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US Army Corps of Engineers

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JEFFERSON BARRACKS BRIDGE

Movable-Bed Model Study

by

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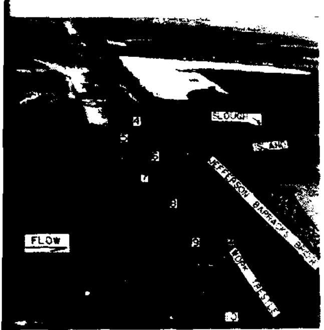

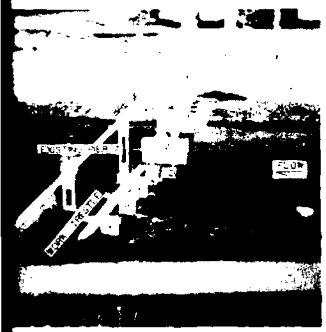

August 1988

Final Report

Prepared for ILLINOIS DEPARTMENT OF TRANSPORTATION
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In July 1977, the Illinois Department of Transportation awarded a contract to construct piers for Interstate Highway 255 Bridge across the Mississippi River at mile 168.7.

As of March 1979, the contractor had constructed a work trestle across Jefferson Barracks Slough and a work trestle from the island to a point past pier 10. The contractor also had constructed cofferdams for the construction of piers 5-10, 12, and 13.

In the spring of 1979, the discharge in the river increased, and debris accumulated upstream of the work trestle. On 21 March 1979, the portion of the work trestle between cofferdams at piers 9 and 10 failed. It is not known exactly when the cofferdam at pier 10 failed, but it is assumed that it failed about the same time as the trestle

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19. ABSTRACT (Continued).

between cofferdams at piers 9 and 10 failed. By 19 April 1979, the cofferdam at pier 9 and the portion of the work trestle between cofferdams at piers 8 and 9 had failed.

This study was conducted to investigate the relationship of the existence of the work trestle, the cofferdams, and the accumulation of debris that occurred upstream of the work trestle to the riverbed movement that occurred before, during, and after the failure of the work trestle and cofferdams.

Results obtained during the model study indicate the following:

a. Discharges of the magnitude of the 1979 flood (maximum of 685,000 cfs) would result in minimal bed scour of the left side of the river. The left side of the Mississippi River at Jefferson Barracks Bridge is on the inside of a gentle bend where the water is shallow and the velocities are slower than those in the deeper part of the channel.

b. The addition of the work trestle and cofferdams would have no effect on general bed scour. There would be minimal local scour around the piles driven to support the trestle and there would be local scour around cofferdams at piers 8, 9, and 10.

c. The addition of the 10-acre area of debris (9- and 18-ft thicknesses) that accumulated upstream of the work trestle would cause flow in the area to be concentrated under and around the west end of the debris. This concentrated flow would scour the bed of the river in the vicinity of the west end of the work trestle. The depth of scour in the vicinity of the work trestle would vary directly with the thickness of the debris. The greater the thickness of debris, the deeper the scour.

(1) The 9-ft-thick area of debris upstream of the work trestle would cause considerable scour of the bed between and around cofferdams at piers 8, 9, and 10.

(2) The 18-ft-thick area of debris upstream of the work trestle would cause extensive scour of the bed between and around cofferdams at piers 8, 9, and 10.

Design considerations for movable-bed models are discussed in Appendix A, the general adjustment and verification procedure for movable-bed models is presented in Appendix B, and the adjustment and verification of the St. Louis Harbor model are described in Appendix C.

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PREFACE

This model study was conducted by the Hydraulics Laboratory of the US Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, during the period September 1984 to May 1985 for the US Army Engineer District, St. Louis (LMS), and funded by the Illinois Department of Transportation (The Department).

The model study was conducted under the general supervision of Mr. Frank A. Herrmann, Jr., Chief, Hydraulics Laboratory, and under the direct supervision of Mr. J. E. Glover, Chief, Waterways Division, and Mr. C. W. O'Neal, Chief, River Regulation Branch. The study was conducted by Mr. D. W. Webb, assisted by Mr. J. L. McGregor and Ms. L. G. Porter, Technicians, River Regulation Branch. Mr. James E. Foster, consultant for The Department, was present during all testing to observe model conditions and participated in conferences to determine model operating procedures, determine adequacy of the model verification, and review test results. Dr. Glendon Stevens, consultant for The Department, visited WES during the course of the study to observe the model in operation and discuss test results. This report was written by Mr. Foster and edited by Mrs. M. C. Gay, Information Technology Laboratory, WES.

COL Dwayne G. Lee, EN, is the Commander and Director of WES. Dr. Robert W. Whalin is the Technical Director.

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CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.873	square metres
cubic feet	0.02831685	cubic metres
feet	0.3048	metres
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres

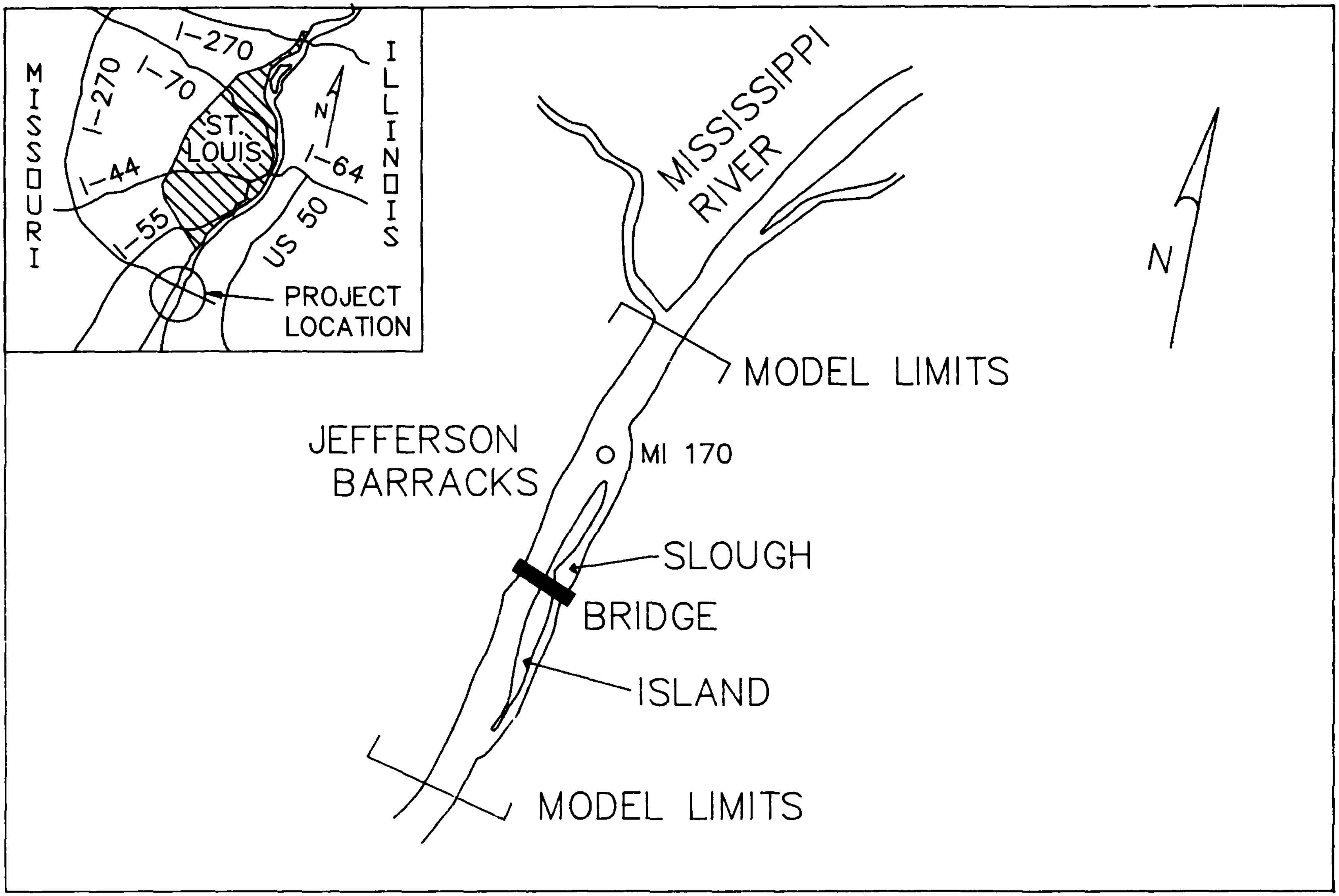

Figure 1. Location and vicinity map

JEFFERSON BARRACKS BRIDGE

Movable-Bed Model Study

PART I: INTRODUCTION

Location and Description of the Study Reach

1. This model study was conducted to analyze general bed scour in the Mississippi River from mile 171.5* to mile 166.5 (Figure 1). This 5-mile** reach of the Mississippi River, which throughout this report will be referred to as the prototype, varies in width from 2,000 to 2,500 ft wide. The bed varies from el 355† to el 380 in the vicinity of Jefferson Barracks Bridge with the island (between Jefferson Barracks Slough and the river) to el 399 (Plate 1). The thalweg, the deepest part of the channel, crosses from the left bank†† to the right bank at the upstream end of the study reach, follows the right bank through the Jefferson Barracks Bridge, and crosses back to the left bank at the downstream end of the study reach. The left side of the river at the bridge is on the inside of a gentle bend and consists of shallow depths and sand bars (from el 366 to el 380). The velocities in the left side of the river are considerably slower than those in the right side of the river, which is normal for the inside of a bend.

The Problem

2. In 1977, the contract for construction of the substructure for a new bridge across the Mississippi River within the study reach was awarded, and the work was begun. The substructure was to have 14 piers numbered consecutively from east to west, as shown in Plate 2. Seven piers (7-13) were to be constructed in the Mississippi River. Piers 7-10 were located in the shallow

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* Mile 171.5 and other locations so cited are in river miles above the mouth of the Ohio River.

** A table of factors for converting non-SI units of measurement to SI (metric) units of measurement is found on page 3.

† All elevations cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

†† Left and right banks are oriented toward downstream.

depths and on sand bars on the inside of the gentle bend.

3. The contractor began working on the piers in the fall of 1977, and by 5 March 1979, had built a work trestle across Jefferson Barracks Slough and a work trestle from the island to a point past pier 10. This work trestle was 22 ft 8 in. wide, curb to curb, to a top el of 400. It also had upstream and downstream extensions at cofferdams for piers 8-10 as shown in Plate 3. Sheet piles for cofferdams at piers 4-10, 12, and 13 had been placed. Other piers and cofferdams had been built, but these were the only ones within model limits. Figure 2 shows cofferdams at piers 4-10.

4. From 8 March to 27 March 1978, the discharge in the river increased from 88,000 to 570,000 cfs. From 21 February to 26 February 1979, the discharge increased from 91,000 to 300,000 cfs; and after a slight decrease, the discharge again increased during the period 1 through 7 March 1979, from 243,000 to 429,000 cfs. Discharge increases of such magnitude in short periods of time are not uncommon in this reach of the Mississippi River. These increases in discharge increase the concentration of floating debris in the river. Debris tends to accumulate on the upstream side of stationary objects. As the debris accumulates upstream of the stationary objects, water is forced around and under the debris. The water that goes under the debris carries additional debris that will catch on objects that extend down into the water. The debris can potentially accumulate to the bed of the river.

5. In 1978, debris accumulated upstream of the completed portion of the work trestle as shown in Figure 3. Debris remained under and upstream of the trestle at the time of the increase in discharge in 1979 as shown in Figure 4. During the 1979 increases in discharge, debris continued to accumulate upstream along the full length of the work trestle. By 10 March 1979, debris covered more than 10 acres upstream of the work trestle as shown in Figure 2.

6. The discharge continued to increase and the debris continued to accumulate in area and depth. On 21 March 1979, with a discharge of 426,000 cfs, the trestle between cofferdams at piers 9 and 10 failed. It is not known exactly when the cofferdam at pier 10 failed, but it is assumed that it failed about the same time as the trestle between cofferdams at piers 9 and 10 failed. When the trestle and cofferdams failed, the debris upstream of the failed portion of the work trestle floated downstream. The discharge increased to 570,000 cfs on 27 March, decreased to 324,000 cfs on 6 April, and increased to 429,000 cfs on 19 April 1979. By this time the cofferdam at

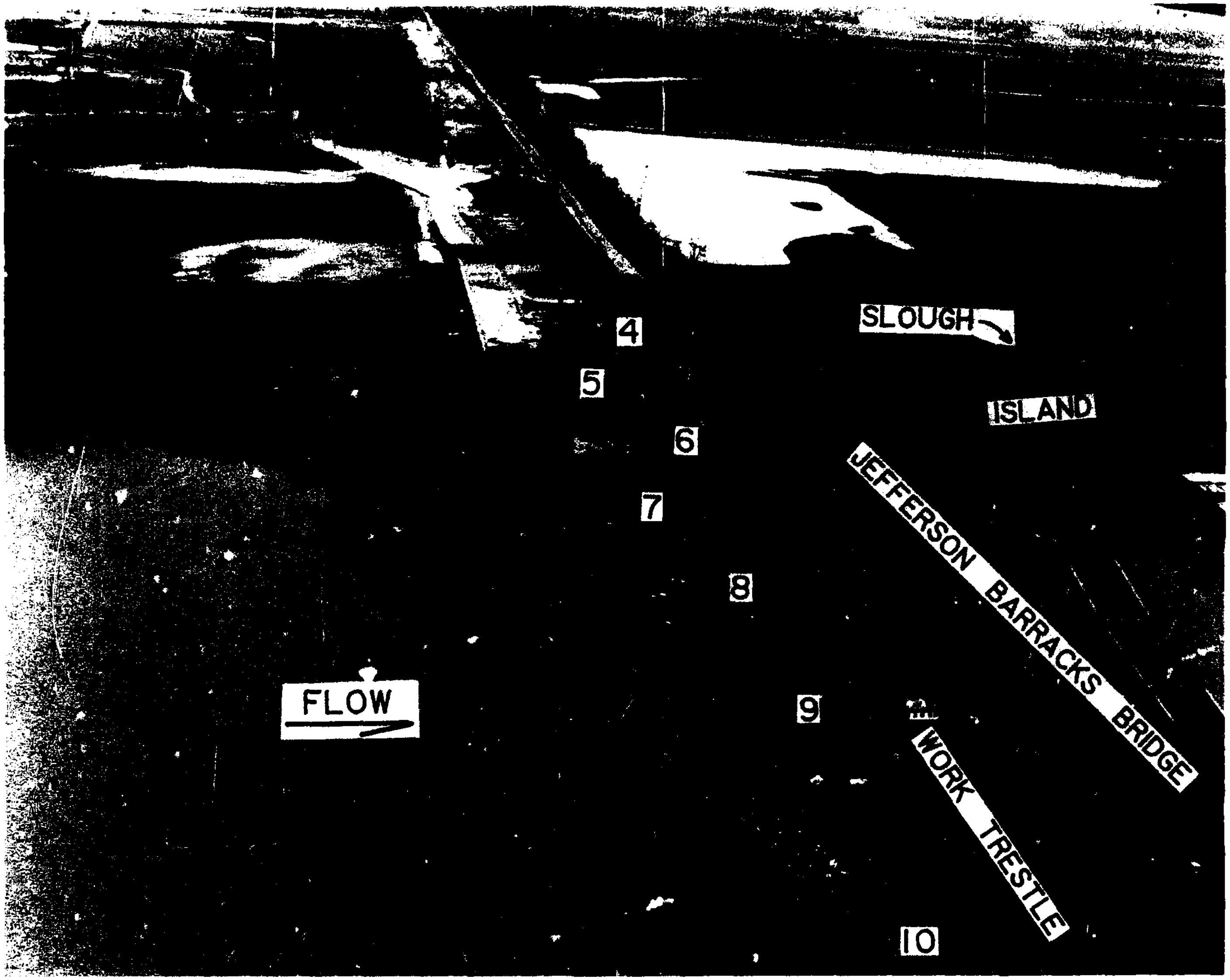

Figure 2. Mississippi River at Jefferson Barracks Bridge on 10 March 1979. Note work trestle, cofferdams, and debris accumulated upstream of work trestle

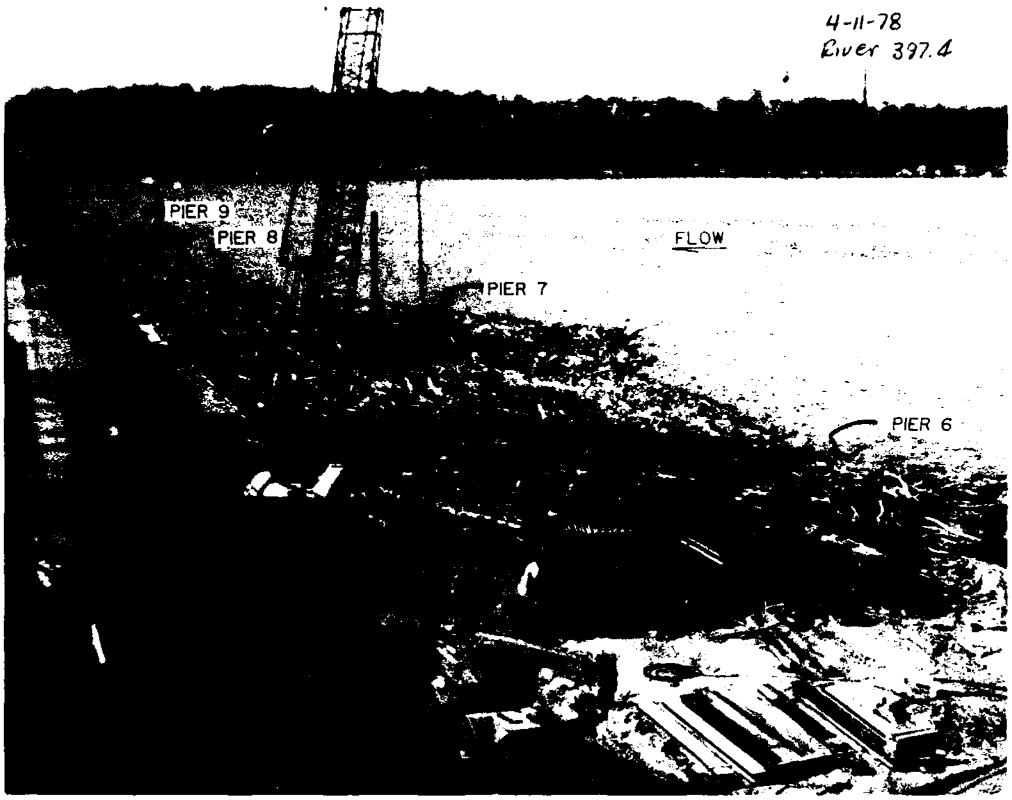

Figure 3. Mississippi River at Jefferson Barracks Bridge on 11 April 1978 looking west toward the river. Note debris upstream of work trestle

Figure 4. Mississippi River at Jefferson Barracks Bridge on 19 February 1979 looking west toward the river. Note debris under the work trestle

pier 9 and the trestle between cofferdams at piers 8 and 9 had failed. The trestle between cofferdams at piers 8 and 9 failed progressively, and it is not known exactly when the cofferdam at pier 9 failed. When that portion of the trestle and cofferdam failed, the debris upstream of them floated downstream.

Purpose of the Model Study

7. The purpose of this study was to investigate the relationship of the existence of the work trestle, the cofferdams, and the accumulation of debris that occurred upstream of the work trestle to the riverbed movement that occurred before, during, and after the failure of the work trestle and cofferdams.

PART II: THE MODEL AND ITS VERIFICATION

Selection of Model

8. The Illinois Department of Transportation (The Department) requested the US Army Engineer District, St. Louis, to have tests conducted on the St. Louis Harbor model, an existing movable-bed model at the US Army Engineer Waterways Experiment Station (WES) at Vicksburg, MS, that during previous tests had proven its ability to determine riverbed scour and deposition in this reach of the Mississippi River. This model was initially constructed and operated for the St. Louis District during the period September 1967 to January 1971. A subsequent model study was conducted during the period April 1972 to August 1975. Studies conducted during these periods are discussed in reports by Franco (1972)* and Foster, Noble, and Franco (1978).**

Design Considerations and Adjustment and Operating Procedures

9. The general design, adjustment, and operation considerations for this and other movable-bed river models built and operated at WES are discussed in a report by Franco (1978).† Design considerations for this type of model are discussed in Appendix A.

