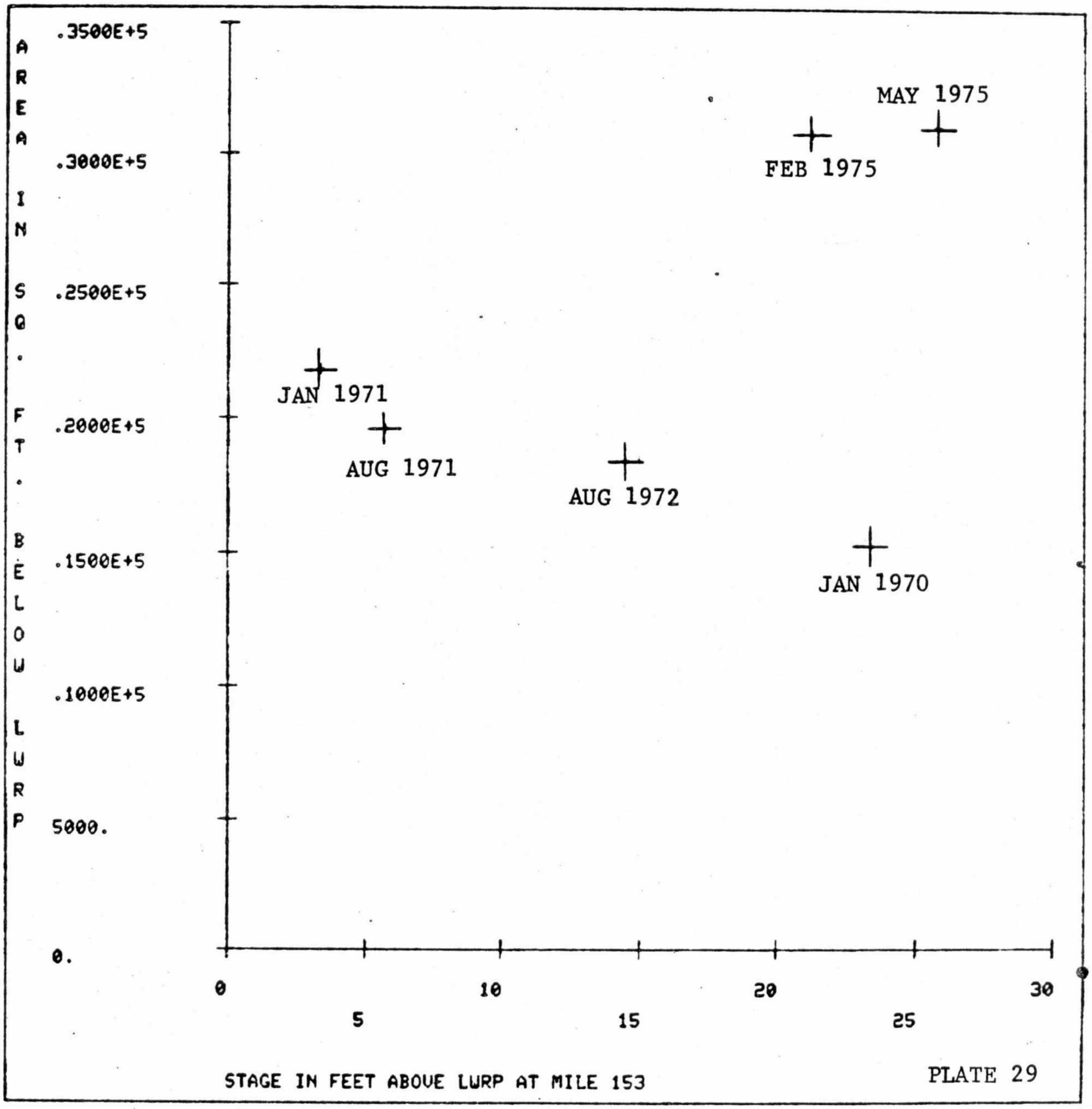

AREA IN SQ. FT. BELOW LWRP
.3500E+5
.3000E+5
.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
0
5
10
15
20
25
30
MAY 1975
FEB 1975
JAN 1971
AUG 1971
AUG 1972
JAN 1970
STAGE IN FEET ABOVE LWRP AT MILE 153

