WRE 87-1

SCOUR AROUND BRIDGE PIERS IN OKLAHOMA STREAMS

by

A. K. TYAGI
PRINCIPAL INVESTIGATOR

Report No. 87-1
Water Resources Engineering
School of Civil Engineering

Oklahoma State University
Stillwater, Oklahoma 74078
March, 1987

SCOUR AROUND BRIDGE PIERS IN OKLAHOMA STREAMS

by

A. K. Tyagi

Principal Investigator

Report No. 87-1

Water Resources Engineering
School of Civil Engineering
Oklahoma State University
Stillwater, Oklahoma 74078

March 1987

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
FHWA/OK 87 (2)	X	X

4. TITLE AND SUBTITLE Scour Around Bridge Piers in Oklahoma Streams	5. REPORT DATE March 1987 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) A. K. Tyagi	8. PERFORMING ORGANIZATION REPORT 87-1
9. PERFORMING ORGANIZATION AND ADDRESS School of Civil Engineering Oklahoma State University Stillwater, OK 74078	10. WORK UNIT NO. 11. CONTRACT OR GRANT NO. 2150
12. SPONSORING AGENCY NAME AND ADDRESS Oklahoma Department of Transportation Research and Development Division 200 NE 21st Street Oklahoma City, OK 73105	13. TYPE OF REPORT AND PERIOD COVERED Interim Report; November 1986 - March 1987 14. SPONSORING AGENCY CODE 86-05-3, Item 2150

15. SUPPLEMENTARY NOTES
Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration

16. ABSTRACT

This study consisted of a hydrographic survey and determined maximum scour around the piers at eighteen selected bridges on the Cimarron, Arkansas, and Caney Rivers. The survey was performed soon after the 50- to 100-year-frequency flood in October, 1986. It was determined from the survey that maximum scour varied from 0.60 to 18 feet with depth of flow ranging between 0.75 to 25 feet. Visual inspection and measurement showed that a sandy river bed and clayey river bed in the three streams seemed to affect scour depth. Also, heavy damages occurred in overflow structures in flood plains rather than at piers in the main stream.

Because design criteria for scour depths at piers are based mostly on laboratory work and because some bridges designed according to these criteria have failed, it is recommended that this study be extended to collect field data on the maximum scour at selected bridges over a four-year period. Field data will be collected four times a year for various high and low flow conditions. Laboratory and field data are to be analyzed and used to produce design criteria so that damages to bridge piers are minimized. Further laboratory and field data will be generated for different river-bed soils (sand, silt and clay) and for varying hydraulic conditions.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
Scour Depth, Bridge Piers, Flood, Depth of Flow, Rivers, Field Data	No Restrictions

19. SECURITY CLASSIF. (OF THIS REPORT)	20. SECURITY CLASSIF. (OF THIS PAGE)	21. NO. OF PAGES	22. PRICE
None	None	24	X

The contents of this report reflect the view of the authors who are not responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Oklahoma Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

ACKNOWLEDGEMENTS

This project was funded by the Oklahoma Department of Transportation (ODOT) under Contract No. EN-87-R-37. The technical support of Mr. Bill Hartronft, Chief Engineer; Mr. Dwight Hixon, Research Engineer; and Mr. Veldo Goins, Bridge Engineer, is gratefully acknowledged. Discussions and suggestions of Mr. Tony Abyad, Hydraulic Engineer of ODOT, Mr. Art Hamilton, Hydraulic Engineer of the Federal Highway Administration (FHWA), and Mr. Frank Cunningham, Assistant Division Administrator of FHWA, were valuable in this research investigation. Last, but not least, the support of Dr. Robert Hughes, the Head of the Civil Engineering Department, and Dr. Phil Manke, Professor of Civil Engineering, is most appreciated.

ABSTRACT

This study consisted of a hydrographic survey and determined maximum scour around the piers at eighteen selected bridges on the Cimarron, Arkansas, and Caney Rivers. The survey was performed soon after the 50- to 100-year-frequency flood in October, 1986. It was determined from the survey that maximum scour varied from 0.60 to 18 feet with depth of flow ranging between 0.75 to 25 feet. Visual inspection and measurement showed that a sandy river bed and clayey river bed in the three streams seemed to affect scour depth. Also, heavy damages occurred in overflow structures in flood plains rather than at piers in the main stream.