Description

10. The last 5 miles of the existing St. Louis Harbor model were modified to simulate the conditions of the Mississippi River as of May 1977 from mile 171.5 to mile 166.5, including the installation of the Jefferson Barracks

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* J. J. Franco. 1972 (Nov). "Shoaling Conditions, St. Louis Harbor, Mississippi River; Hydraulic Model Investigation," Technical Report H-72-7, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

** J. E. Foster, C. M. Noble, and J. J. Franco. 1978 (Jun). "Shoaling Conditions in Sawyer Bend and Lower Entrance to Chain of Rocks Canal, Mississippi River; Hydraulic Model Investigation," Technical Report H-78-7, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

† J. J. Franco. 1978 (Aug). "Guidelines for the Design, Adjustment and Operation of Models for the Study of River Sedimentation Problems," Instruction Report H-78-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Bridge at mile 168.7. All features affecting flow characteristics were simulated in the model. This movable-bed model is constructed to a horizontal scale of 1:250 and a vertical scale of 1:100. The bed of the river (from bank to bank including the island and slough) was molded in crushed coal. The remainder of the model was molded in sand-cement mortar. The crushed coal had a median diameter of 4 mm and a specific gravity of 1.30. Bedrock was simulated in the model with crushed stone. Folded strips of wire mesh were used to simulate the overbank roughness and resistance to flow caused by overbank growth. Pile dikes and work trestle piles were simulated by 1/8-in. welding rods. The work trestle was constructed from Plexiglas; the cofferdams from sheet metal; and the bridge from wood, sheet metal, and Plexiglas.

11. The fixed portions of the model, i.e., those molded in sand-cement mortar, were molded in accordance with US Geological Survey data.* The movable-bed portion of the model, i.e., that portion molded in crushed coal, was molded at the start of the adjustment tests in accordance with the hydrographic survey taken by the St. Louis District on 21 June 1966. The Jefferson Barracks Bridge was installed in the model in accordance with construction plans furnished by The Department.

Appurtenances

12. A circulating flow system was used to supply water to the model from a storage sump near the model. The discharge in the model was regulated at the upper end of the model with two venturi meters, one 12 by 6 in. and the other 6 by 3 in. This combination of venturi meters allowed regulation over the range of discharges to be reproduced. Water-surface elevations along the channel were measured at seven locations by seven piezometers located in the model channel and connected to a centrally located gage pit. An adjustable tailgate was provided at the downstream end of the model to control the water-surface elevation in the model. A graduated container was used to measure the bed material to be introduced at the upstream end of the model. A sediment trap was provided at the downstream end of the model where material transported by the water during testing could be retrieved, measured, and used for

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* Presented on US Geological Survey Quadrangle sheets labeled Oakville, Mo.-Ill. Quadrangle dated 1954, Photo-revised 1982, and Webster Groves, Mo.-Ill. Quadrangle dated 1968 and 1974.

reintroduction during additional tests. A rail was installed along each side of the channel to provide horizontal and vertical control for a sounding rail and rod used to mold and survey the bed and to install the trestle, cofferdams, and pile dikes.

Adjustment and Verification

Procedure

13. Before a movable-bed model can be used to predict prototype bed changes, the ability of the model to reproduce bed changes observed in the prototype must be demonstrated. The general adjustment procedure for movable-bed models is discussed in detail in Appendix B.

Description

14. Since this model was an extension of the St. Louis Harbor model, the prototype surveys, discharge hydrograph, discharge scale, and bed-load curve used in the St. Louis Harbor model study were used in the beginning of the adjustment of this model. The adjustment of the St. Louis Harbor model is discussed in Appendix C. The model bed for this study was molded to the 1966 prototype survey with the old Jefferson Barracks Bridge installed (Plate 4). The discharge hydrograph for the Mississippi River at St. Louis, MO, for the period 1 September 1966 to 31 August 1967 (Plate 5), modified by the discharge-ratio curve shown in Plate 6, was introduced in block form* in the upstream end of the model. Coal was introduced with each discharge according to the bed-load curve shown in Plate 7. The tailgate at the downstream end of the model was adjusted for each discharge so the stage at Jefferson Barracks Bridge agreed with the stages that were measured in the prototype. At the end of the adjustment period, the model was drained and the bed was surveyed. The bed survey was compared with the hydrographic survey of the prototype taken by the St. Louis District in September 1967 (Plate 8). During adjustment tests, vanes, shown in Figure 5, were installed in the upstream end of the model and adjusted to make flow conditions in the model entrance agree with those of the prototype. The model was satisfactorily adjusted using the discharge-ratio

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* The discharges are averaged for periods of at least 6 days to give enough time for the model operator to set the flow and adjust the tailgate and for the stabilized flow to move the model bed appropriately.

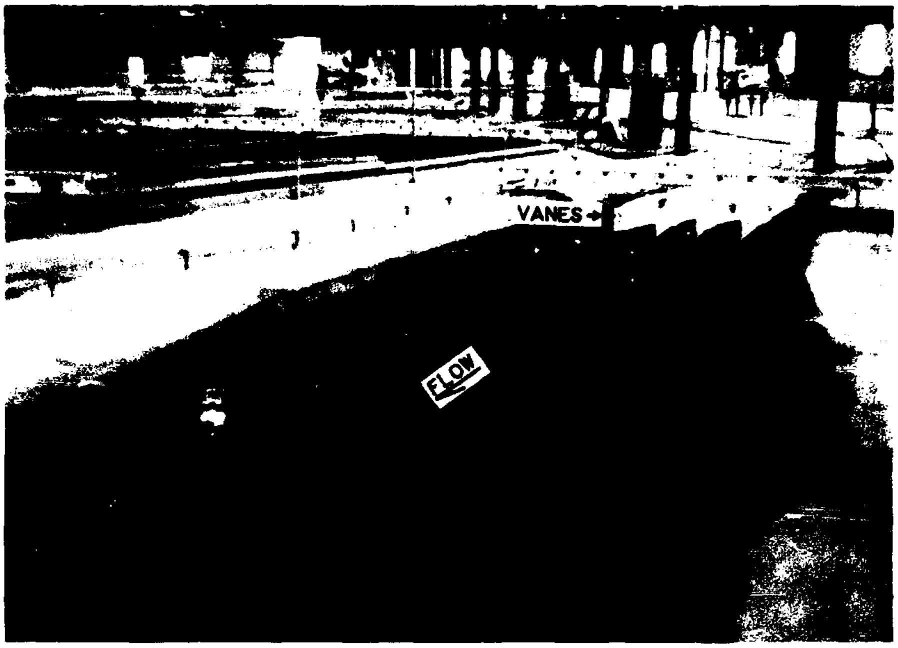

Figure 5. Upstream portion of the model. Note vanes installed to make flow conditions in the model entrance agree with those of the prototype

curve and the bed-load curve previously used for the St. Louis Harbor model adjustment and tests.

Results

15. The resulting bed configurations of the final adjustment test are shown in Plate 9. A comparison of this survey (Plate 9) with the prototype survey of September 1967 (Plate 8) shows that the model satisfactorily reproduced the prototype survey.

PART III: TESTS AND RESULTS

Selection of Test Hydrograph

16. After the model was adjusted, tests were conducted with flows that occurred during the period 5 May 1977 to 24 January 1980 (Plates 10 and 11). These dates were selected because they encompassed the time period of the problem and because of the availability of prototype hydrographic survey data. The prototype hydrographic survey of 5 May 1977 by the St. Louis District (Plate 1) was the last hydrographic survey of the prototype prior to the failure of the work trestle and cofferdams. This survey provided a bed condition to be molded in the model at the beginning of the test. The hydrographic survey taken by the St. Louis District on 24 January 1980 was the first hydrographic survey of the prototype following the failure of the work trestle and cofferdams. This hydrographic survey (Plate 12) provided a prototype bed condition to compare with the model results.

17. The discharge hydrograph for the period 5 May 1977 to 24 January 1980 was divided into three segments, as shown in the following tabulation:

Segment	Period	Used in Tests
1	5 May 1977- 12 Feb 1979	1,2,3
2	12 Feb 1979- 28 Jul 1979	1,3
3	12 Feb 1979- 24 Jan 1980	2

Segment 1 was used to develop the bed configuration for the first portion of Tests 1, 2, and 3. Segment 2 extended from a period of low discharge prior to the accumulation of the 10-acre debris field to a period of low discharge following the crest of the 1979 flood. Segment 3 extended from a period of low discharge prior to the accumulation of the 10-acre debris field to the date of the ending hydrographic survey (Plate 12). The resulting model survey was compared to the prototype survey of 24 January 1980 to determine the capability of the model to reproduce the prototype bed changes during the 2-year 8-month period.

Test Procedure

18. Four tests (base test and Tests 1-3) were conducted. For each test, the appropriate portion of the discharge hydrograph, modified by the discharge-ratio curve shown in Plate 6, was introduced into the upstream portion of the model. Crushed coal was added at the upstream end of the model for each discharge in accordance with the bed-load curve shown in Plate 7. The tailgate was adjusted to produce model stages comparable to the recorded prototype stages at Jefferson Barracks Bridge. During each test, the work trestle, cofferdams, and debris were placed in the model according to the sequence furnished by The Department. At the end of each test and at the time of the first and second failures of the trestle, the model bed was surveyed to determine the scour and fill that had occurred, especially in the vicinity of the old Jefferson Barracks Bridge, the trestle, and cofferdams. A video camera was used to record flow patterns, bed movement, scour, and deposition during the tests.*

Base Test

Description

19. The base test was begun with the model bed molded to the May 1977 prototype survey (Plate 1). The dikes on the left bank at the upstream end of the model and the old Jefferson Barracks Bridge were installed. The discharge hydrograph for the period 5 May 1977 to 12 February 1979 was introduced into the model. On 2 March 1978,** the work trestle across Jefferson Barracks Slough and from the island to the site of pier 9 and the cofferdams for piers 4-7 were installed. On 20 October 1978, the cofferdam for pier 8 was installed. On 2 November 1978, the work trestle was installed from the site of pier 9 to the site of pier 10. On 10 December 1978, cofferdams for piers 9 and 10 were installed. On 12 February 1979, the test was stopped, the model drained, and the model bed surveyed.

Results

20. A comparison of the model bed survey of 12 February 1979 (Plate 13,

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* The video tape was furnished The Department upon completion of the tests.

** Dates given in the remainder of this report refer to test (prototype) dates.

Sheet 1) with the prototype bed survey of 5 May 1977 (Plate 1) shows that during the period May 1977 to February 1979, there was 3 to 4 ft of general bed scour in the navigation channel (along the right side of the river) in the vicinity of Jefferson Barracks Bridge (mile 169.0 to mile 168.2). In the vicinity of the work trestle (along the left side of the channel), there were no significant changes in bed elevation. Observations during the test revealed no general bed movement in the vicinity of the work trestle. There was 1 to 2 ft of local scour observed around the upstream end of cofferdams at piers 9 and 10 and existing pier 7. The observed direction of flow along the left side of the channel was generally parallel to the channel through the work trestle from the cofferdam at pier 7 to the cofferdam at pier 10. This flow pattern was visible during the test.

Test 1

Description

21. Test 1 was begun with the model bed molded as it was at the end of the base test (Plate 13, Sheet 1). Cofferdams at piers 4-10, 12, and 13 and the piles for the craneway at pier 10 were installed. Figure 6 shows the work trestle and cofferdams at piers 7-10, 12, and 13. The discharge hydrograph for the period 12 February 1979 to 28 July 1979 was introduced into the model. On 22 March 1979 (about the time of the first failure of the trestle), model operation was stopped, the model was drained, and the model bed in the vicinity of the bridge was surveyed. Model operation was resumed, and on 28 July 1979, operation was again stopped, the model drained, and the model bed surveyed.

Results

22. A comparison of hydrographic surveys of the model bed of 22 March 1979 (Plate 14) and of 12 February 1979 (Plate 13, Sheet 2) shows that during the period 12 February to 22 March there was no significant change in general bed elevation in the vicinity of the work trestle. Observations during the test also revealed no general bed movement in the vicinity of the work trestle. This comparison also showed that local scour occurred at cofferdams for piers 8, 9, and 10 but none occurred at the cofferdam for pier 7. Local scour shown was from 5 to 6 ft at the cofferdam for pier 8 (to el 368 on the north and west and to el 369 on the east); 12 ft at the cofferdam for pier 9

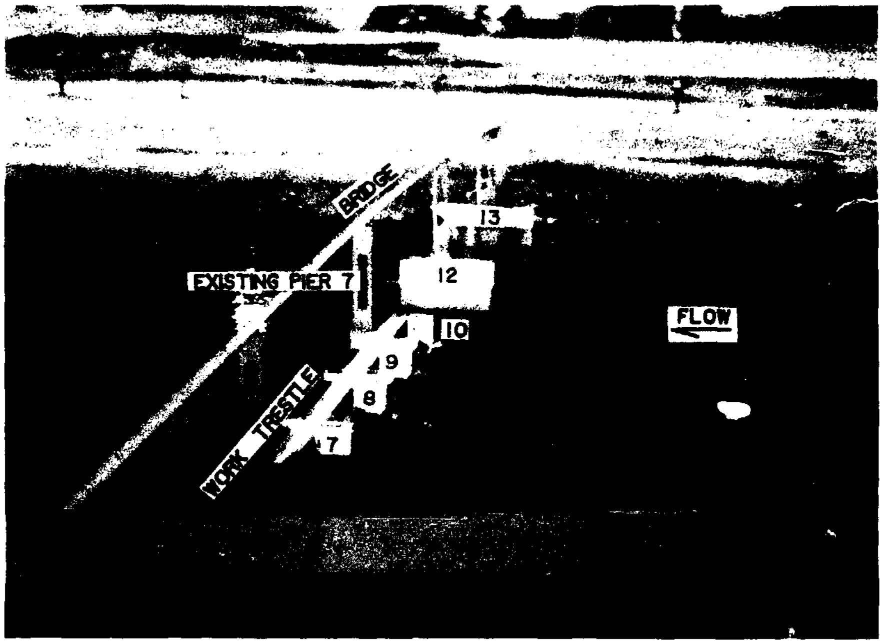

Figure 6. The model at the beginning of Test 1 looking west toward Missouri (12 February 1979). Note work trestle to past pier 10, cofferdams at piers 7-10, 12, and 13, piles for craneway at pier 10, and old Jefferson Barracks Bridge

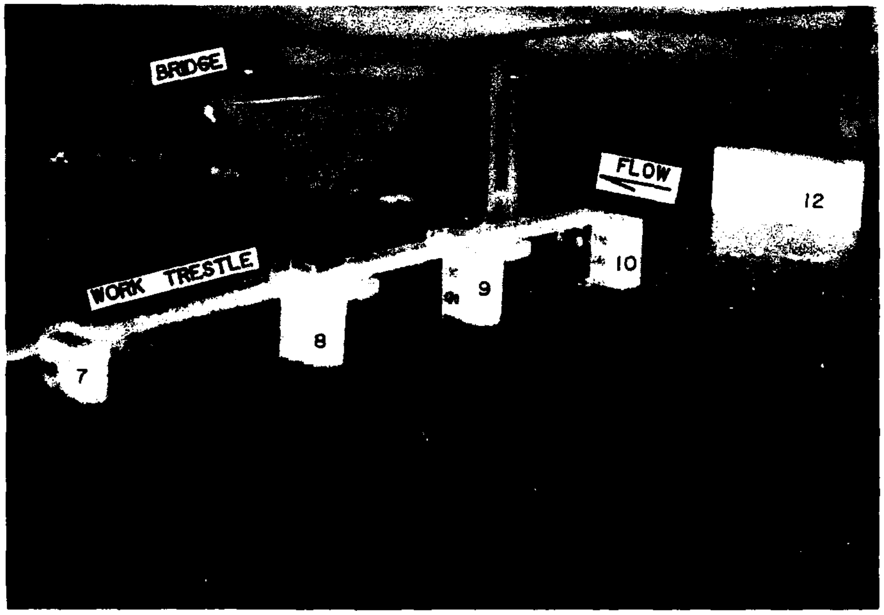

Figure 7. The model for Test 1 on 22 March 1979 looking downstream from Illinois side. Note local scour around cofferdams at piers 8-10

(to el 360); and from 11 to 16 ft at the cofferdam for pier 10 (to el 360 on the east and to el 355 on the north and west). Figure 7 shows the model bed in the vicinity of the work trestle on 22 March 1979 with the model partially drained. This figure shows local scour at cofferdams for piers 8, 9, and 10 but shows no general bed scour between these cofferdams. The observed direction of flow along the left side of the channel was generally parallel to the channel from the cofferdam at pier 7 to the cofferdam at pier 10.

23. A comparison of hydrographic surveys of the model bed of 22 March 1979 (Plate 14) and of 28 July 1979 (Plate 15, Sheets 1 and 2) shows that there was a maximum of 3 ft of general bed scour in the vicinity of the work trestle during the crest discharges of the 1979 flood. Observations during the test revealed some general bed movement in the vicinity of the work trestle during the crest discharges and some local scour at cofferdams for piers 8-10, 12, 13, and existing pier 7. The observed direction of flow along the left side of the channel was generally parallel to the channel from the cofferdam for pier 7 to the cofferdam for pier 10.

Test 2

Description

24. Test 2 was the same as Test 1 except material simulating an 18-ft-thick layer of debris was placed upstream of the work trestle to determine the effect debris would have on bed scour. The discharge hydrograph was continued until 24 January 1980 to see how the model would reproduce prototype bed changes during the period May 1977 to January 1980. Test 2 was begun with the model bed molded as it was at the end of the base test (Plate 13, Sheet 1). Cofferdams at piers 4-10, 12, and 13 and the piles for the craneway at pier 10 were installed. Figure 6 shows the work trestle and cofferdams at piers 7-10, 12, and 13. The discharge hydrograph for the period 12 February 1979 to 24 January 1980 was introduced into the model. On 4 March 1979, a material* simulating an 18-ft-thick layer of debris was placed upstream of the trestle where debris is shown in a photograph taken of the prototype on 10 March 1979 (Figure 2). Figure 8 shows the debris in the model. This debris covered more

* A rubberized hair material that has a porosity of 98 percent was used to simulate debris. Plastic wrap was attached to the top of the debris to prevent it from sinking below the water surface.