PLATE 29

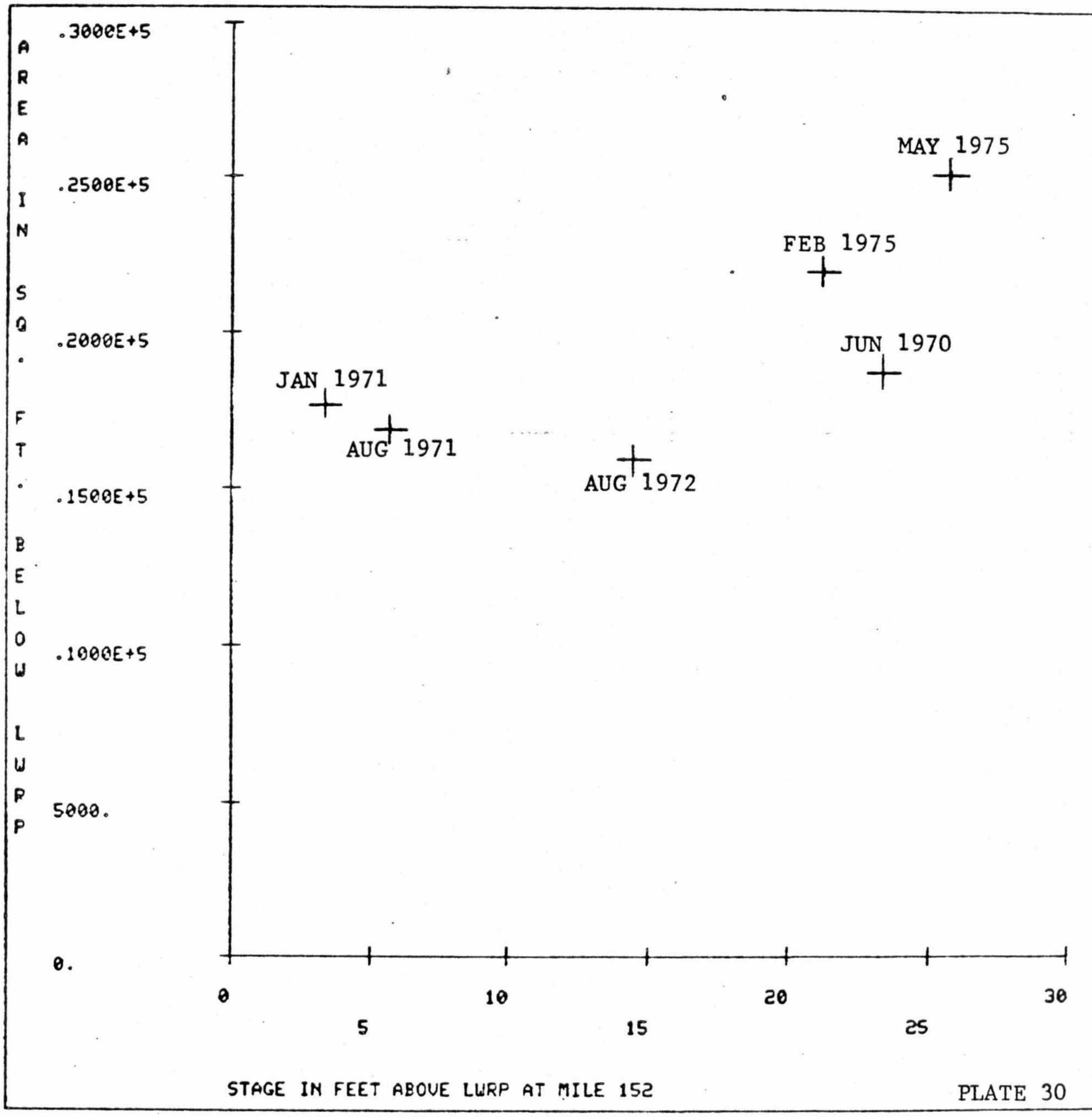

AREA IN SQ. FT. BELOW LWRP
.3000E+5
.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
MAY 1975
FEB 1975
JUN 1970
JAN 1971
AUG 1971
AUG 1972
0
5
10
15
20
25
30
STAGE IN FEET ABOVE LWRP AT MILE 152