Because design criteria for scour depths at piers are based mostly on laboratory work and because some bridges designed according to these criteria have failed, it is recommended that this study be extended to collect field data on the maximum scour at selected bridges over a four-year period. Field data will be collected four times a year for various high and low flow conditions. Laboratory and field data are to be analyzed and used to produce design criteria so that damages to bridge piers are minimized. Further laboratory and field data will be generated for different river-bed soils (sand, silt and clay) and for varying hydraulic conditions.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

A large storm in September and October of 1986 resulted in a record runoff causing substantial flooding in the Arkansas River Basin. The Cimarron and Caney Rivers are tributaries of the Arkansas River near Tulsa, Oklahoma. Near Perkins, Oklahoma, a total of 27 inches of precipitation (a 15-year rainfall) was observed during the storm, which led to a 50- to 100-year flood at the Perkins Bridge on Hwy. 177.

The orientation of the storm was such that the runoff quickly brought the rivers to full capacity. More runoff from additional rainfall simply backed up in urban and rural areas causing property damages of millions of dollars.

This 50- 100-year frequency flood caused excessive damage to the piers of many bridges. The damage to overflow structures in flood plains was more extensive than the damage to main stream bridge piers. This investigation consisted of a hydrographic survey of eighteen selected bridges on the Cimarron, Arkansas, and Caney Rivers. The main objective of the study was to collect maximum scour depth and scour profile at piers soon after the flood.

II. DATA COLLECTION PROCEDURES

Hydrographic data was collected for this project on various bridge sites. A review of the construction plans for the exact pier locations and benchmark elevations and advanced surveying equipment were used to conduct bridge surveys and determine maximum scour at bridge piers in the Cimarron River, Caney River, and Arkansas River.

An electronic distance meter (EDM) and a sonar were used to collect hydraulic conditions and profiles of the scour hole at each bridge site. With this equipment, water surface elevation, channel width, flow velocity, and a profile of the scour holes were measured. The EDM and sonar are described below.

1) Electronic Distance Meter

   The EDM is a highly advanced instrument. This instrument determines the distance by using high frequency radio waves that leave the machine, reflect back off of a prism held at the point where elevation is to be determined, and then return with an accurate measure of distance. This instrument greatly reduces the human error in judgment that is always possible with less sophisticated, manually operated equipment. Another feature of the EDM is its internal computer that atuomatically determines angle changes and horizontal, vertical, and slope distances. The EDM also determines locations of a boat from which scour depths are measured.

2) Sonar

   The sonar is an intrument used in hydrographic survey to measure depths under water by emitting high frequency waves that are reflected from the bottom of the river bed back to the instrument. The depth of water at a location in the river can be measured by taking sonar readings from a boat above the point in question.

These instruments were used to determine the elevation of the water surface. The width of the water section in the river was measured also. The river depths at different points upstream of the selected bridge pier were measured with the help of sonar and EDM. The depths from the water surface to the river bed were plotted and are presented in the next section.

III. SCOUR PROFILES

The elevations of the water surface and the river bed were measured starting from the pier in the upstream direction. A pier was selected by visual observation of the current flow. River bed elevations were taken in the upstream direction of the flow until two consecutive values were in close agreement. Elevations of pier, river bed, and water surface are shown in each profile of a scour hole. Three sets of profiles are presented. Figures 1 through 13 present scour hole profiles of bridge piers at Cleo Springs, Ringwood, Lacey, Dover, Cimarron City, Guthrie, I-35, Coyle, Perkins, Ripley, Cushing, Oilton-99 and Oilton-51 bridges on the Cimarron River.

Scour profiles for Sand Springs, Tulsa-33, and Ponca City bridges on the Arkansas River are shown in Figures 14, 15, and 16. Figure 17 indicates a scour pattern at the Bartlesville bridge on the Caney River.