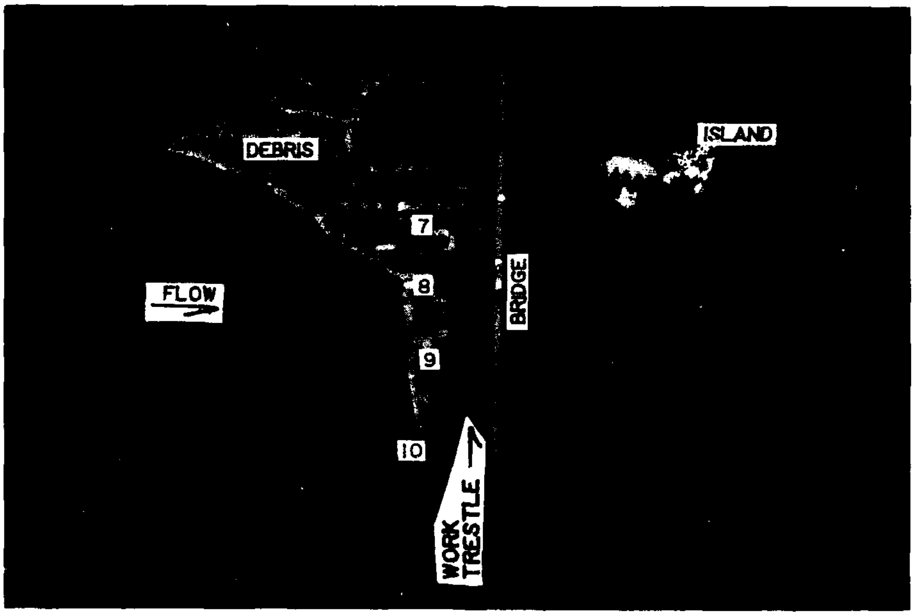

Figure 8. The model for Test 2 on 4 March 1979. Note material upstream of the work trestle simulating the debris that accumulated in the prototype

than 10 acres (prototype) upstream of the trestle. On 22 March 1979 (about the time of the first failure of the work trestle), model operation was stopped, the model drained, the debris removed, and the bed in the vicinity of the trestle surveyed. Following the survey, the work trestle from pier 9 to pier 10 and the cofferdam at pier 10 were removed. The debris accumulation to pier 9 was replaced as shown in Figure 9. Model operation was resumed, and on 11 April 1979, some of the debris upstream of the island and the work trestle was removed to simulate that portion of the debris that floated over the island and over and around the trestle. The remaining debris, except that in the slough, is shown in Figure 10. On 19 April 1979 (about the time of the second failure of the work trestle), testing was stopped, the model was drained, the debris upstream of the work trestle from the cofferdam at pier 7 to the cofferdam at pier 9 was removed, and the bed in the vicinity of the bridge was surveyed. Following the survey, the work trestle from pier 8 to pier 9 and the cofferdam at pier 9 were removed. Testing of the model was resumed. On 28 July 1979, testing was stopped, the model was drained, and the model bed was surveyed. Following the survey, model operation was resumed. On 24 January 1980, testing was stopped, the model was drained, and the model bed was surveyed.

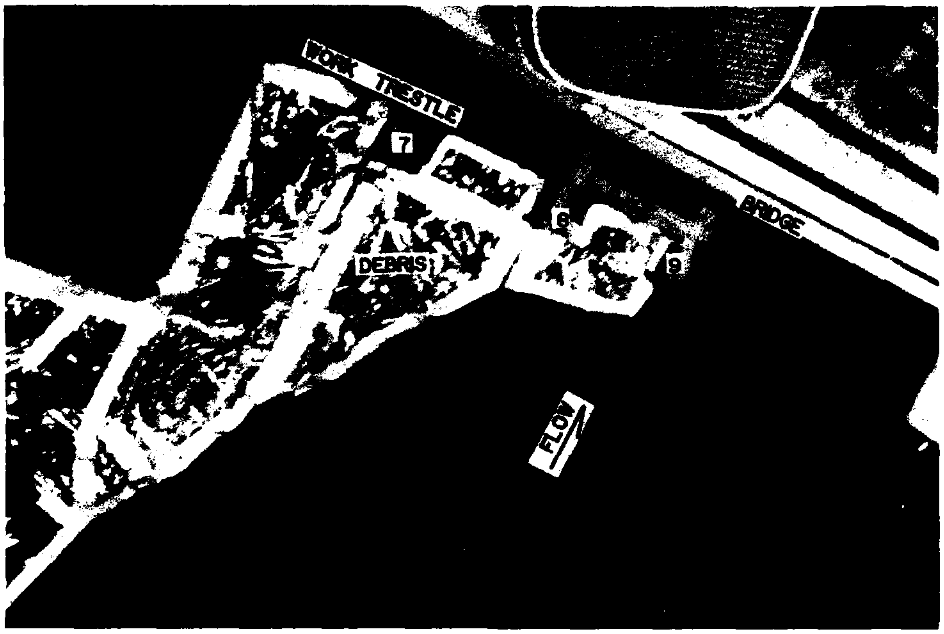

Figure 9. The model for Test 2 on 22 March 1979. Note that work trestle from cofferdam at pier 9 to pier 10 and cofferdam at pier 10 were removed

Figure 10. The model for Test 2 on 11 April 1979. Note that some of the debris upstream of the work trestle and island and east of the cofferdam at pier 7 is removed

Results

25. A comparison of the surveys taken on the model on 22 March 1979 for Test 2 (Plate 16) and for Test 1 (Plate 14) indicated that the 18-ft-thick layer of debris upstream of the work trestle caused extensive bed scour immediately upstream of and under the work trestle from the cofferdam at pier 8 to the cofferdam at pier 10 and up to 12 ft of additional local scour (in addition to the local scour caused by the work trestle and cofferdams during Test 1) around cofferdams at piers 8-10. A comparison of the surveys taken on the model on 12 February 1979 (Plate 13, Sheet 2), and on 22 March 1979 (Plate 16) showed that the bed between cofferdams at piers 7 and 8 scoured 6 ft (to el 370), between cofferdams at piers 8 and 9 scoured 12 ft (to el 360), and between cofferdams at piers 9 and 10 scoured 20 ft (to el 352). Model results showed local scour as follows: up to 2 ft at the cofferdam for pier 7 (to el 378 on the west); from 8 to 11 ft at the cofferdam for pier 8 (to el 366 on the east, to el 364 on the north, and to el 363 on the west); from 18 to 22 ft at the cofferdam for pier 9 (to el 351 on the east, to el 350 on the north, and to el 354 on the west); and from 27 to 29 ft at the cofferdam for pier 10 (to el 342 on the east, to el 343 on the north, and to el 344 on the west). It was observed during testing that the bed material that had scoured from around the trestle and cofferdams was being deposited just downstream of the work trestle. A comparison of the bed surveys taken just downstream of the work trestle (Plate 16 versus Plate 14) shows a deposition of up to 12 ft (to el 382) in this area. Photographs taken of the model on 22 March 1979 with the debris removed (Figures 11 and 12) show bed scour around the work trestle from the cofferdam at pier 8 to the cofferdam at pier 10 and the deposition downstream of the bridge. The observed direction of the flow along the left side of the channel was along the west side of the debris concentrating around the west side of cofferdam 10. An eddy was observed along the debris upstream of the work trestle between cofferdams for piers 7 and 8 during the test. It was also observed that some of the flow was going under the debris.

26. A comparison of the hydrographic surveys of the model taken on 19 April 1979 (Plate 17) and on 22 March 1979 (Plate 16) showed that with the 18-ft-thick layer of debris upstream of the remaining portion of the work trestle, the crest flows of the 1979 flood caused additional bed scour upstream of and under the work trestle between cofferdams at piers 7 and 9 and

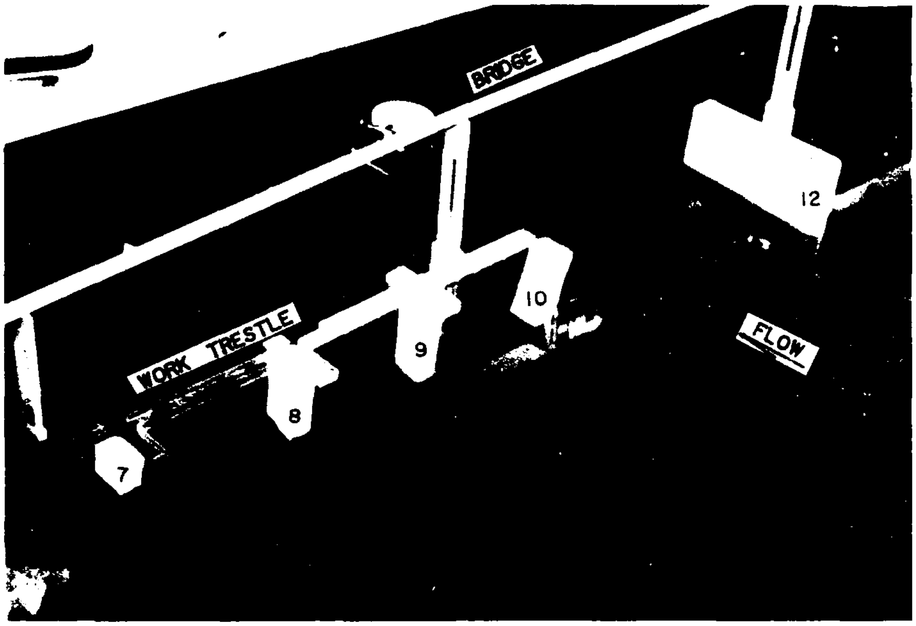

Figure 11. The model, Test 2, on 22 March 1979, looking downstream. Note scour of the bed around the work trestle from the cofferdam at pier 8 to cofferdam at pier 10 and the deposition downstream of the work trestle

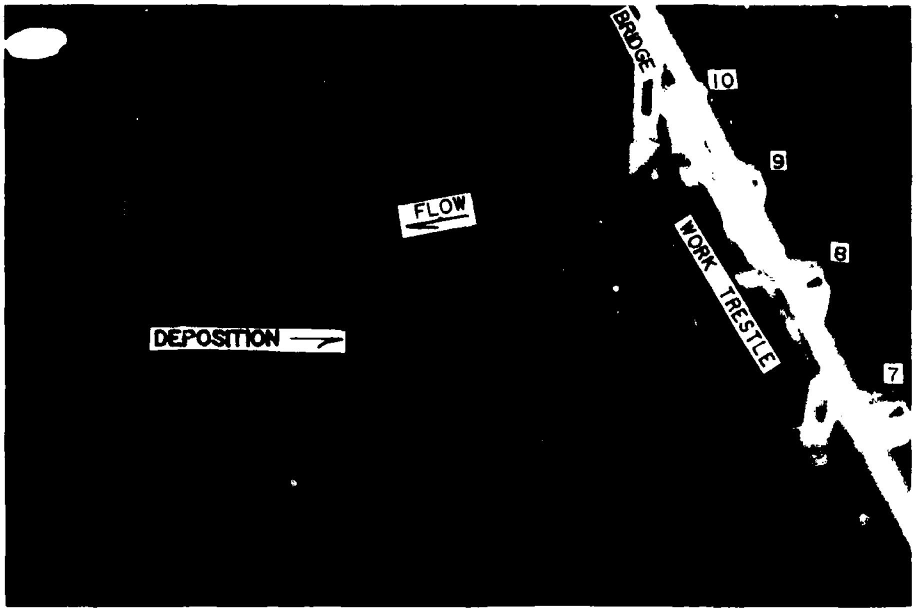

Figure 12. The model, Test 2, on 22 March 1979, looking upstream. Note scour of the bed around the work trestle from cofferdam at pier 8 to the cofferdam at pier 10 and the deposition downstream of the work trestle

additional local scour around cofferdams at piers 8 and 9. The bed 250 to 300 ft upstream of the work trestle between cofferdams at piers 7 and 9 scoured 2 to 6 ft between 22 March and 19 April. A comparison of the surveys taken on the model on 12 February 1979 (Plate 13, Sheet 2) and on 19 April 1979 (Plate 17) showed up to 7 ft of bed scour between cofferdams at piers 7 and 8; up to 12 ft of bed scour between cofferdams at piers 8 and 9; up to 5 ft of local scour around the cofferdam at pier 7 (to el 378 on the north and to el 375 on the west); from 9 to 14 ft of local scour around the cofferdam at pier 8 (to el 365 on the east, to el 360 on the north, and to el 362 on the west); and from 22 to 26 ft of local scour around the cofferdam at pier 9 (to el 350 on the east, to el 346 on the north, and to el 352 on the west).

27. A comparison of the hydrographic surveys taken of the model on 28 July 1979 (Plate 18, Sheets 1 and 2) and on 19 April 1979 (Plate 17) showed that the local scour that occurred around the cofferdams for piers 9 and 10 filled in to the surrounding bed elevations when the cofferdams were removed, but the general bed scour around the work trestle between the cofferdams at piers 8 and 10 did not fill in. The deposition downstream of the bridge scoured after the debris upstream of the work trestle was removed. It was observed that the eddy in surface current directions disappeared when the debris upstream of the work trestle between the cofferdams at piers 8 and 10 was removed.

28. A comparison of the hydrographic survey taken of the model on 24 January 1980 (Plate 19) with the prototype hydrographic survey of the same date (Plate 12) shows that the model reproduced the scour and deposition tendencies of the prototype.

Test 3

Description

29. Test 3 was the same as Test 2 except a 9-ft-thick layer of debris was placed upstream of the work trestle instead of an 18-ft-thick layer of debris and the portion of the discharge hydrograph from 28 July 1979 to 24 January 1980 was not tested. This test was conducted to determine the effect of a layer of debris that was not so deep since the exact thickness of the debris in the prototype is not known.

Results

30. The hydrographic surveys taken of the model on 22 March 1979, 19 April 1979, and 28 July 1979 are shown in Plates 20, 21, and 22, respectively. A comparison of the surveys taken on 22 March and 19 April for Test 3 (Plates 20 and 21, respectively) with the surveys taken on the same dates for Test 2 (Plates 16 and 17, respectively) showed that bed scour with a 9-ft-thick layer of debris occurred in the same areas as with an 18-ft-thick layer of debris but the scour was not as great with the 9-ft-thick layer of debris. A comparison of bed elevations taken on 22 March for Test 1 (Plate 14) with those for Test 3 (Plate 20) showed that the 9-ft-thick layer of debris caused considerable bed scour immediately upstream of and under the work trestle from the cofferdam at pier 8 to the cofferdam at pier 10 and up to 6 ft of additional local scour (in addition to the local scour caused by the work trestle and cofferdams during Test 1) at cofferdams for piers 8-10. A comparison of the surveys taken on the model on 12 February 1979 (Plate 13, Sheet 2) and on 22 March 1979 (Plate 20) showed no bed scour between the cofferdams at piers 7 and 8, bed scour of 9 ft (to el 363) between cofferdams at piers 8 and 9, and bed scour of 12 ft (to el 360) between cofferdams at piers 9 and 10. This comparison also showed no local scour around the cofferdam at pier 7; local scour from 6 to 10 ft around the cofferdam at pier 8 (to el 368 on the east, to el 364 on the north, and to el 366 on the west); from 12 to 17 ft around the cofferdam at pier 9 (to el 357 on the east, to el 355 on the north, and to el 360 on the west); and from 17 to 20 ft around the cofferdam at pier 10 (to el 354 on the east, to el 352 on the north, and to el 351 on the west).

31. A comparison of the surveys taken on the model on 12 February 1979 (Plate 13, Sheet 2) and on 19 April 1979 (Plate 21) showed up to 2 ft of bed scour between cofferdams at piers 7 and 8; up to 11 ft of bed scour between cofferdams at piers 8 and 9; and up to 8 ft of bed scour between the cofferdam at pier 9 and the location site of pier 10. This comparison also showed 1 ft of local scour at the cofferdam at pier 7 (to el 382 on the north and to el 379 on the west); from 7 to 12 ft of local scour around the cofferdam at pier 8 (to el 367 on the east, to el 362 on the north, and to el 364 on the west); and from 15 to 17 ft of local scour around the cofferdam at pier 9 (to el 357 on the east, to el 355 on the north, and to el 357 on the west).

32. The flow directions along the left side of the channel were similar to those for Test 2. Flow concentrated along the west side of the debris,

especially around the west side of the cofferdam at pier 10. As in Test 2, an eddy formed upstream of the debris between cofferdams at piers 7 and 8 when all of the debris was in place, but the eddy disappeared when the debris between cofferdams at piers 8 and 10 was removed.

PART IV: DISCUSSION OF RESULTS AND CONCLUSIONS

Summary of Results

33. The results of the model tests are summarized as follows:

a. For Test 1, with the old Jefferson Barracks Bridge, the work trestle, and cofferdams at piers 4-10, 12, and 13 installed, a comparison of the model results taken on 12 February 1979 with those of 22 March 1979 shows the following:

(1) No local scour around the cofferdam at pier 7.

(2) No bed scour between cofferdams at piers 7 and 8.

(3) From 5 to 6 ft of local scour around the cofferdam at pier 8.

(4) No bed scour between cofferdams at piers 8 and 9.

(5) Local scour of 12 ft around the cofferdam at pier 9.

(6) No bed scour between cofferdams at piers 9 and 10.

(7) From 11 to 16 ft of local scour around the cofferdam at pier 10.

b. Model conditions for Test 2 were the same as for Test 1 plus the addition of an 18-ft-thick layer of debris upstream of the work trestle. A comparison of model results taken on 12 February 1979 with those of 22 March 1979 shows the following:

(1) Up to 2 ft of local scour around the cofferdam at pier 7.

(2) Up to 6 ft of bed scour between cofferdams at piers 7 and 8.

(3) From 8 to 11 ft of local scour around the cofferdam at pier 8.

(4) Up to 12 ft of bed scour between cofferdams at piers 8 and 9.

(5) From 18 to 22 ft of local scour around the cofferdam at pier 9.

(6) Up to 20 ft of bed scour between cofferdams at piers 9 and 10.

(7) From 27 to 29 ft of local scour around the cofferdam at pier 10.

c. For Test 2, a comparison of model results taken on 12 February 1979 with those of 19 April 1979 shows the following:

(1) Up to 5 ft of local scour around the cofferdam at pier 7.

(2) Up to 7 ft of bed scour between cofferdams at piers 7 and 8.

(3) From 9 to 14 ft of local scour around the cofferdam at pier 8.

(4) Up to 12 ft of bed scour between cofferdams at piers 8 and 9.

(5) From 22 to 26 ft of local scour around the cofferdam at pier 9.

d. Model conditions for Test 3 were the same as for Test 2 except the debris was 9 ft thick instead of 18 ft. A comparison of model results taken on 12 February 1979 with those of 22 March 1979 shows the following:

(1) No local scour around the cofferdam at pier 7.

(2) No bed scour between cofferdams at piers 7 and 8.

(3) From 6 to 10 ft of local scour around the cofferdam at pier 8.

(4) Up to 9 ft of bed scour between cofferdams at piers 8 and 9.

(5) From 12 to 17 ft of local scour around the cofferdam at pier 9.

(6) Up to 12 ft of bed scour between cofferdams at piers 9 and 10.

(7) From 17 to 20 ft of local scour around the cofferdam at pier 10.

e. For Test 3, a comparison of model results taken on 12 February 1979 with those of 19 April 1979 shows the following:

(1) Up to 1 ft of local scour around the cofferdam at pier 7.

(2) Up to 2 ft of bed scour between cofferdams at piers 7 and 8.

(3) From 7 to 12 ft of local scour around the cofferdam at pier 8.

(4) Up to 11 ft of bed scour between cofferdams at piers 8 and 9.

(5) From 15 to 17 ft of local scour around the cofferdam at pier 9.

(6) Up to 8 ft of bed scour between the cofferdam at pier 9 and the site of pier 10.

Interpretation of Model Results

34. The adjustment of the model was proven adequate; however, there are certain facets of river behavior that cannot be duplicated in a physical model such as sediment moving in suspension or the erosion of riverbanks.

35. The upstream portion of this model (mile 191 to mile 180), adjusted in the same manner, with the same scales and the same operating procedure, has

proved its ability to predict prototype occurrences. A model study* was conducted on this model for the St. Louis District to develop plans to eliminate or reduce shoaling along the right bank in the Mississippi River at Sawyer Bend and in the entrance to the Chain of Rocks Canal. The Sawyer Bend reach, located about 10 miles downstream of the mouth of the Missouri River, contributed relatively large amounts of sediment, particularly during flood periods. The discharge in the reach is divided by Mosenthein Island with Mosenthein Chute to the left and Sawyer Bend to the right. The channel in the upstream end of Sawyer Bend followed the left side (along the island) to mile 188 and crossed to the right side at mile 187.3 causing erosion of the head of the island and deposition along the right bank downstream. In 1973, this deposition prevented tows from servicing industrial docking facilities at mile 187.7 during periods when the stage at the St. Louis, MO, gage was less than 17 ft. A plan of dikes developed in the model to remove this deposition was constructed in the river. In 6 months, the river, without dredging, had scoured the debris along the right bank in the vicinity of the docking facility more than 17 ft in depth and tows could service the facility when the stage at the St. Louis gage was above 0.0 ft. A survey of the riverbed 1 year following the construction of the dikes agreed very closely with the model bed survey taken an equivalent of 1 year after the dikes were installed on the model.