PLATE 30

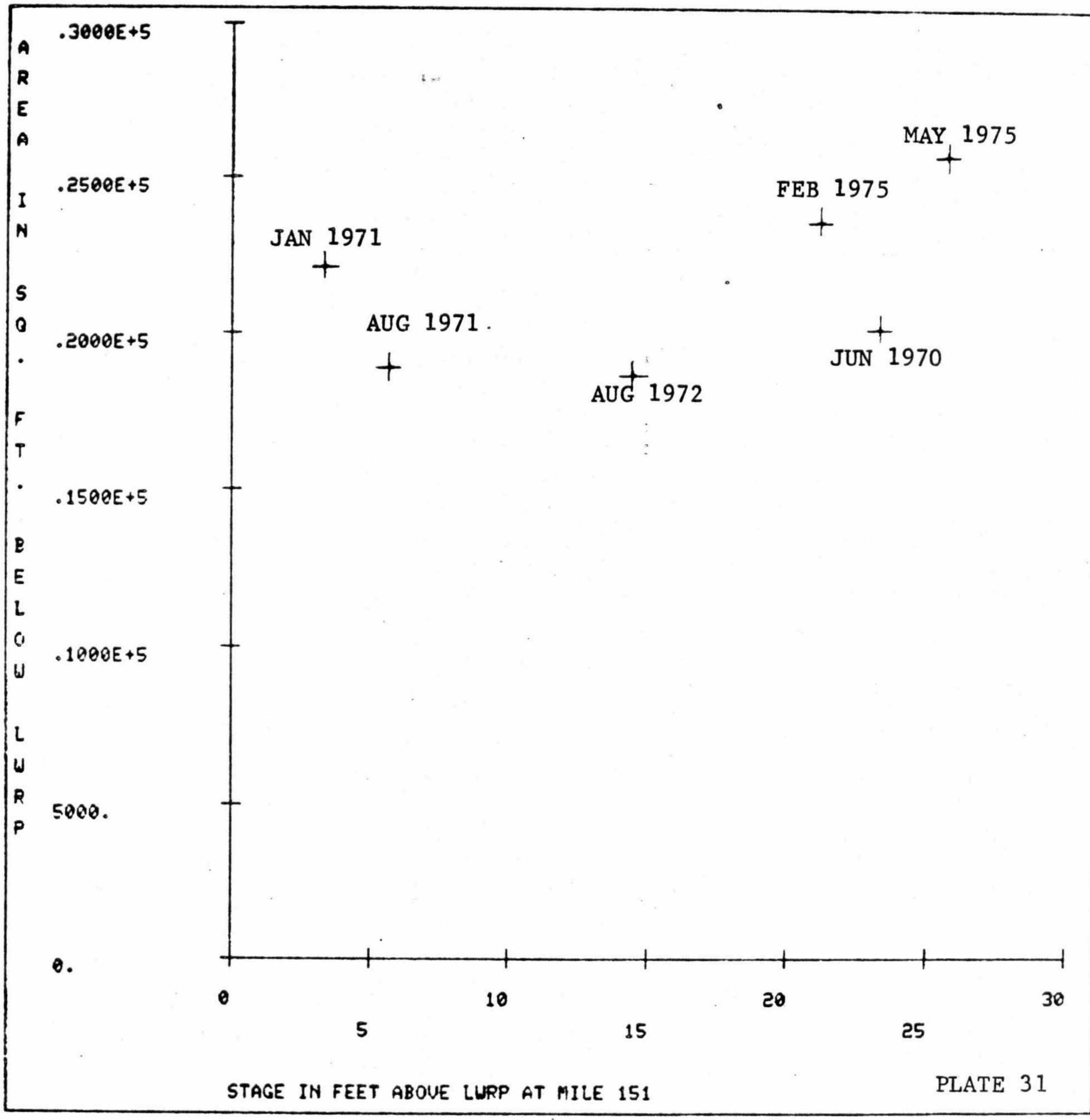