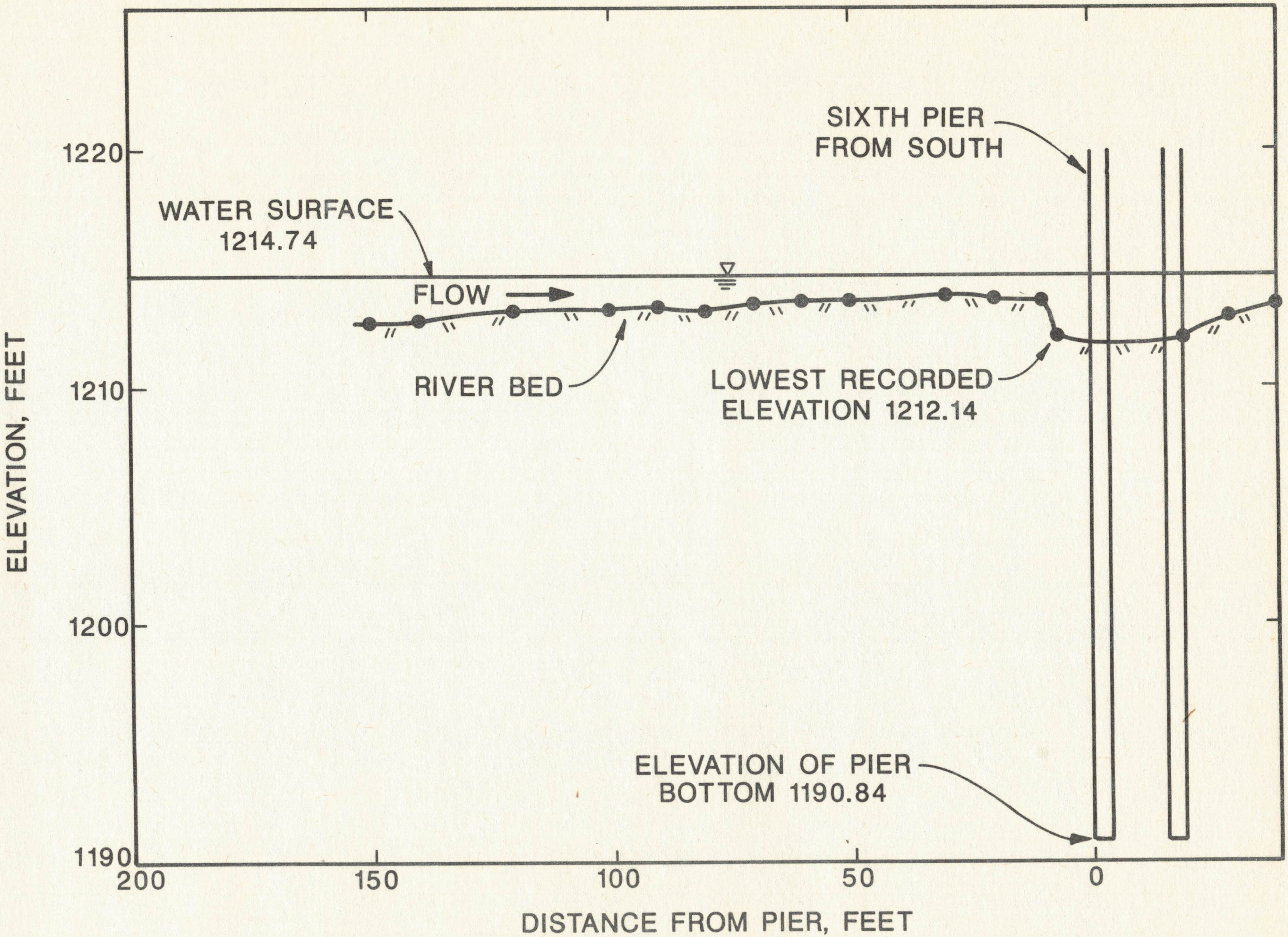

FIGURE 1. CHANNEL PROFILE AT CLEO SPRINGS, HWY 60, CIMARRON RIVER.