36. Considering the accuracy with which the upstream portion of this model predicted prototype developments and the close agreement between model and prototype bed elevations during the verification test, this model can be relied upon to predict bed scour.

Conclusions

37. The following conclusions were drawn from model results and observations during this study:

a. Discharges of the magnitude of the 1979 flood (maximum of 685,000 cfs) would result in minimal bed scour of the left side of the river. The left side of the Mississippi River at Jefferson Barracks Bridge is on the inside of a gentle bend where the water is shallow and the velocities are slower than those in the deeper part of the channel.

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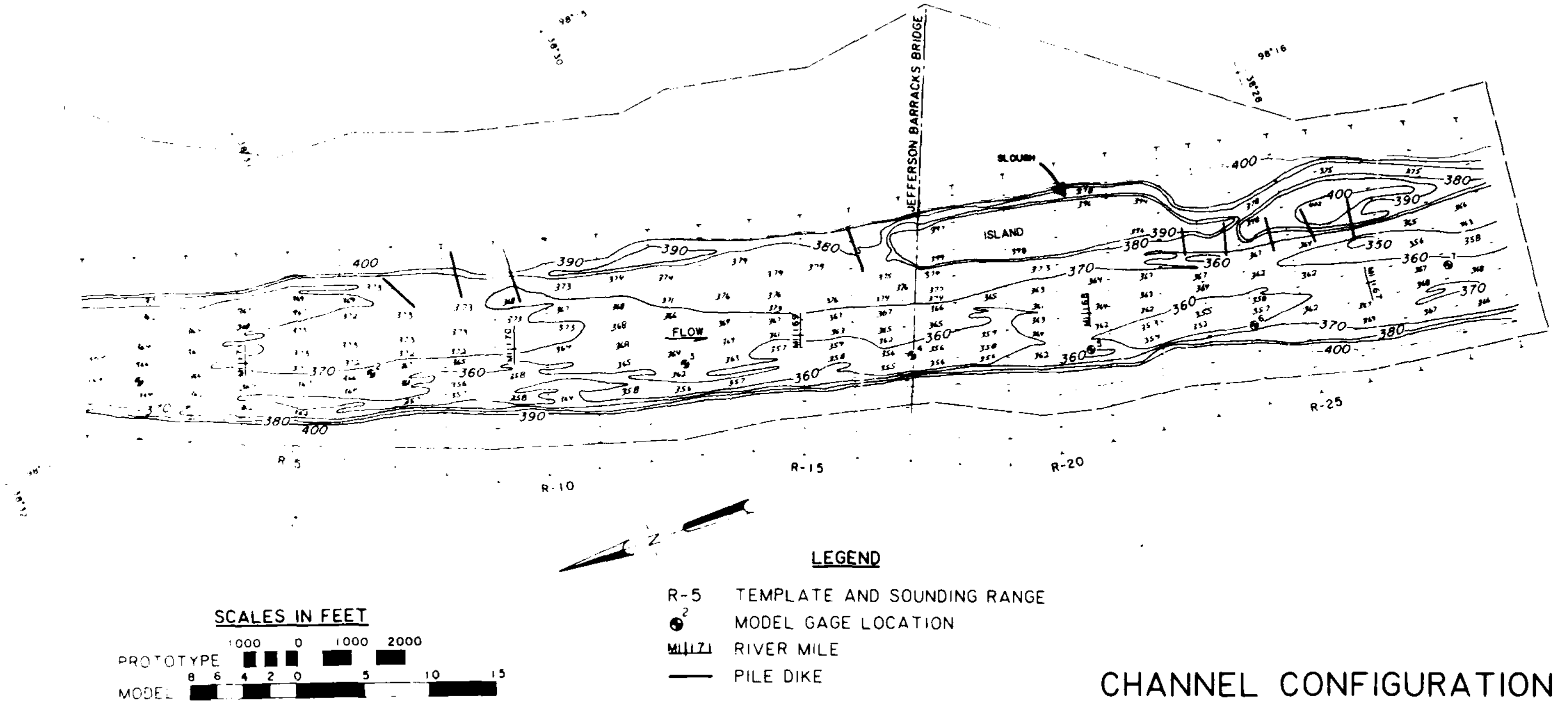
* Foster, Noble, and Franco, op. cit.

b. The addition of the work trestle and cofferdams would have no effect on general bed scour. There would be minimal local scour around the piles driven to support the trestle and there would be local scour around cofferdams at pier 8 (6 ft of scour to el 368); pier 9 (12 ft of scour to el 360); and pier 10 (16 ft of scour to el 355).

c. The addition of the 10-acre area of debris (9- and 18-ft thicknesses) that accumulated upstream of the work trestle would cause flow in the area to be concentrated under and around the west end of the debris. This concentrated flow would scour the bed of the river in the vicinity of the west end of the work trestle. The depth of scour in the vicinity of the work trestle would vary directly with the thickness of the debris. The greater the thickness of debris, the deeper the scour.

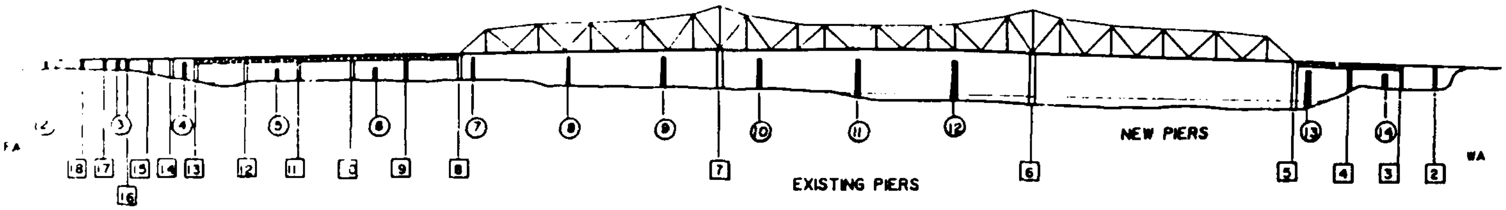
(1) The 9-ft-thick layer of debris upstream of the work trestle would cause considerable scour of the bed between and around cofferdams at piers 8 and 10. The maximum scour with the 9-ft-thick layer of debris would be 11 ft (to el 361) between cofferdams at piers 8 and 9; 12 ft (to el 360) between cofferdams at piers 9 and 10; 12 ft (to el 362) at the cofferdam for pier 8; 17 ft (to el 355) at the cofferdam for pier 9; and 20 ft (to el 351) at the cofferdam for pier 10.

(2) The 18-ft-thick layer of debris upstream of the work trestle would cause extensive scour of the bed between and around cofferdams at piers 8 and 10. The maximum scour with the 18-ft-thick layer of debris would be 12 ft (to el 360) between cofferdams at piers 8 and 9; 20 ft (to el 352) between cofferdams at piers 9 and 10; 14 ft (to el 360) at the cofferdam for pier 8; 26 ft (to el 346) at the cofferdam for pier 9; and 29 ft (to el 342) at the cofferdam for pier 10.

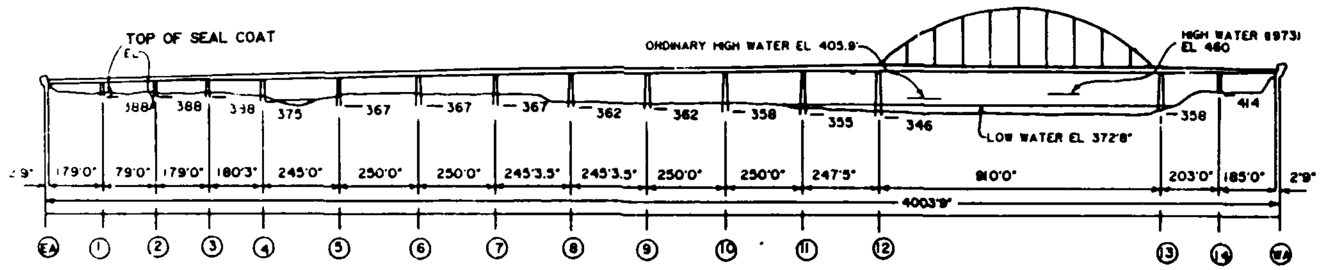


CHANNEL CONFIGURATION

1977 PROTOTYFE SURVEY



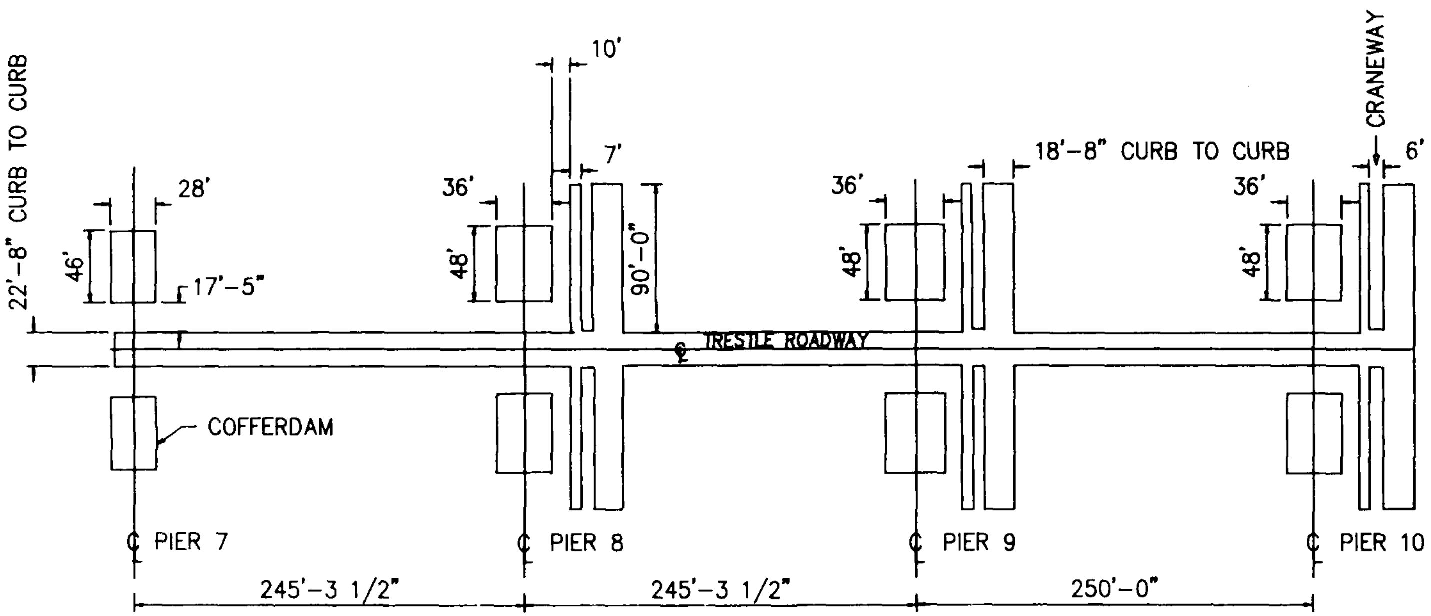
JEFFERSON BARRACKS BRIDGE WITH PIERS OF I-270 BRIDGE



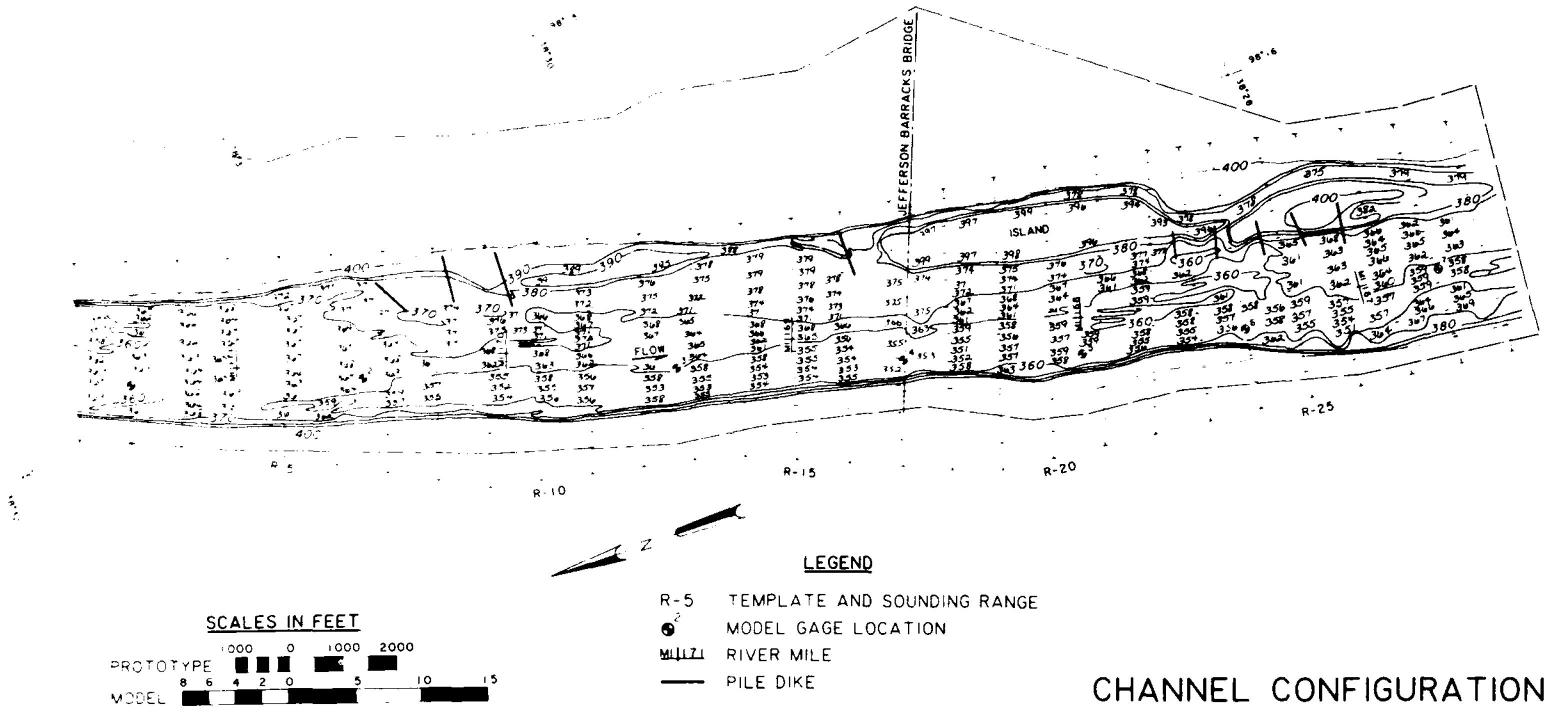
I-270 BRIDGE

I-270 AND JEFFERSON BARRACKS BRIDGES

PLATE 2



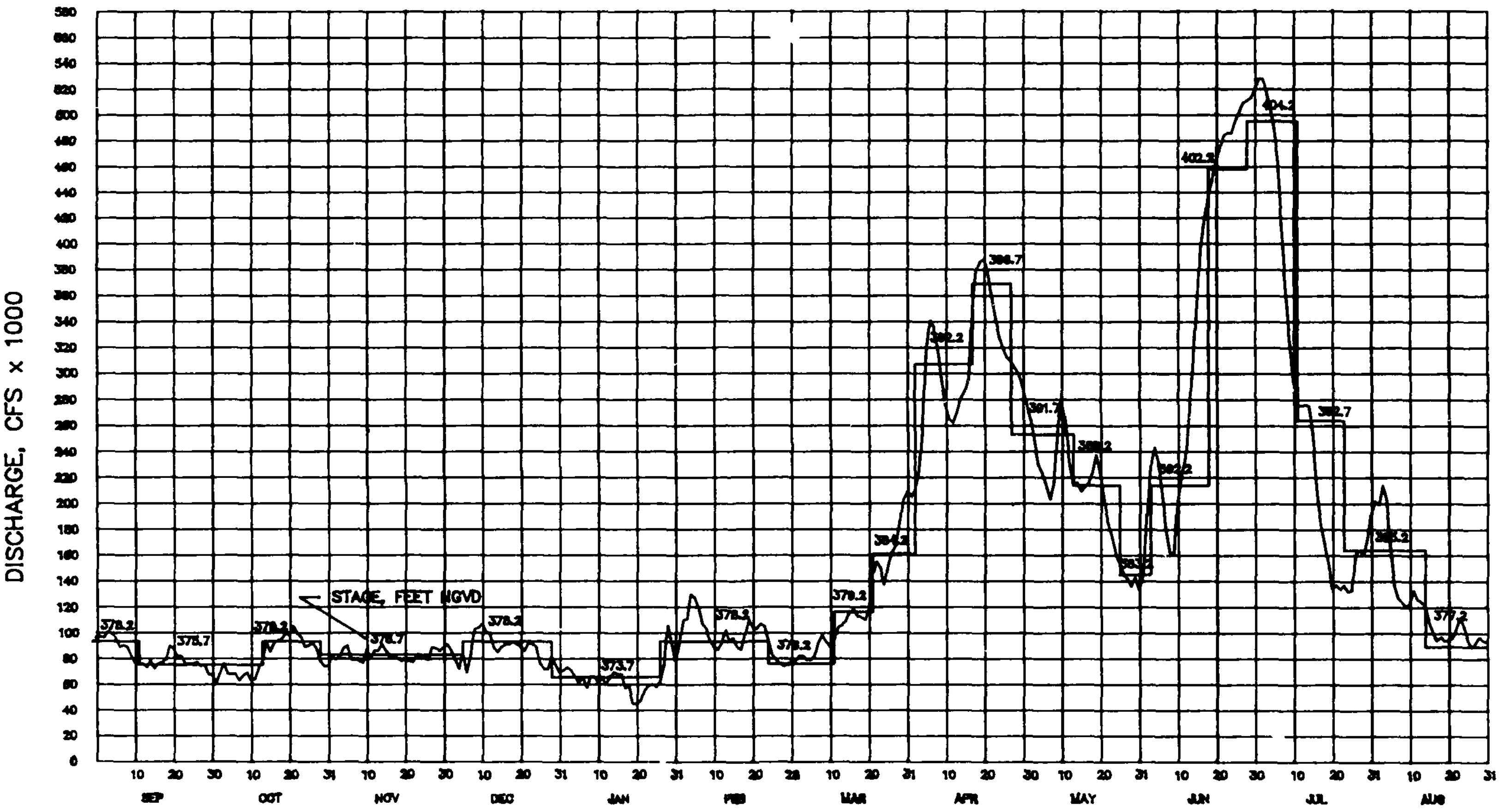
WORK TRESTLE AND COFFERDAMS
PIER 7 TO PIER 10