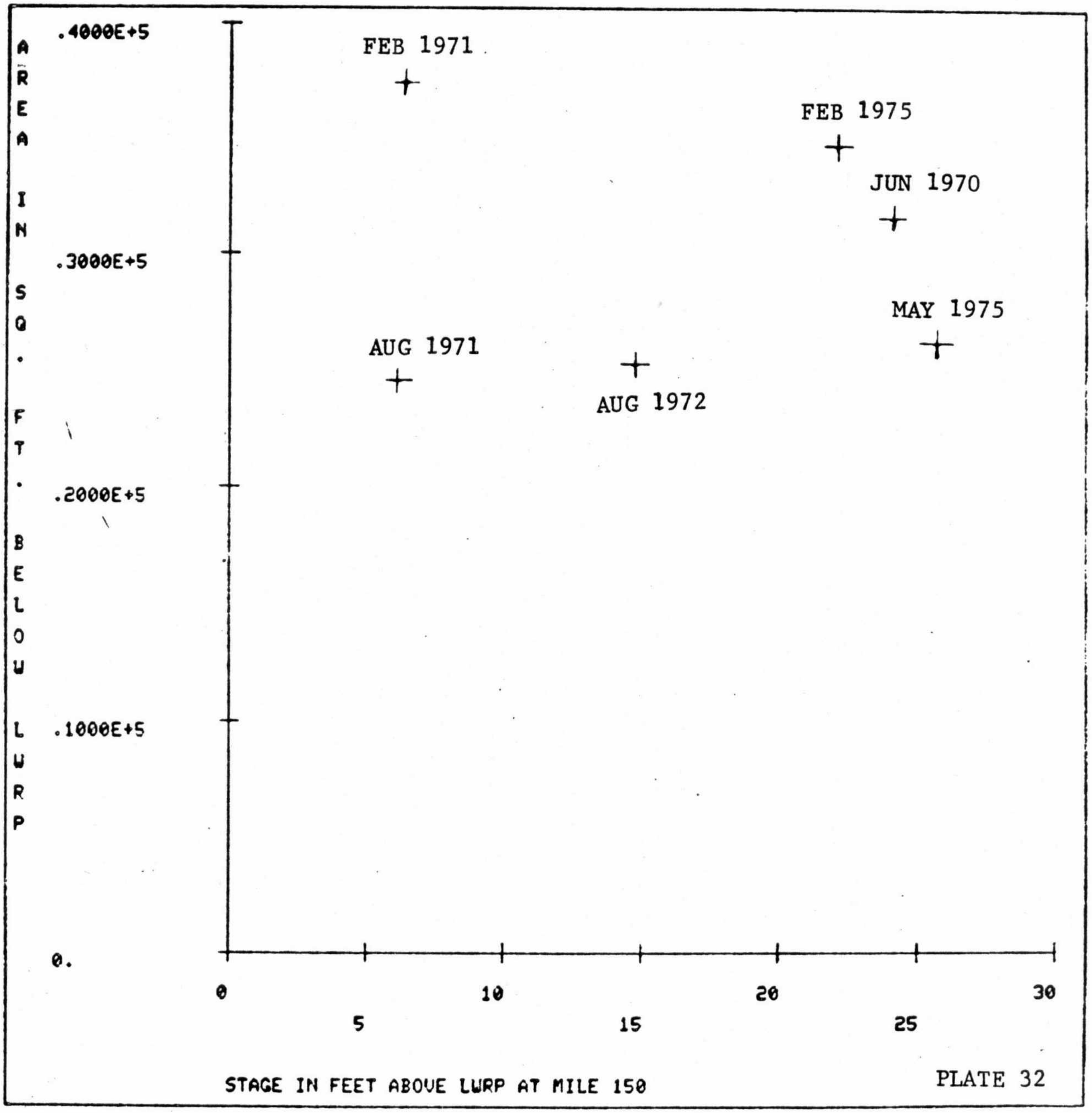