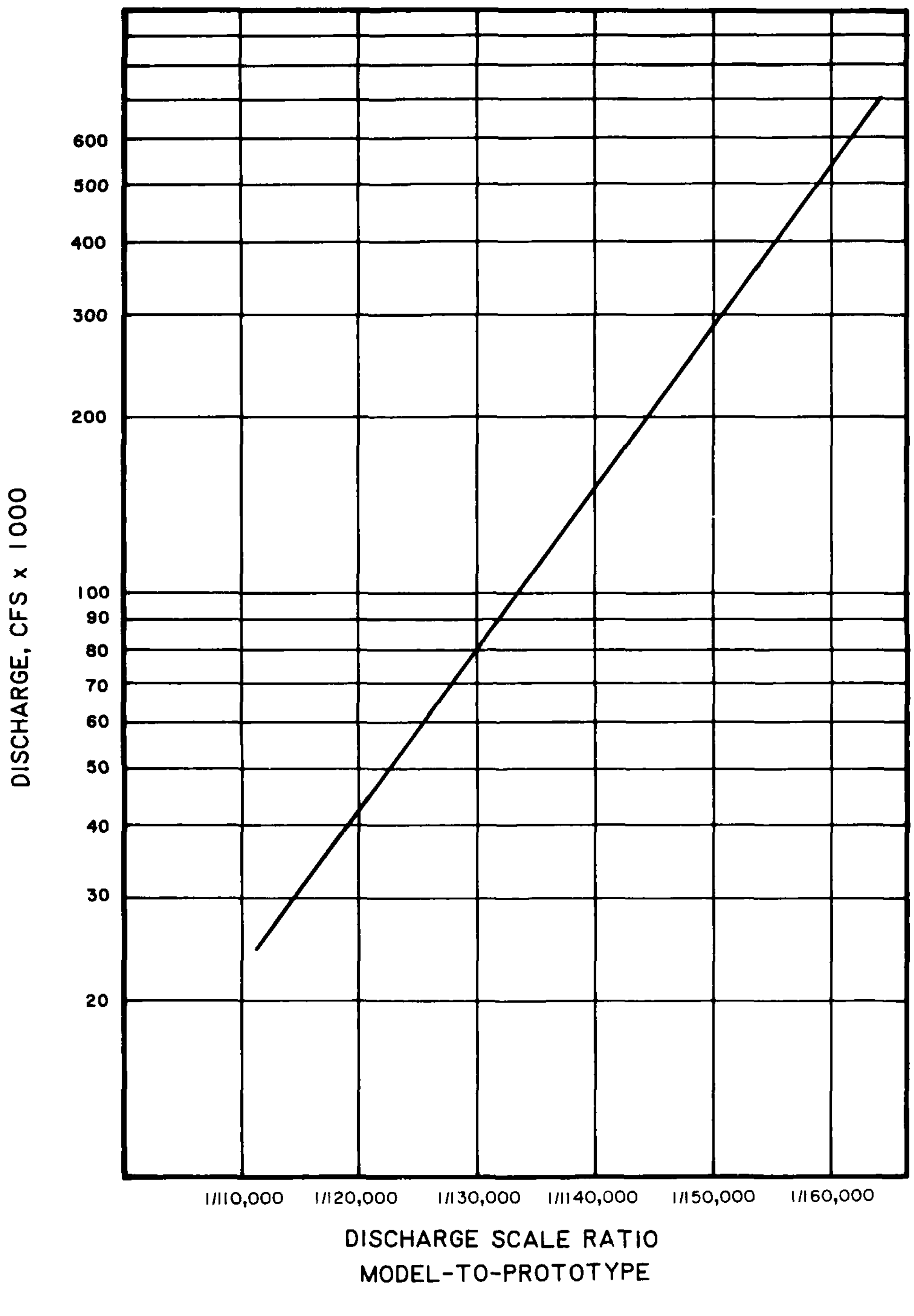
CHANNEL CONFIGURATION

1966 PROTOTYPE SURVEY

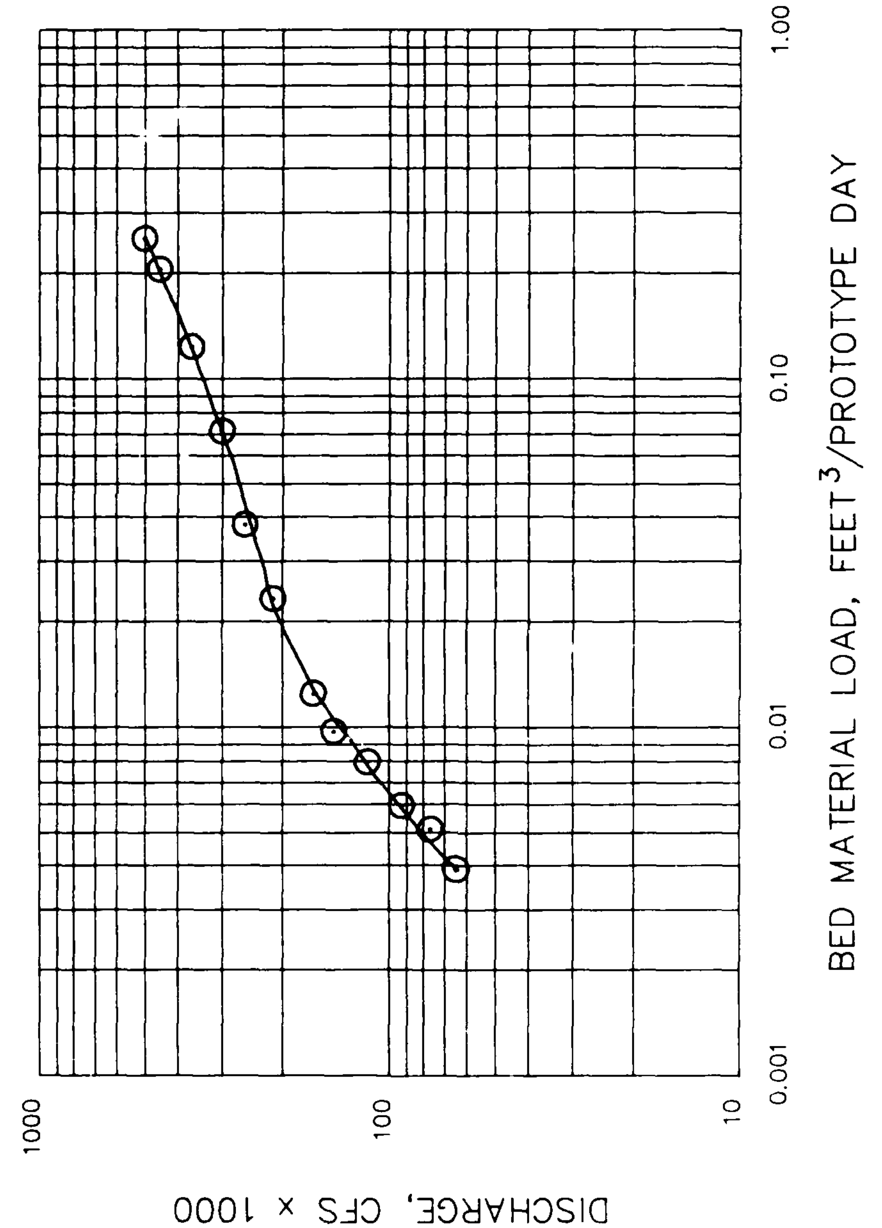
PLATE 4



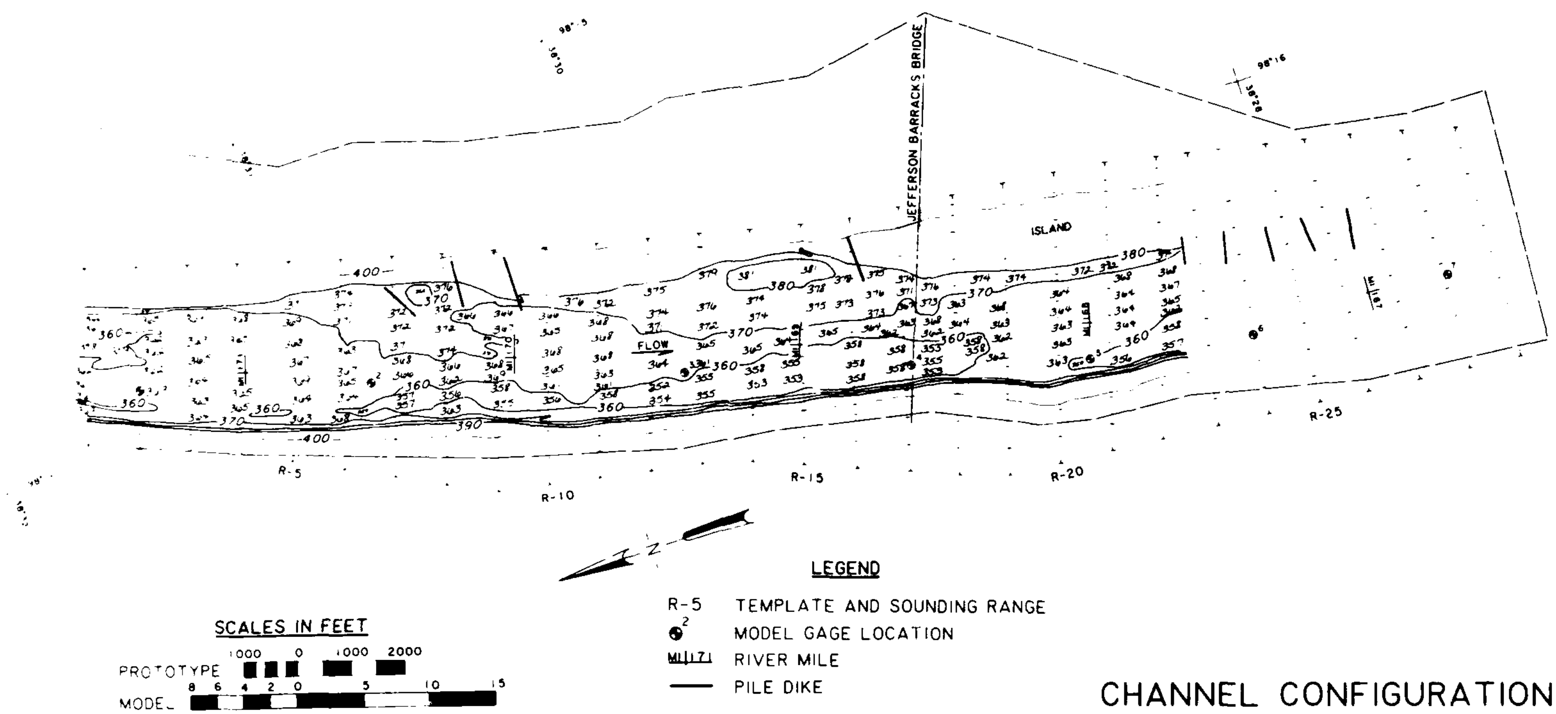
1966–1967 HYDROGRAPH



DISCHARGE-RATIO CURVE



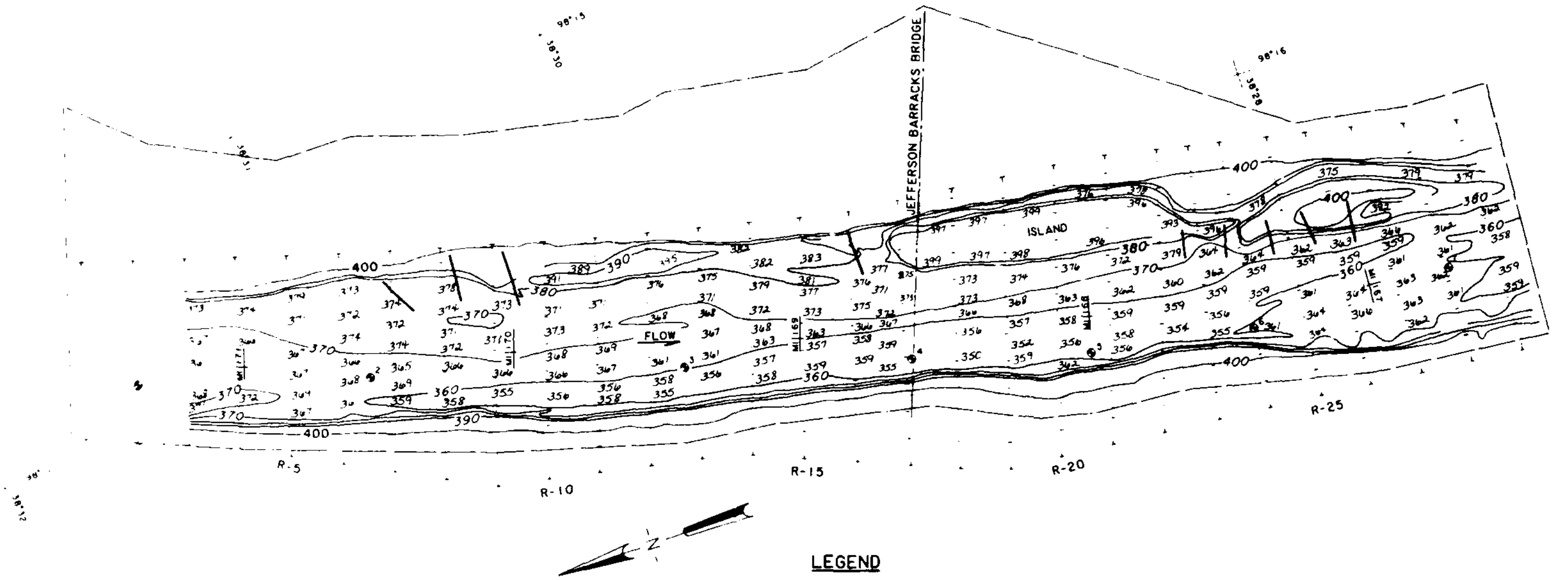
BED-LOAD CURVE



CHANNEL CONFIGURATION

1967 PROTOTYPE SURVEY

PLATE 3



LEGEND

R-5 TEMPLATE AND SOUNDING RANGE
MODEL GAGE LOCATION
RIVER MILE
PILE DIKE

SCALES IN FEET

PROTOTYPE 1000 0 1000 2000
MODEL 8 6 4 2 0 5 10 15

CHANNEL CONFIGURATION

VERIFICATION TEST

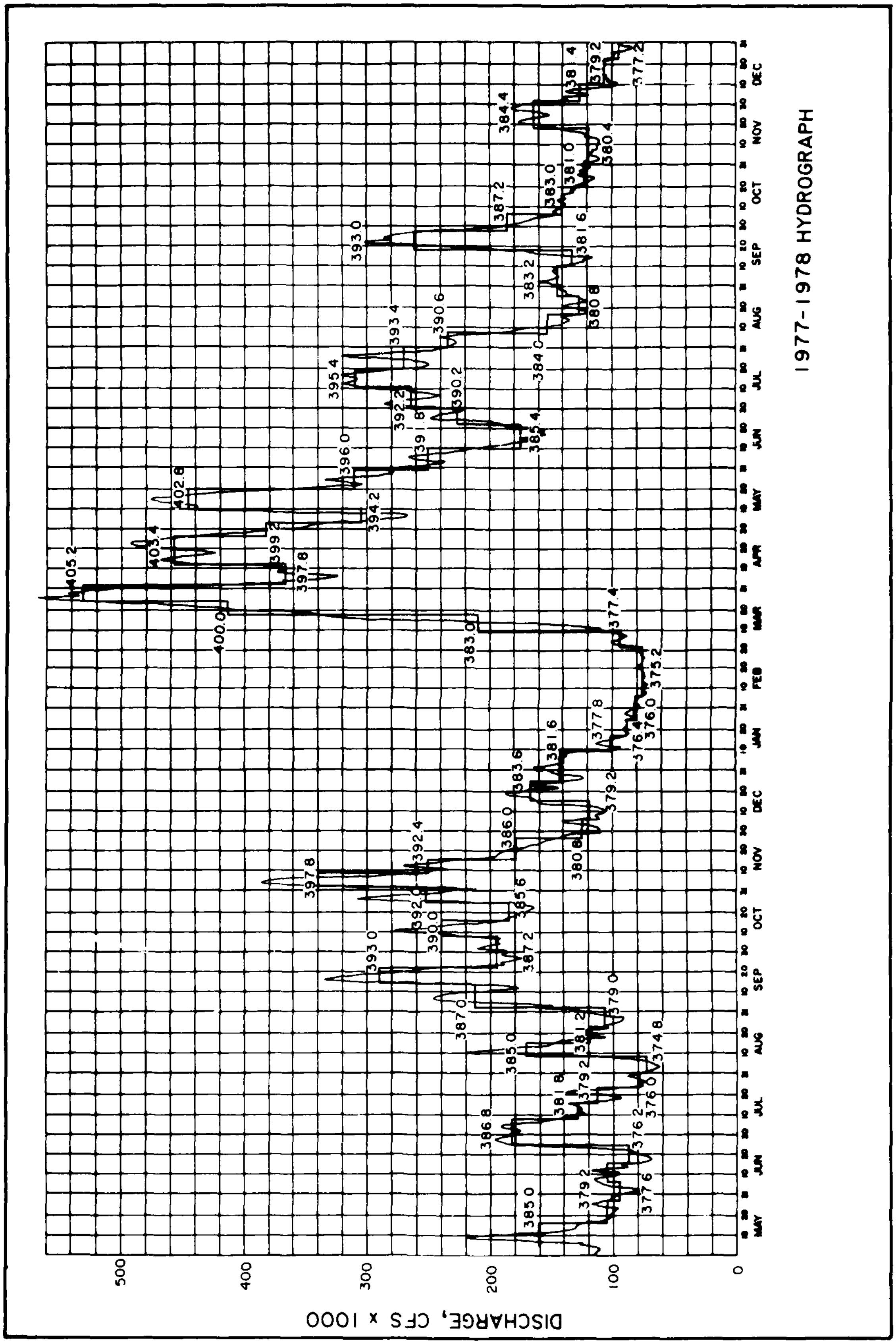

1977-1978 HYDROGRAPH
DISCHARGE, CFS x 1000
0
100
200
300
400
500
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

PLATE 10

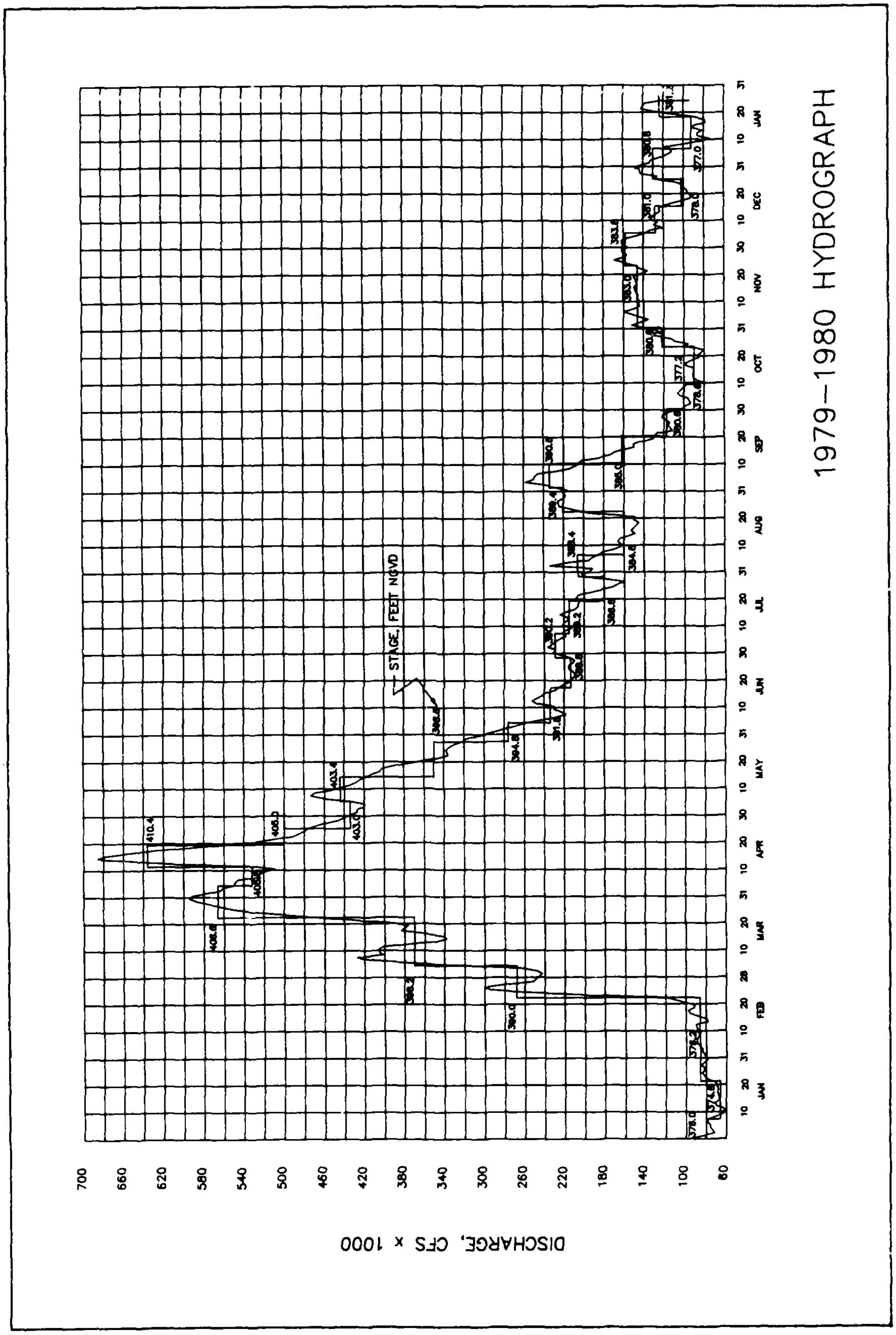

1979–1980 HYDROGRAPH
DISCHARGE, CFS x 1000
STAGE, FEET NGVD
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN

PLATE 11

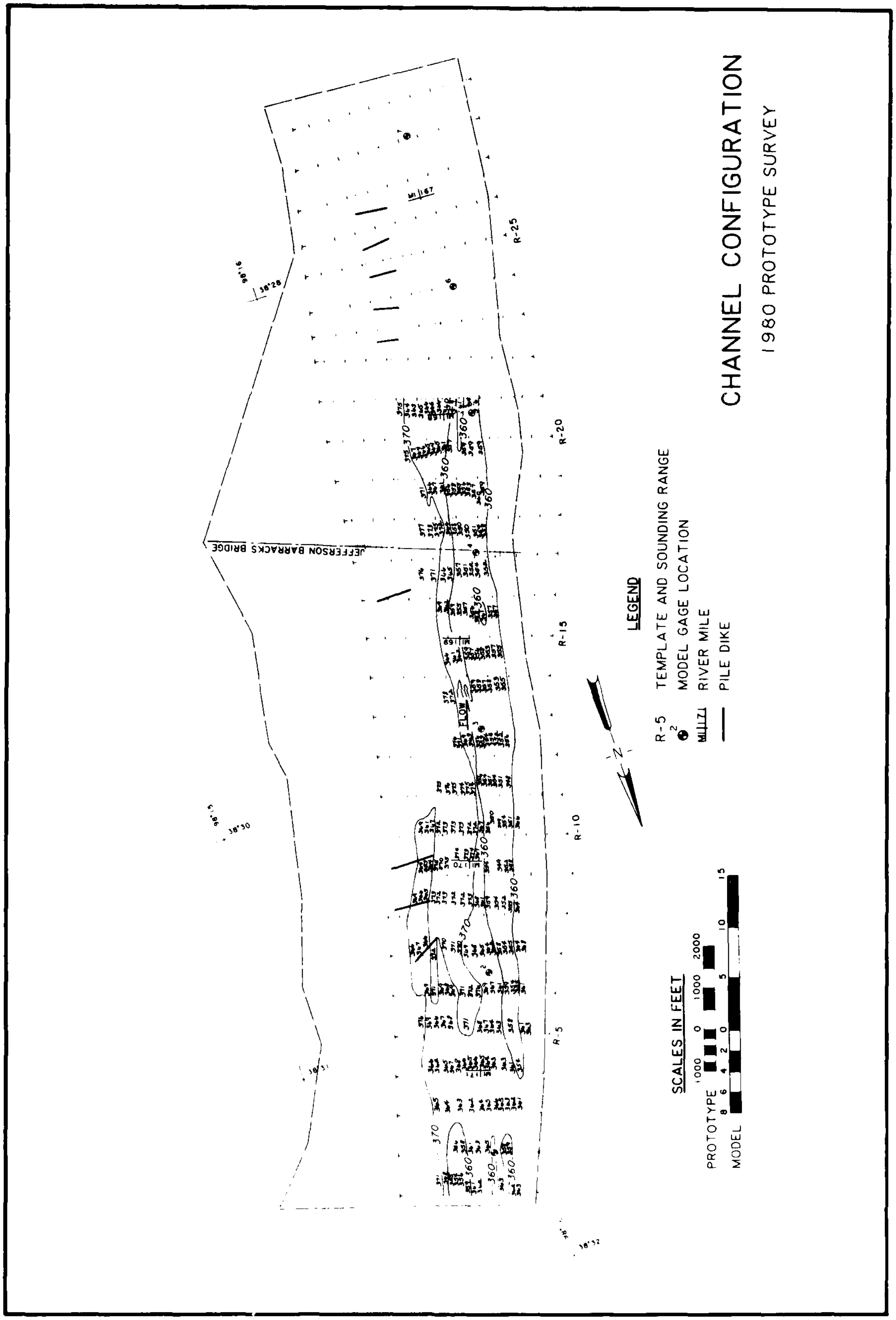
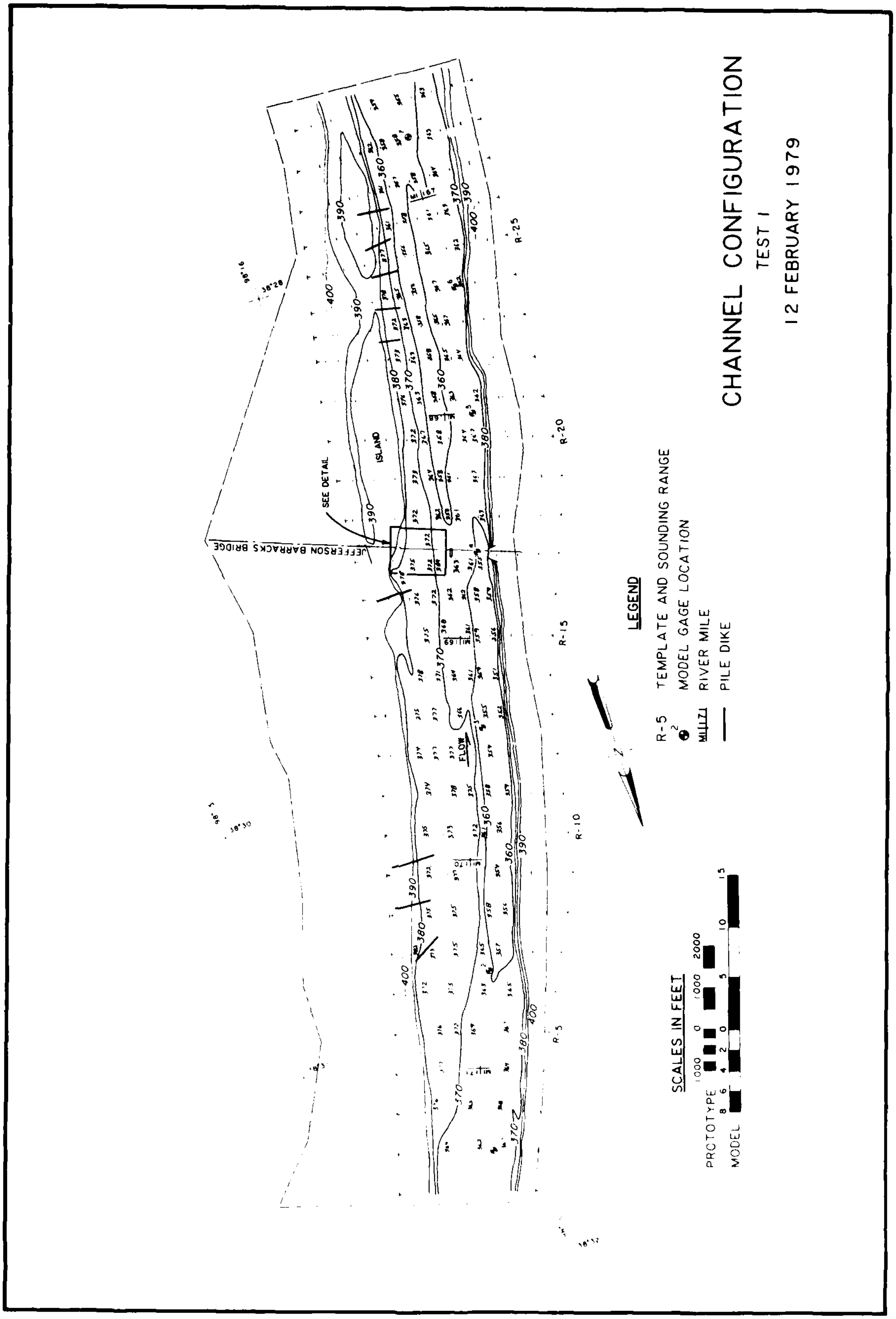

CHANNEL CONFIGURATION
1980 PROTOTYPE SURVEY
LEGEND
R-5 TEMPLATE AND SOUNDING RANGE
MODEL GAGE LOCATION
RIVER MILE
PILE DIKE
SCALES IN FEET
PROTOTYPE 1000 0 1000 2000
MODEL 8 6 4 2 0 5 10 15
JEFFERSON BARRACKS BRIDGE
FLOW
R-5
R-10
R-15
R-20
R-25
N

PLATE 12



CHANNEL CONFIGURATION
TEST 1
12 FEBRUARY 1979

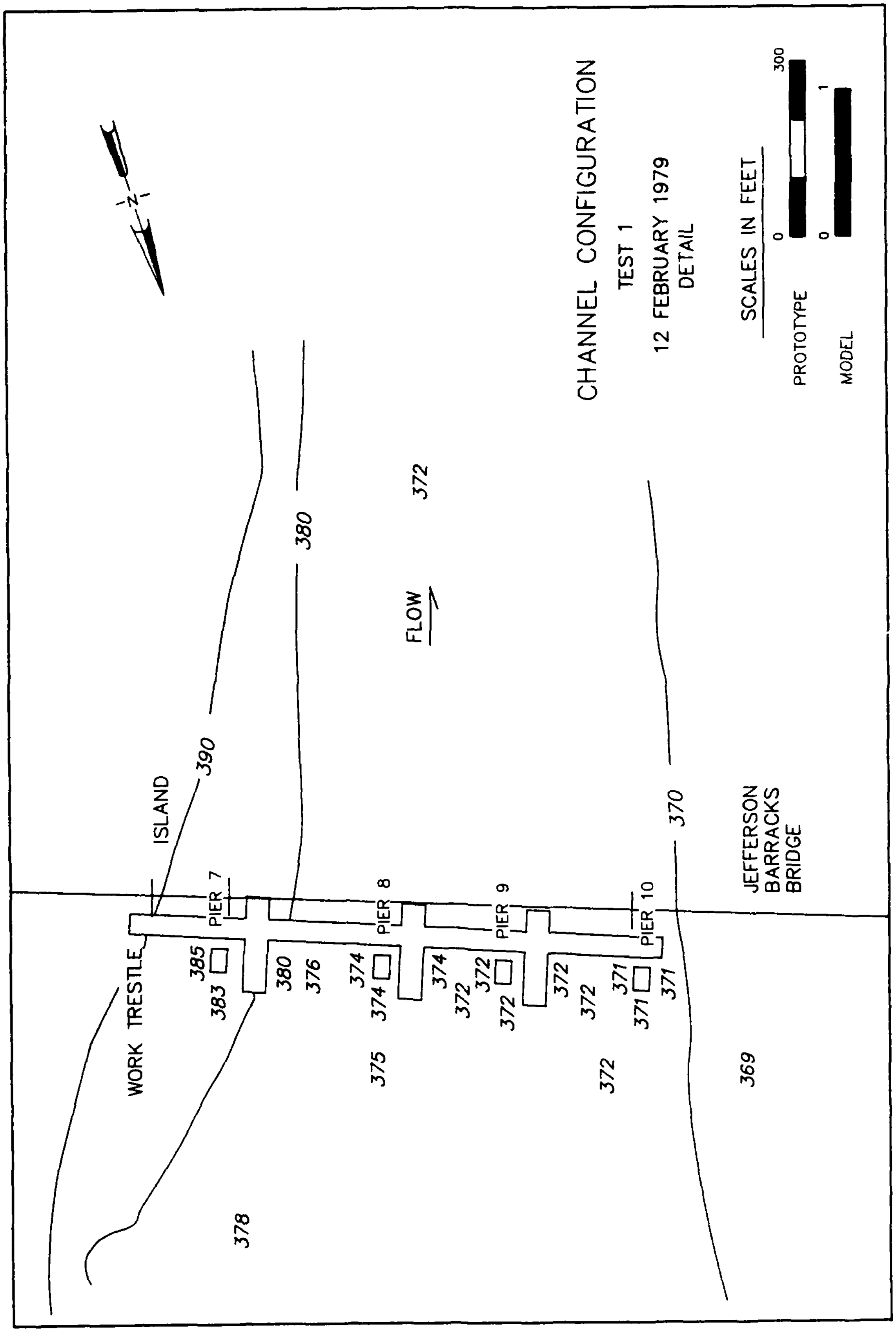
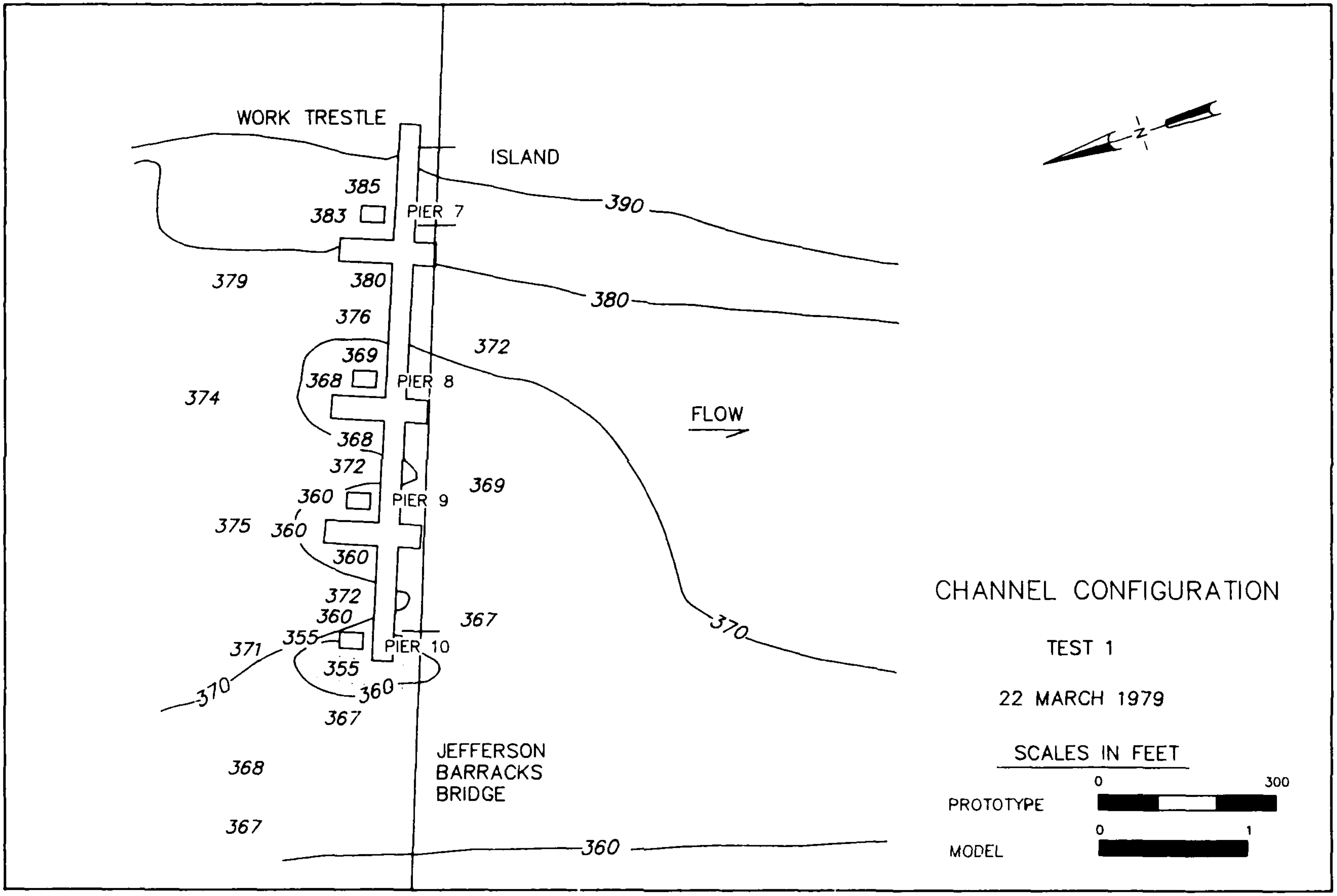


PLATE 13
(SHEET 2 OF 2)



CHANNEL CONFIGURATION

TEST 1

22 MARCH 1979

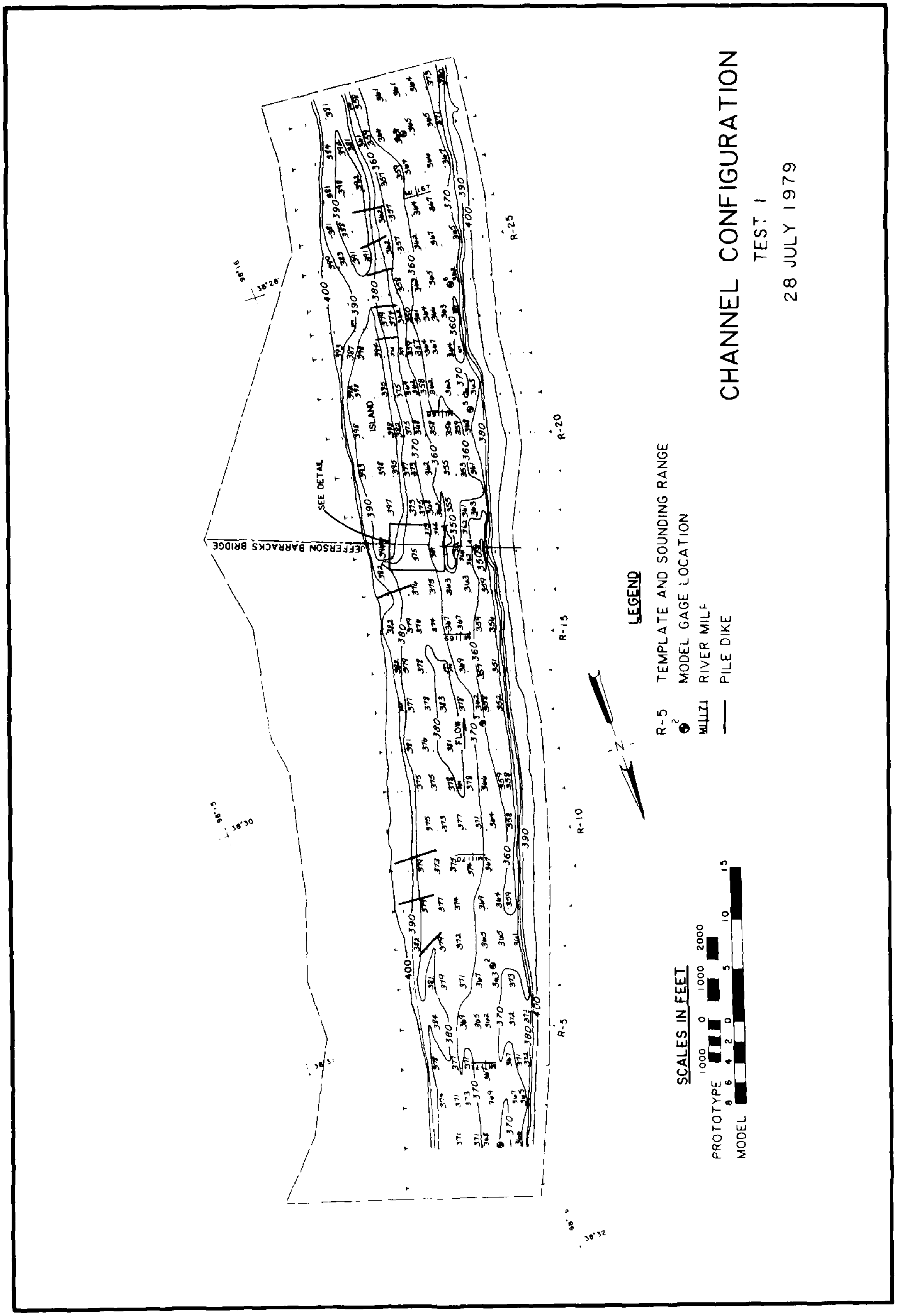


PLATE 15
(SHEET 1 OF 2)