.3000E+5
.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
AREA IN SQ. FT. BELOW LWRP
MAY 1975
FEB 1975
JAN 1971
AUG 1971
JUN 1970
AUG 1972
0
5
10
15
20
25
30
STAGE IN FEET ABOVE LWRP AT MILE 151

PLATE 31



AREA IN SQ. FT. BELOW LWRP
.4000E+5
.3000E+5
.2000E+5
.1000E+5
0.
FEB 1971
FEB 1975
JUN 1970
MAY 1975
AUG 1971
AUG 1972
0
5
10
15
20
25
30
STAGE IN FEET ABOVE LWRP AT MILE 150

PLATE 32

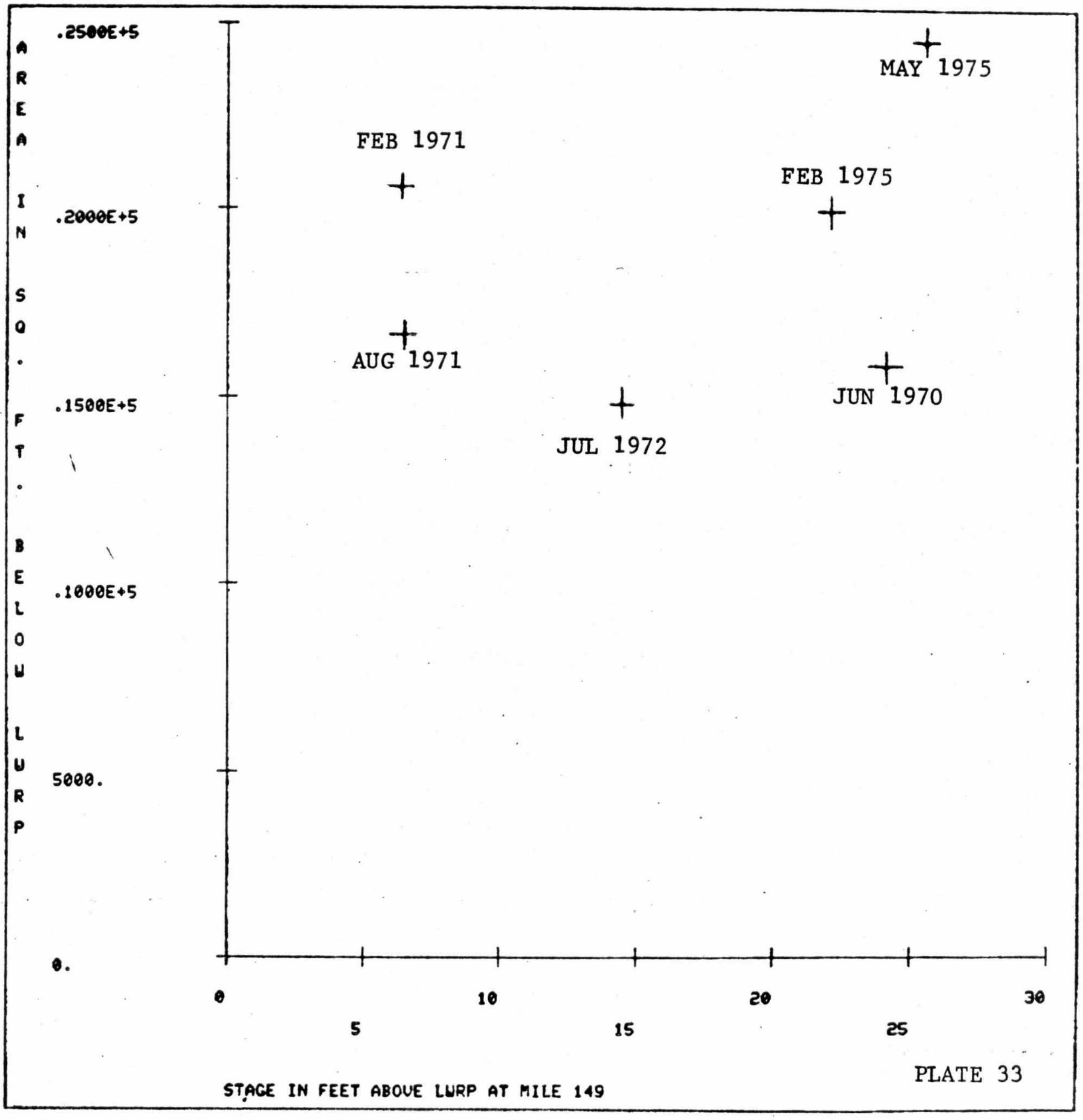

AREA IN SQ. FT. BELOW LWRP
.2500E+5
.2000E+5
.1500E+5
.1000E+5
5000.
0.
MAY 1975
FEB 1971
FEB 1975
AUG 1971
JUN 1970
JUL 1972
0
5
10
15
20
25
30
STAGE IN FEET ABOVE LWRP AT MILE 149