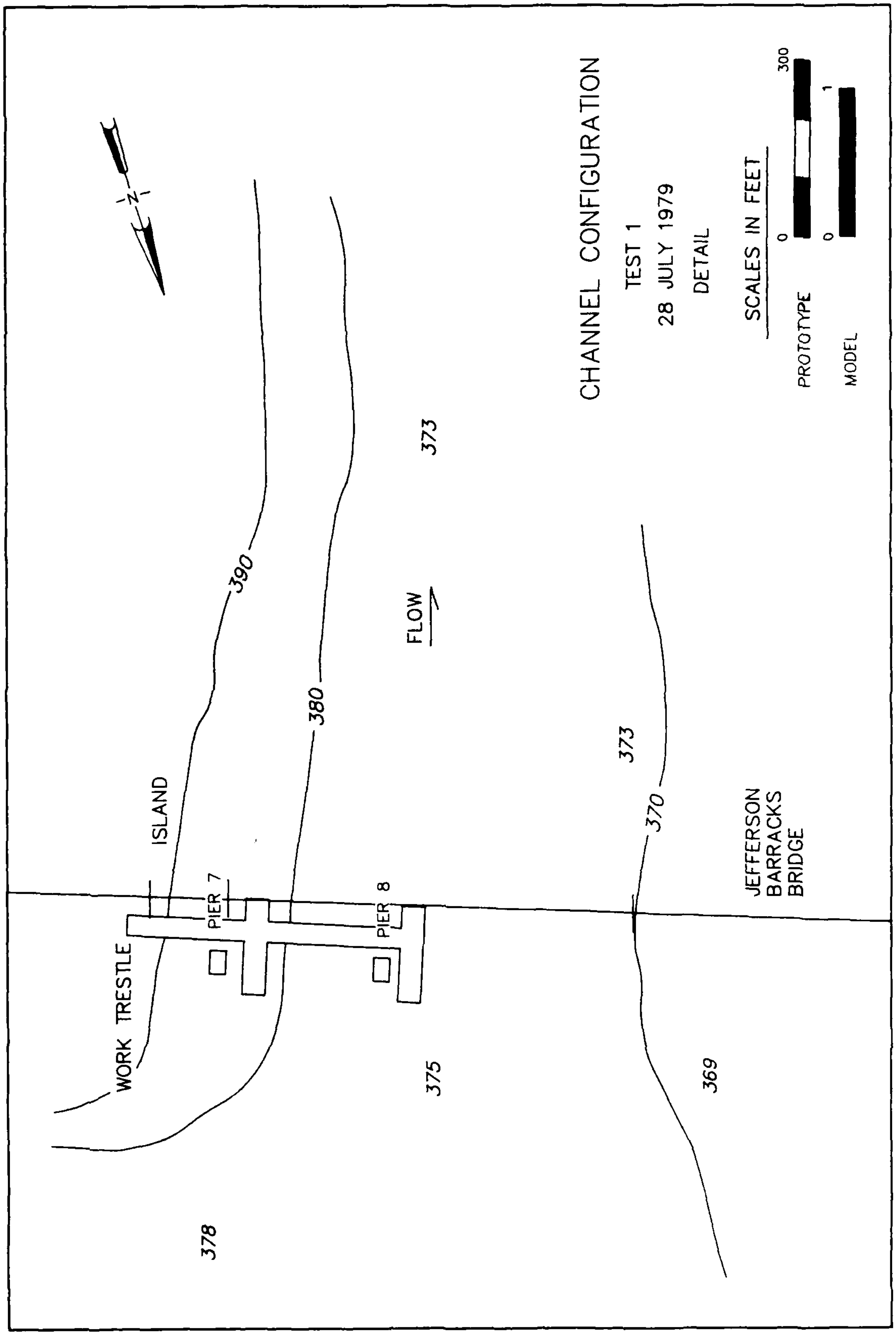


PLATE 15
(SHEET 2 OF 2)

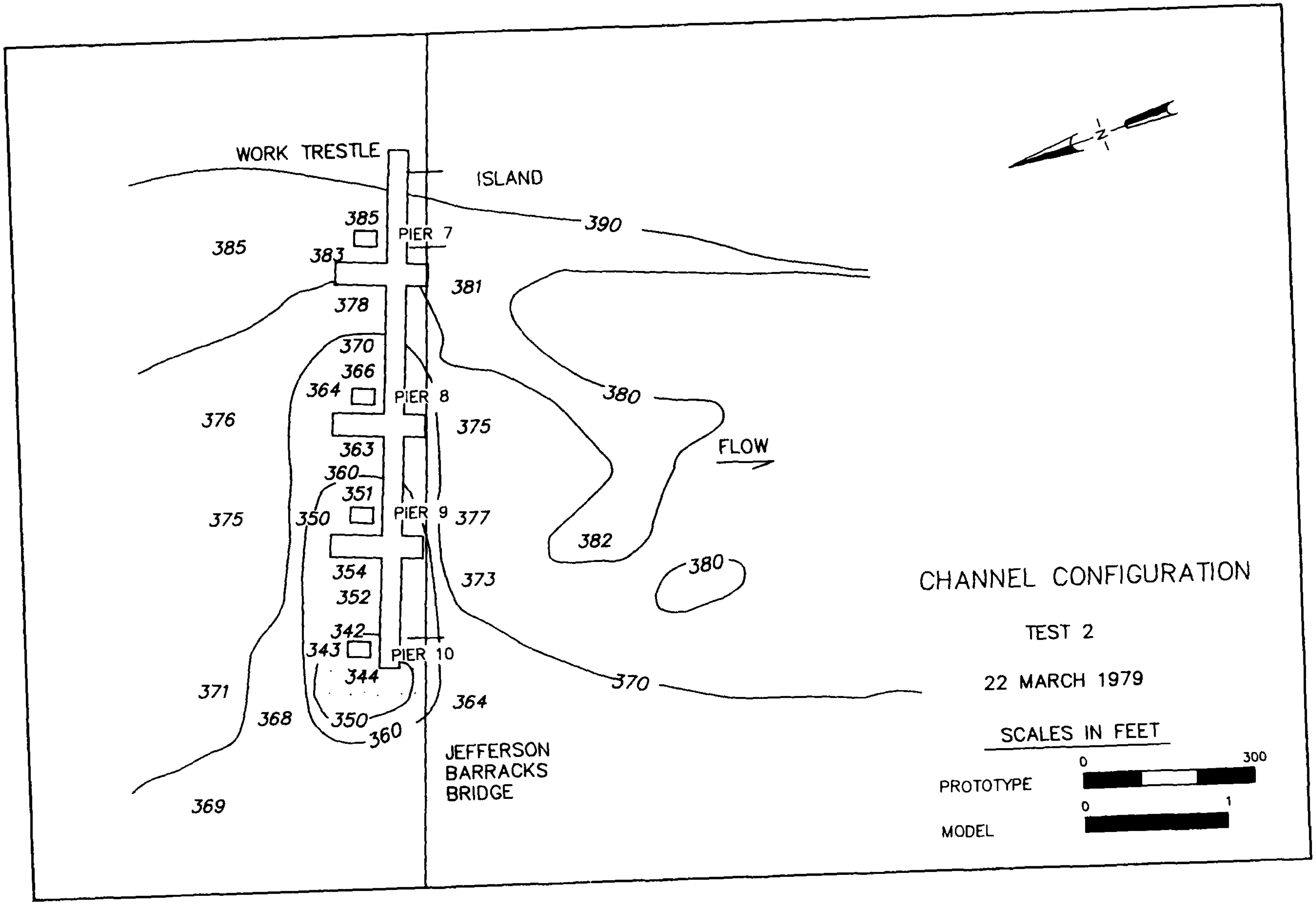
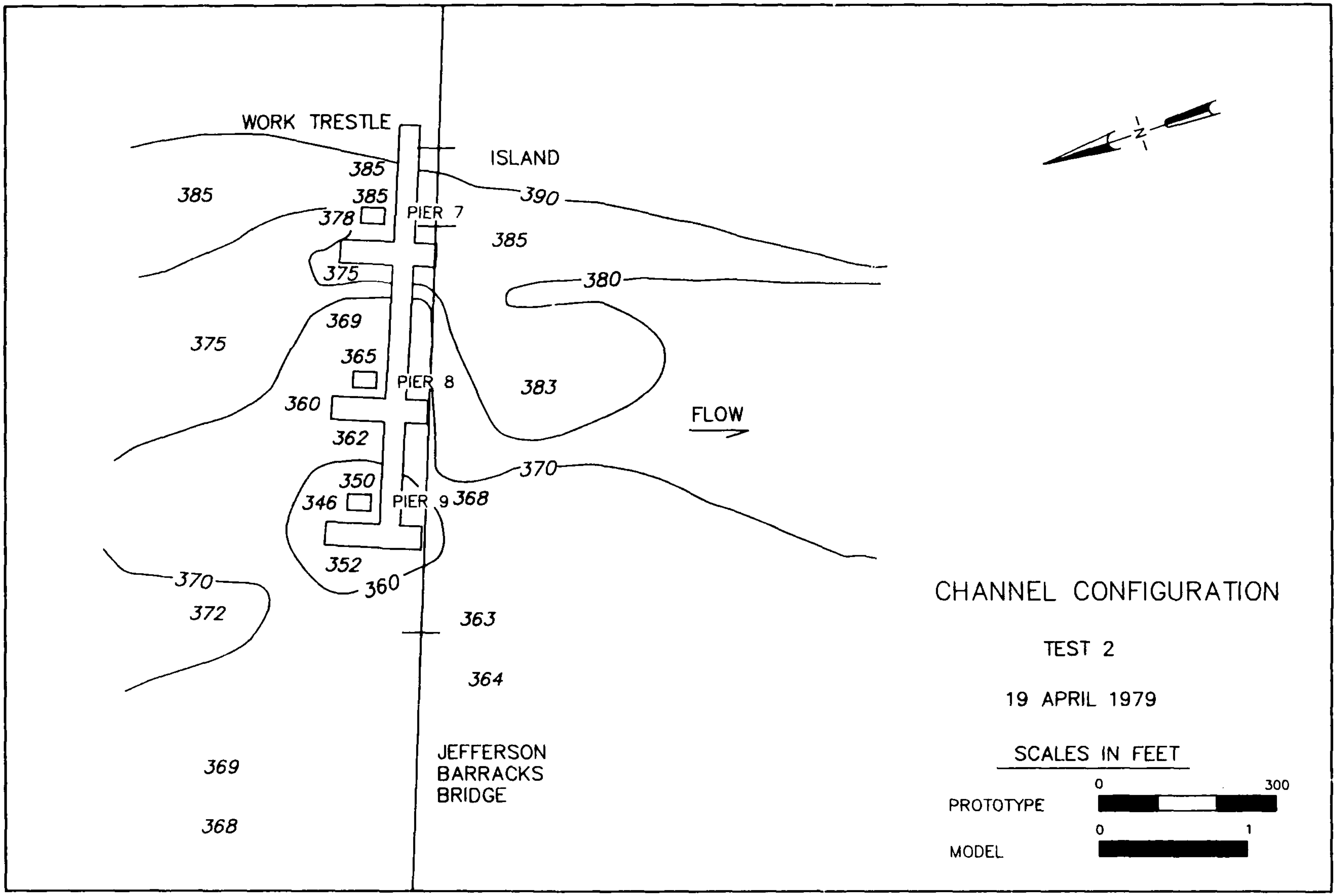

WORK TRESTLE
ISLAND
PIER 7
PIER 8
PIER 9
PIER 10
JEFFERSON
BARRACKS
BRIDGE
FLOW
N
390
385
385
383
381
378
380
370
366
364
376
375
363
360
351
382
350
375
377
354
373
380
352
342
343
344
371
368
350
360
364
370
369
CHANNEL CONFIGURATION
TEST 2
22 MARCH 1979
SCALES IN FEET
PROTOTYPE
0
300
MODEL
0
1

PLATE 16



CHANNEL CONFIGURATION

TEST 2

19 APRIL 1979

SCALES IN FEET

PROTOTYPE 0 300

MODEL 0 1

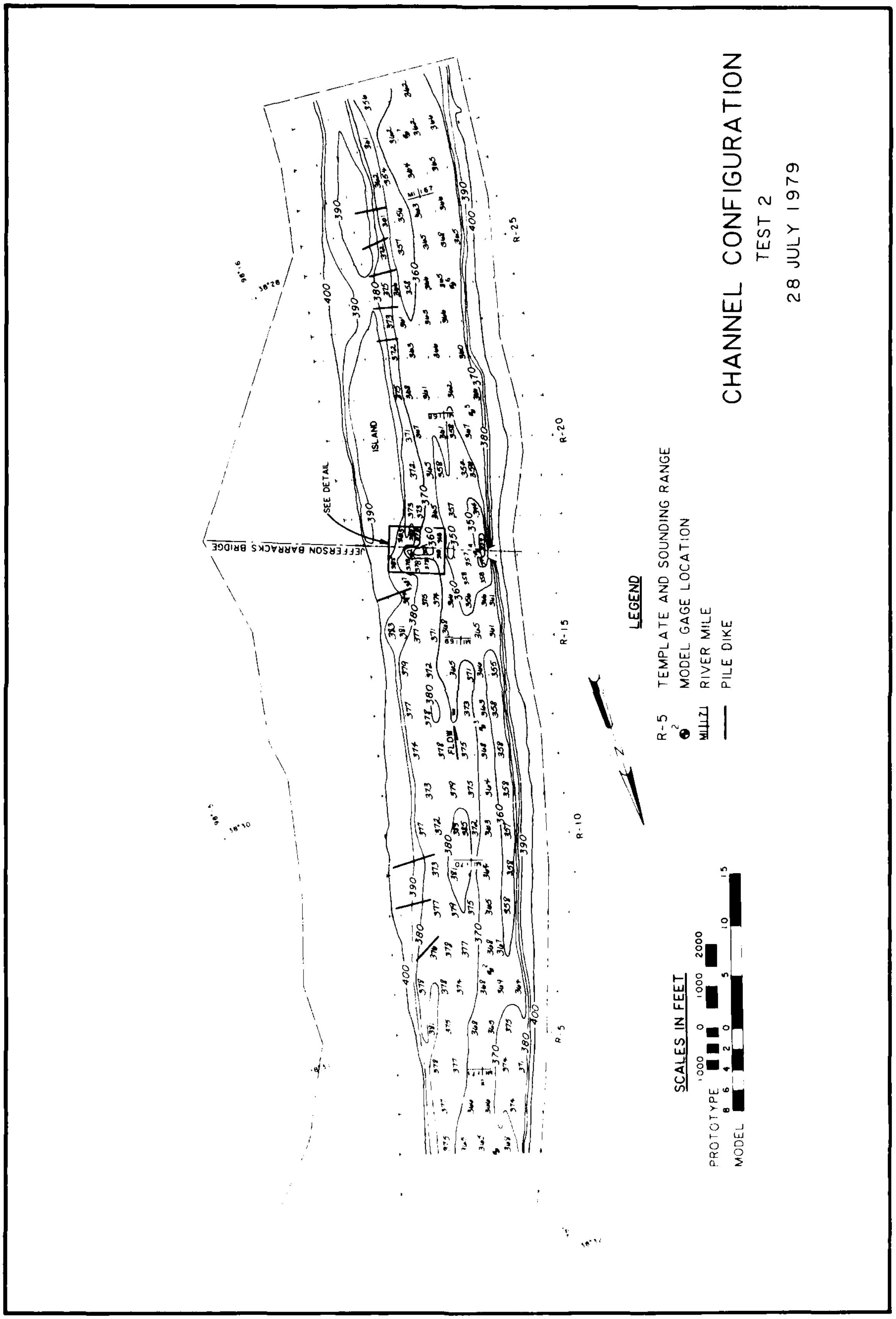


PLATE 18
(SHEET 1 OF 2)