PLATE 33

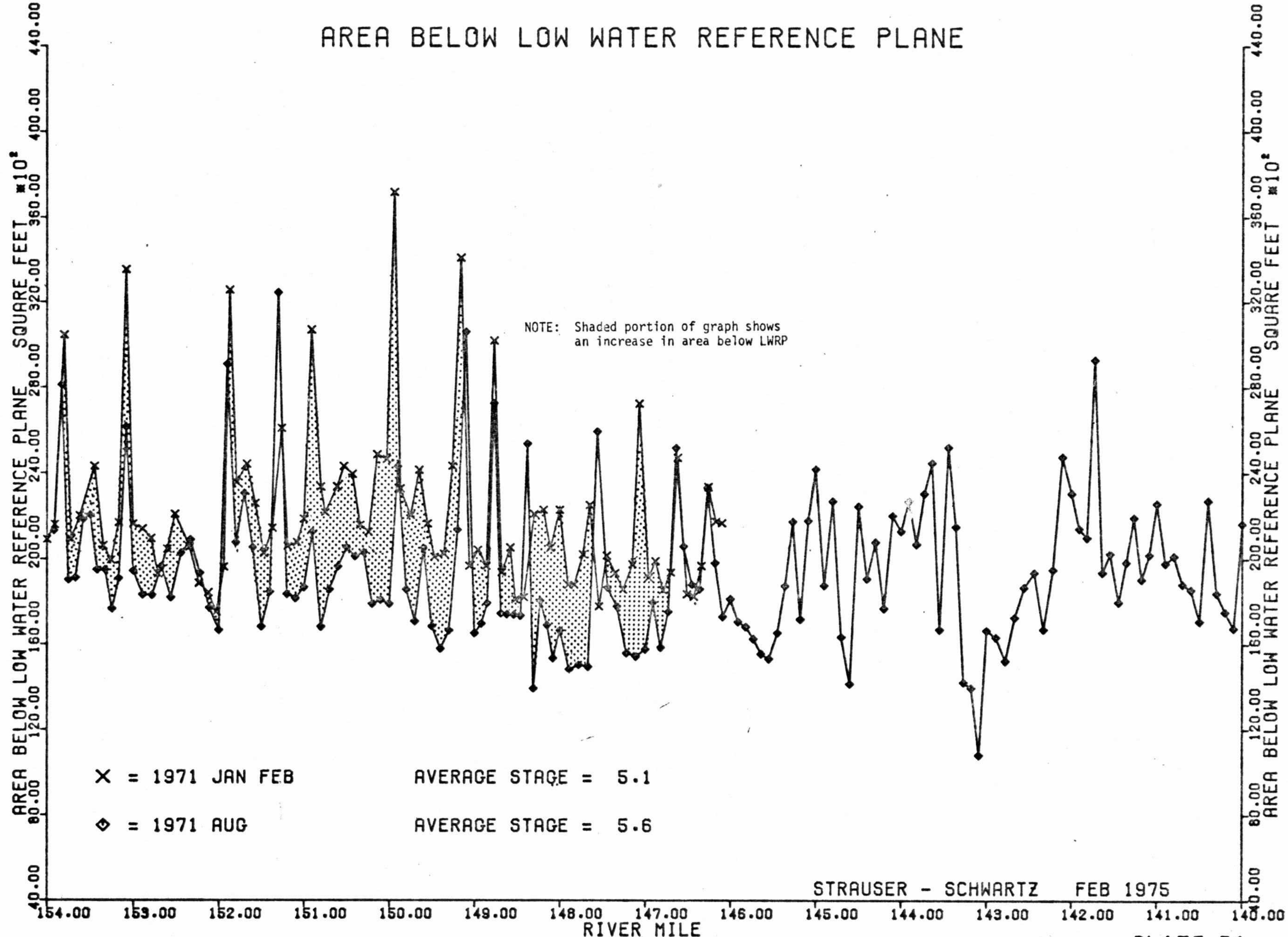