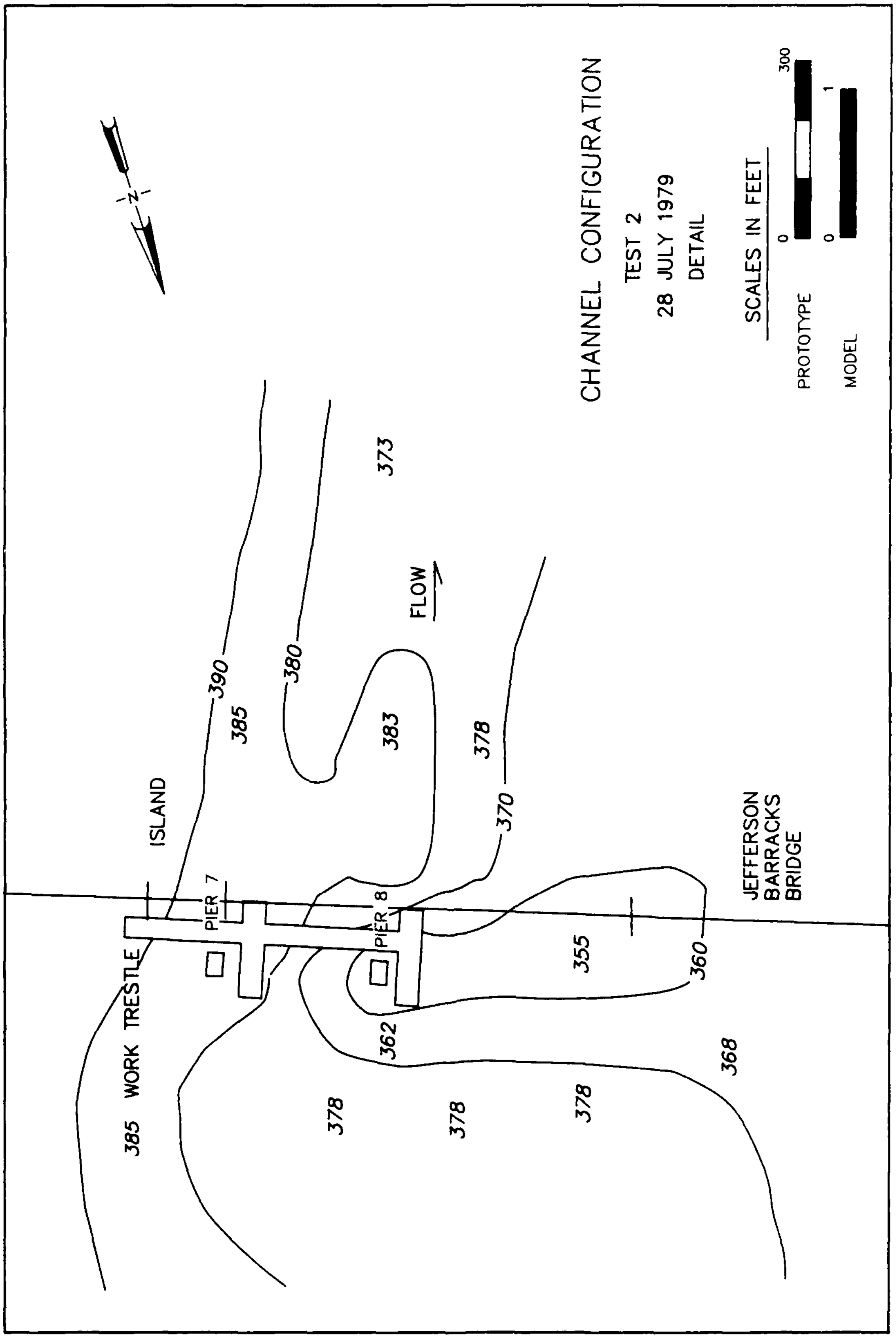
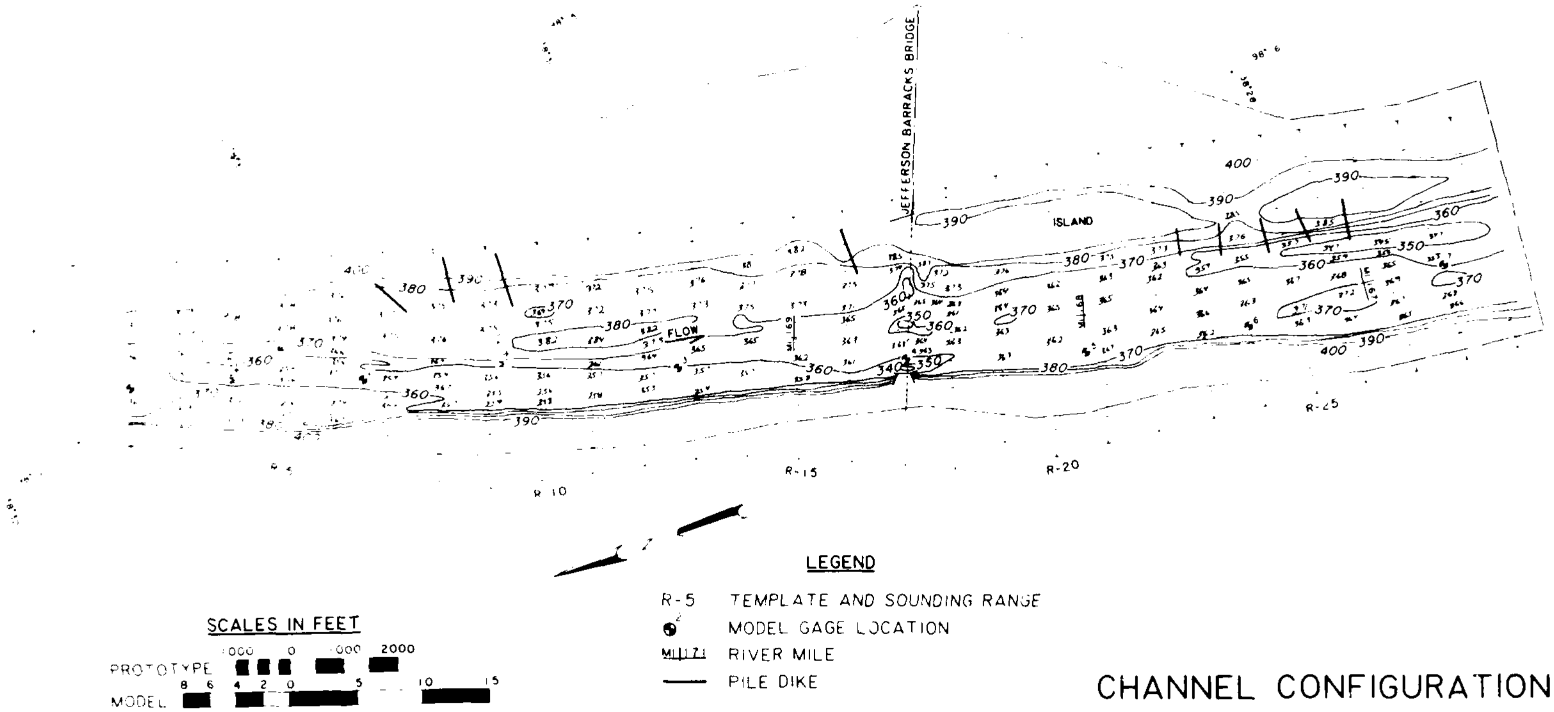
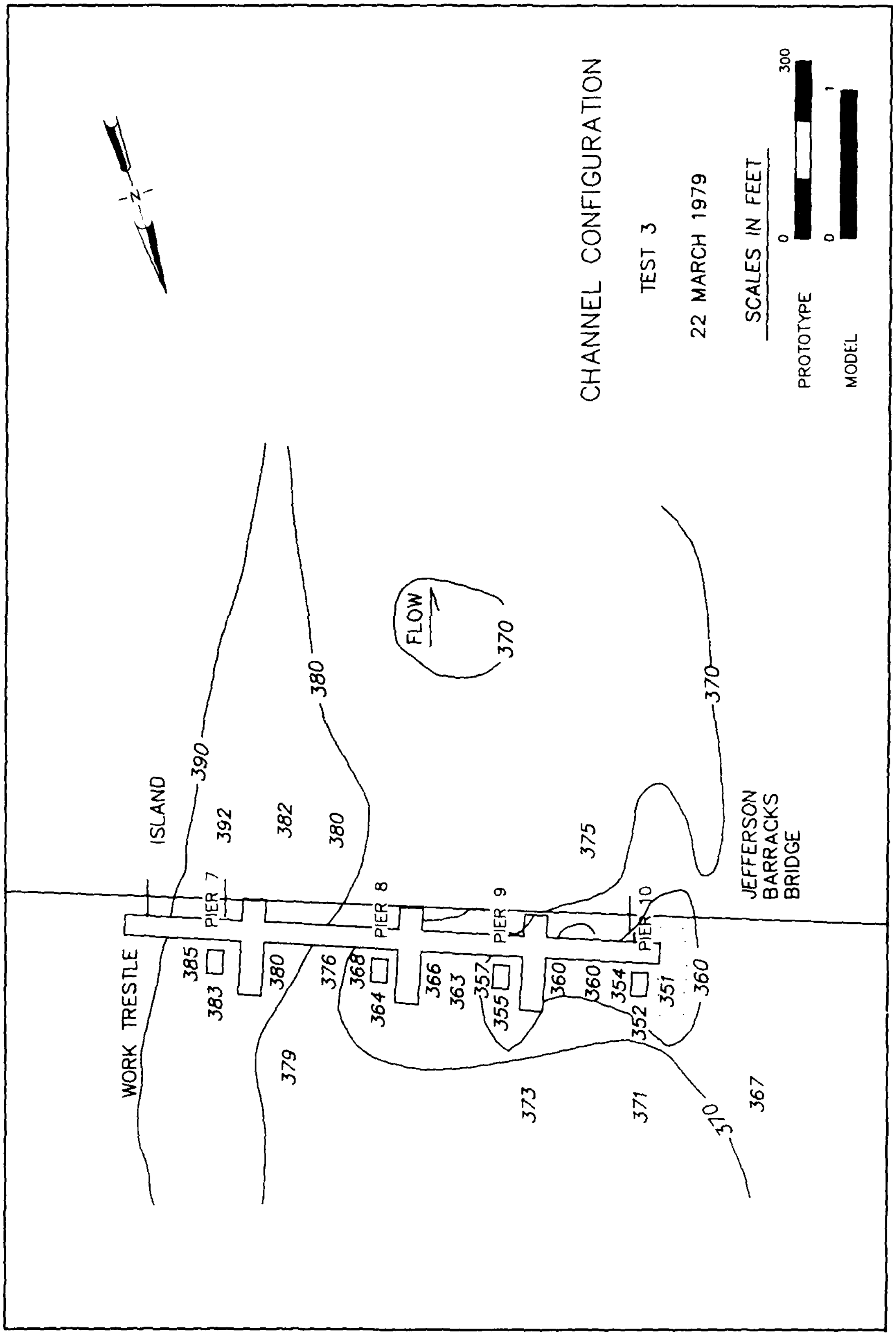
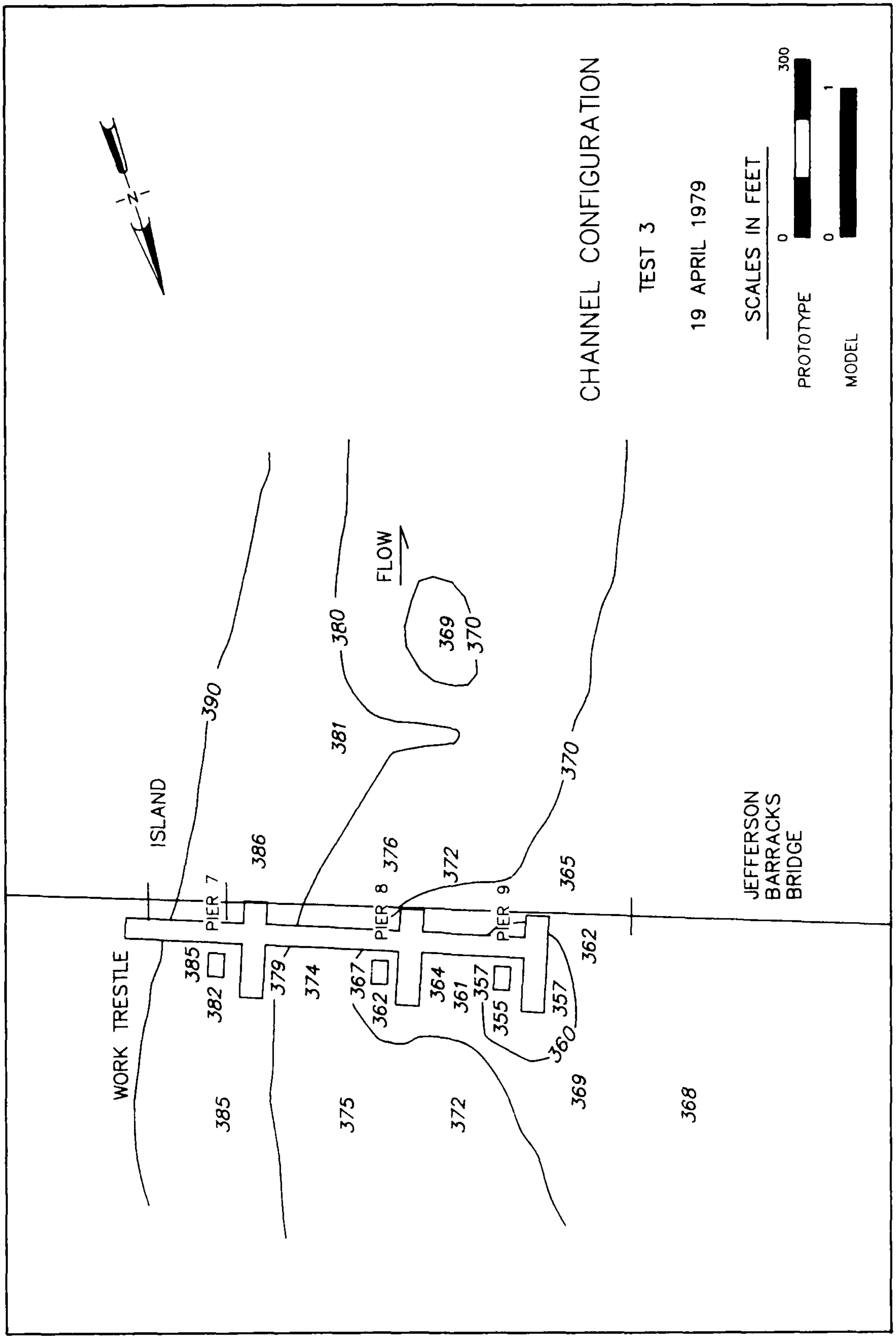


PLATE 18
(SHEET 2 OF 2)



CHANNEL CONFIGURATION
TEST 2
24 JANUARY 1980


CHANNEL CONFIGURATION
TEST 3
22 MARCH 1979
SCALES IN FEET
PROTOTYPE
0
300
MODEL
0
1
N
FLOW
ISLAND
WORK TRESTLE
JEFFERSON BARRACKS BRIDGE
PIER 7
PIER 8
PIER 9
PIER 10
390
392
382
380
380
380
370
370
375
385
383
380
376
368
364
366
363
357
355
360
360
354
351
352
360
379
373
371
370
367



CHANNEL CONFIGURATION
TEST 3
19 APRIL 1979
SCALES IN FEET
PROTOTYPE
0
300
MODEL
0
1
N
FLOW
ISLAND
WORK TRESTLE
PIER 7
PIER 8
PIER 9
JEFFERSON BARRACKS BRIDGE
390
380
381
369
370
370
386
376
372
365
385
382
379
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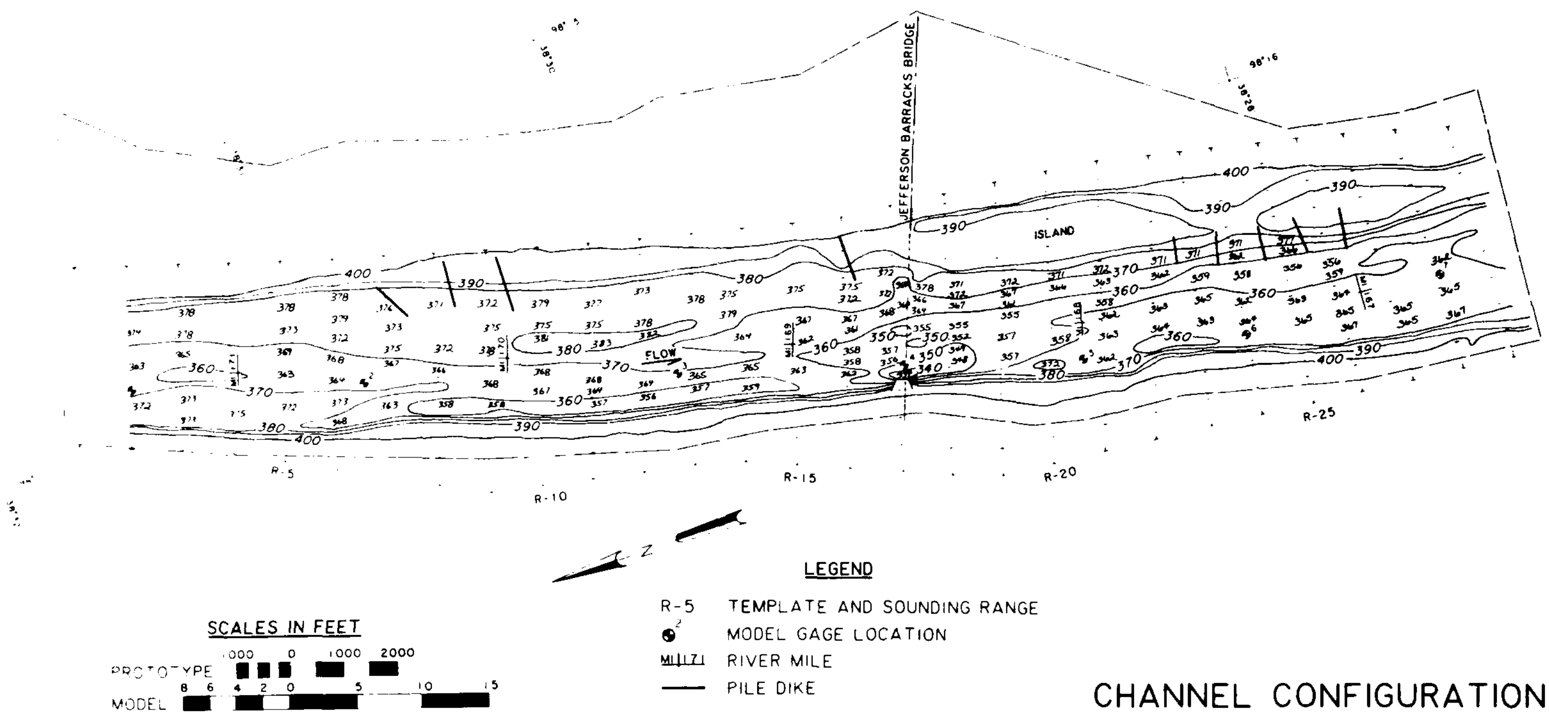
375
372
369
368

PLATE 21



CHANNEL CONFIGURATION

TEST 3

28 JULY 1979

APPENDIX A: DESIGN CONSIDERATIONS FOR MOVABLE-BED MODELS

1. Principal considerations in the design of movable-bed models should be that the hydraulic forces developed be sufficient to move the material forming the model channel bed in simulation of the sediment movement in the river and that the model be capable of defining the problem. The horizontal scales that would result in a practical size model based on operation, space, and cost are usually too small to provide the hydraulic forces sufficient to move material of a practical size and specific weight. Adequate hydraulic forces are obtained by using a vertical scale ratio larger than the horizontal scale ratio and exaggerating the discharge scale relations. Having a vertical scale larger than the horizontal scale provides greater model depths and slopes and increases the volume and velocity of the water, thus increasing the hydraulic forces. Increasing the discharge scale provides a greater volume of water, thus increasing the hydraulic forces.

2. Many materials have been used in beds of movable-bed models, but the most commonly used at the US Army Engineer Waterways Experiment Station (WES) are sand and crushed coal. Sand is readily available and has a rather uniform specific gravity of about 2.65. Sand is reasonably stable, and since it is not affected by weather, it is used in most movable-bed models built outdoors at WES. The disadvantages of using sand are that it requires greater forces to move it than lighter materials and it forms ripples on the model bed. These ripples have a significant effect on flow, particularly where depths are small. Crushed coal is the most common type of bed material used at WES in indoor models. The type of coal used is free of impurities and has a specific gravity of 1.30, which makes it about 5.5 times lighter than sand when submerged in water. The coal, when properly sized, can be moved without forming ripples.

APPENDIX B: GENERAL ADJUSTMENT AND VERIFICATION PROCEDURE FOR MOVABLE-BED MODELS

The adjustment procedure begins with the selection of two prototype surveys. The two surveys should be recent so the model will reflect recent conditions when adjusted to these surveys. The surveys should be at least 1 year apart to give a full range of discharges for channel development, but not so far apart as to make the tests require too much time and expense to conduct. The model bed is molded to agree with the earlier prototype survey. The discharges that occurred during the period between the surveys are reproduced in the model. For each discharge, the water-surface elevation near the center of the model is held to the elevation that was recorded for that discharge in the prototype. During each discharge, bed material is introduced in the upstream end of the model to simulate the bed material that entered the prototype test reach. At the end of each test, the model is slowly and carefully drained so as not to disturb the model bed. The model bed is surveyed and the model survey is compared to the later prototype survey. If the model survey agrees with the prototype survey, the model is considered adjusted and ready for testing. If the model survey does not agree with the prototype survey, modifications are made to the amount of bed material added during each flow, the discharge ratio (model to prototype), and model operating techniques. The model is remolded to the earlier prototype survey, the flows are reintroduced, the bed is surveyed, and the survey is compared to the later prototype survey. This procedure is repeated until the model survey agrees with the prototype survey. When the model satisfactorily reproduces the prototype survey, the model is considered verified, and the scales and procedures developed during the adjustment period are used during the subsequent testing procedures.

APPENDIX C: ADJUSTMENT AND VERIFICATION OF THE ST. LOUIS HARBOR MODEL

1. The St. Louis Harbor model was adjusted to reproduce changes in the prototype bed during the period September 1966 to September 1967. The model bed was molded to conditions shown in the Mississippi River hydrographic survey of September 1966. The discharges that were recorded for St. Louis, MO, for the period 1 September 1966 to 1 September 1967, modified to give appropriate bed movement for each discharge, were introduced at the upstream end of the model. Model stages at Veterans Memorial Bridge (about the center of the model) were held to those recorded in the prototype for this point by a movable tailgate at the downstream end of the model. During each discharge, bed material was introduced in the upstream end of the model to simulate bed material that moved into this reach of the prototype. At the end of the discharge hydrograph, the model was slowly drained and the bed was surveyed. The model survey was compared with the prototype survey of September 1967. Initially the model survey did not agree with the prototype survey. Adjustments were made in the discharge scale, slope, and rate of introducing bed material; the discharge hydrograph was reintroduced; and the bed was surveyed. This procedure was repeated until a reasonably adequate reproduction of the 1967 survey was obtained. The discharge relation curve and the rate of introduction of bed material developed during this verification were used during the testing of this model from 1967 to 1971.

2. For the Sawyer Bend study in April 1972,* the model was adjusted to reproduce the bed configurations shown in the prototype hydrographic survey of March 1971. The discharge relation curve and the rate of introducing bed material developed in the adjustment of the St. Louis Harbor model for the 1967-1971 testing period were also used for this adjustment and model testing from 1972 to 1975.

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* J. E. Foster, C. M. Noble, and J. J. Franco. 1978 (Jun). "Shoaling Conditions in Sawyer Bend and Lower Entrance to Chain of Rocks Canal, Mississippi River; Hydraulic Model Investigation," Technical Report H-78-7, US Army Engineer Waterways Experiment Station, Vicksburg, MS.