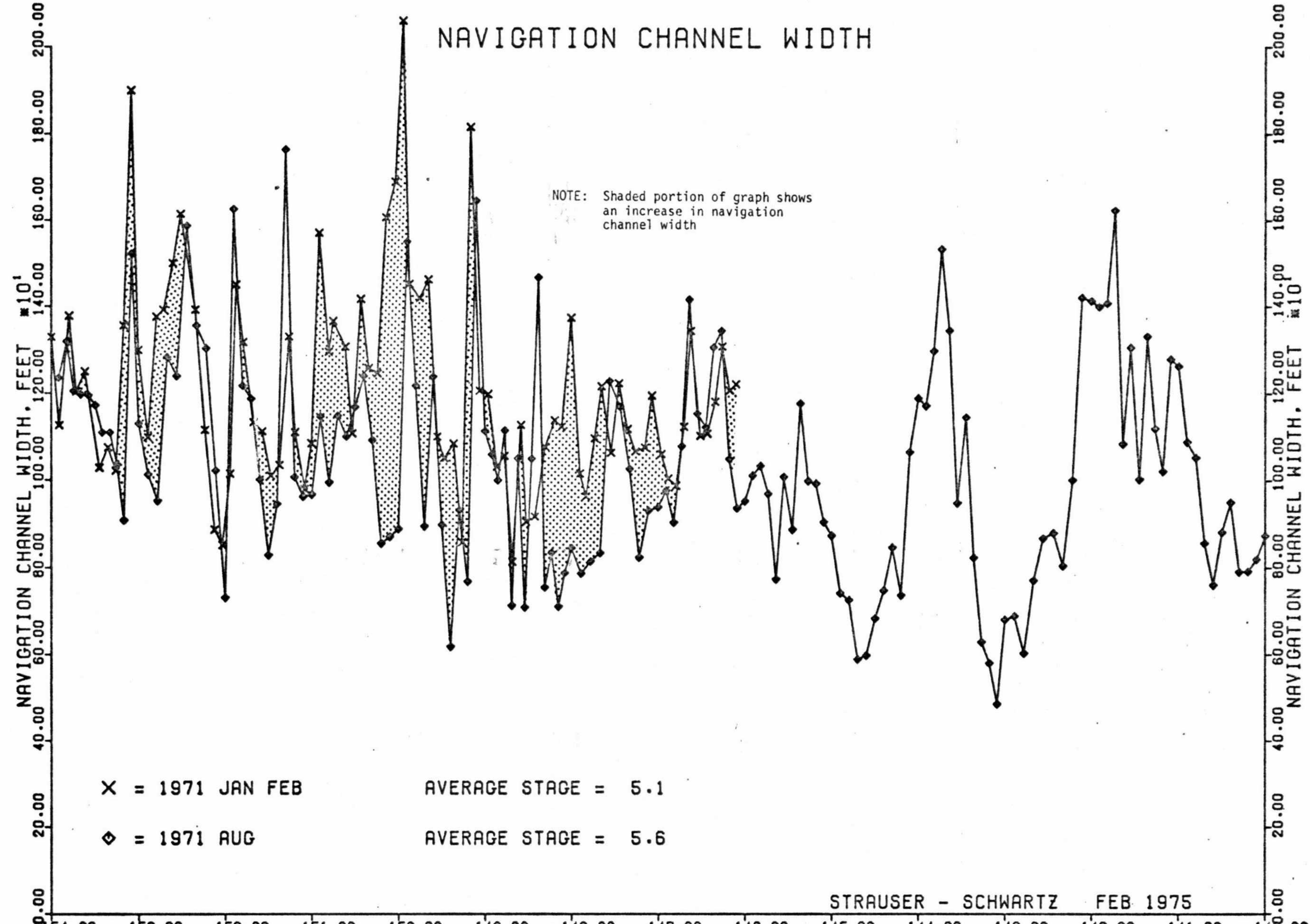
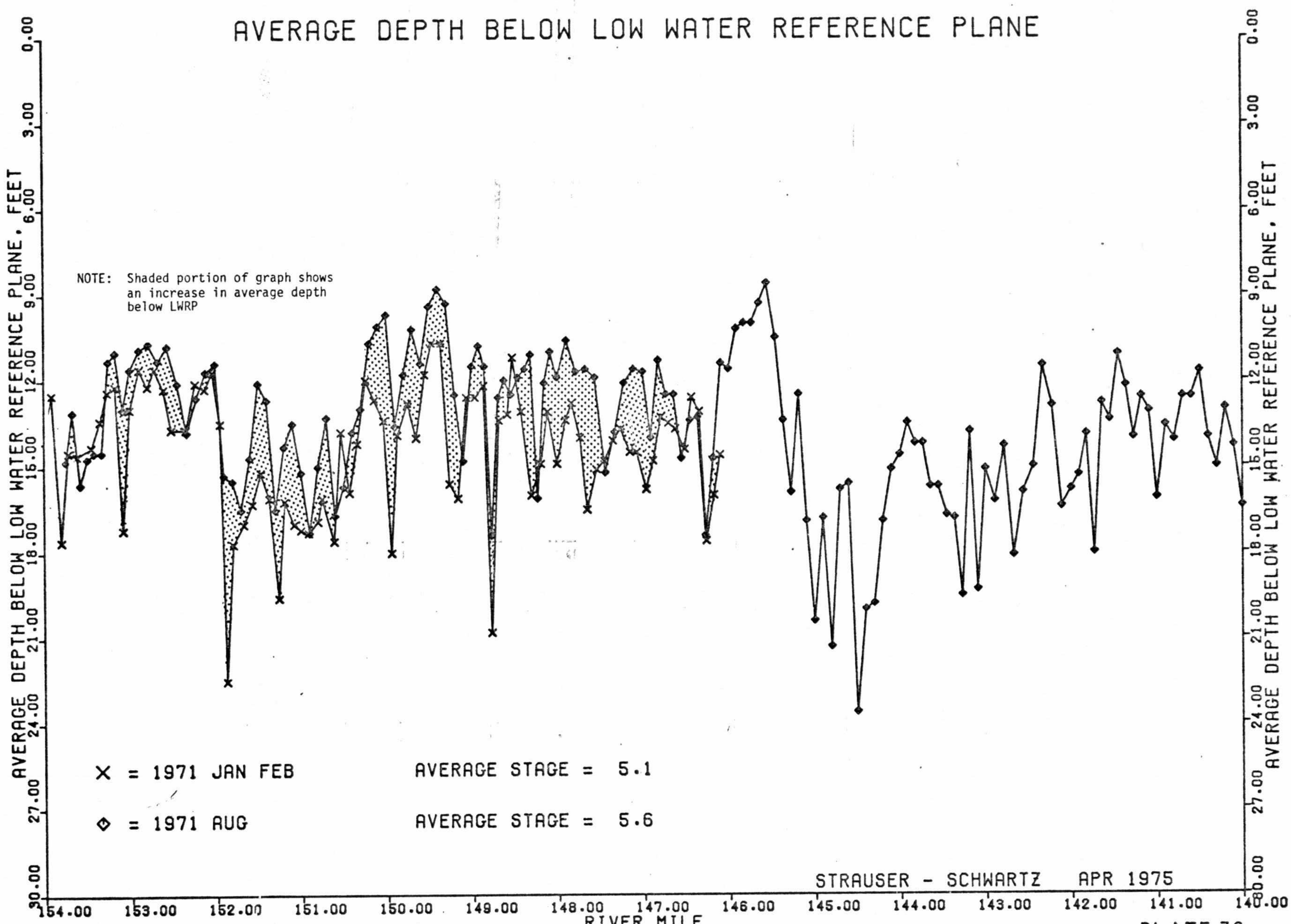

AREA BELOW LOW WATER REFERENCE PLANE
AREA BELOW LOW WATER REFERENCE PLANE SQUARE FEET *10²
40.00
80.00
120.00
160.00
200.00
240.00
280.00
320.00
360.00
400.00
440.00
NOTE: Shaded portion of graph shows an increase in area below LWRP
X = 1971 JAN FEB
AVERAGE STAGE = 5.1
◇ = 1971 AUG
AVERAGE STAGE = 5.6
STRAUSER - SCHWARTZ FEB 1975
154.00
153.00
152.00
151.00
150.00
149.00
148.00
147.00
146.00
145.00
144.00
143.00
142.00
141.00
140.00
RIVER MILE

PLATE 34


NAVIGATION CHANNEL WIDTH
NOTE: Shaded portion of graph shows an increase in navigation channel width
NAVIGATION CHANNEL WIDTH, FEET ×10¹
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
180.00
200.00
154.00
153.00
152.00
151.00
150.00
149.00
148.00
147.00
146.00
145.00
144.00
143.00
142.00
141.00
140.00
RIVER MILE
× = 1971 JAN FEB
AVERAGE STAGE = 5.1
◇ = 1971 AUG
AVERAGE STAGE = 5.6
STRAUSER - SCHWARTZ FEB 1975



AVERAGE DEPTH BELOW LOW WATER REFERENCE PLANE
AVERAGE DEPTH BELOW LOW WATER REFERENCE PLANE, FEET
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00
30.00
NOTE: Shaded portion of graph shows an increase in average depth below LWRP
X = 1971 JAN FEB
AVERAGE STAGE = 5.1
◇ = 1971 AUG
AVERAGE STAGE = 5.6
STRAUSER - SCHWARTZ APR 1975
154.00
153.00
152.00
151.00
150.00
149.00
148.00
147.00
146.00
145.00
144.00
143.00
142.00
141.00
140.00
RIVER MILE

PLATE 36