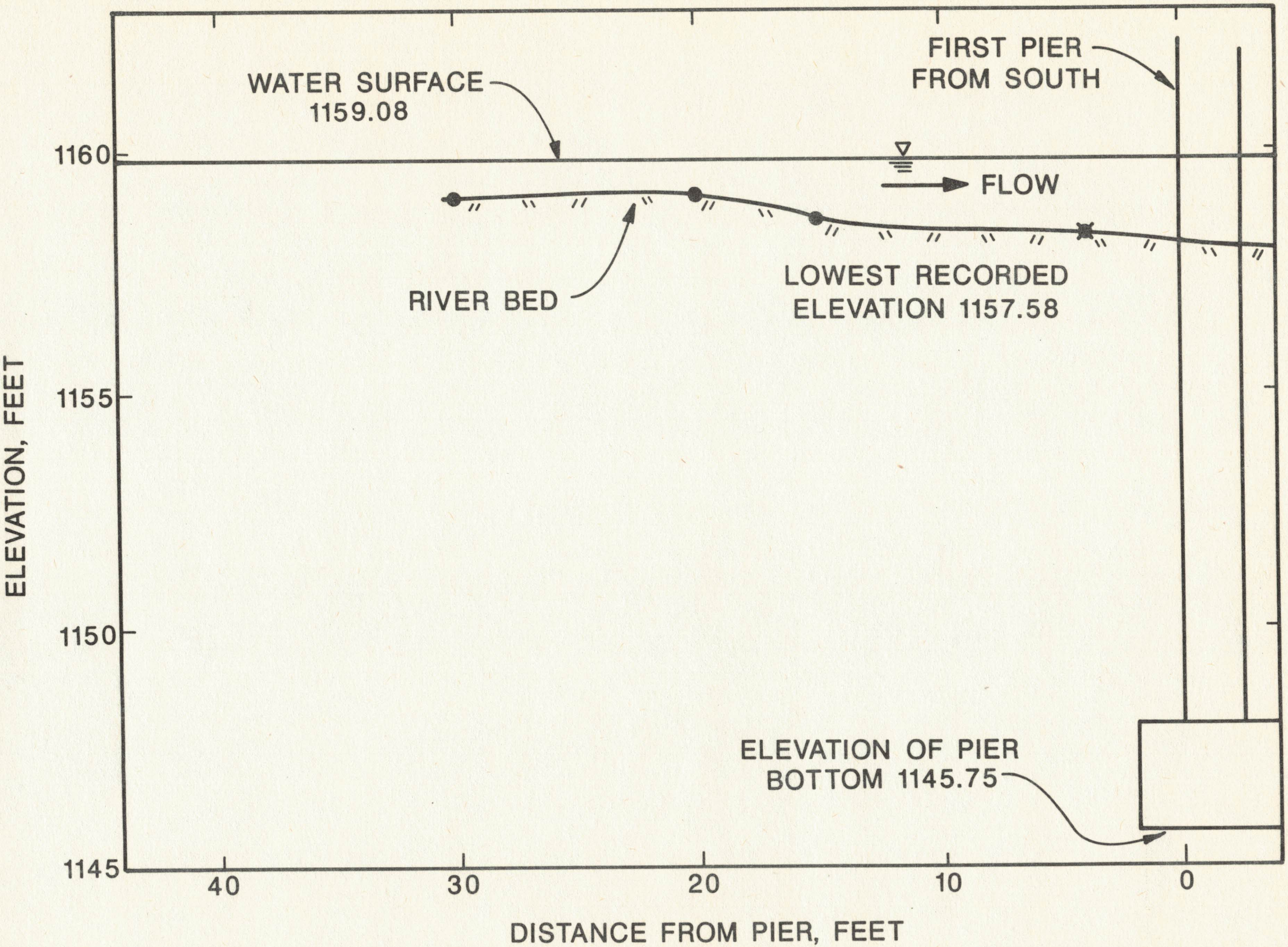

FIGURE 2. CHANNEL PROFILE AT RINGWOOD, HWY 58, CIMARRON RIVER.

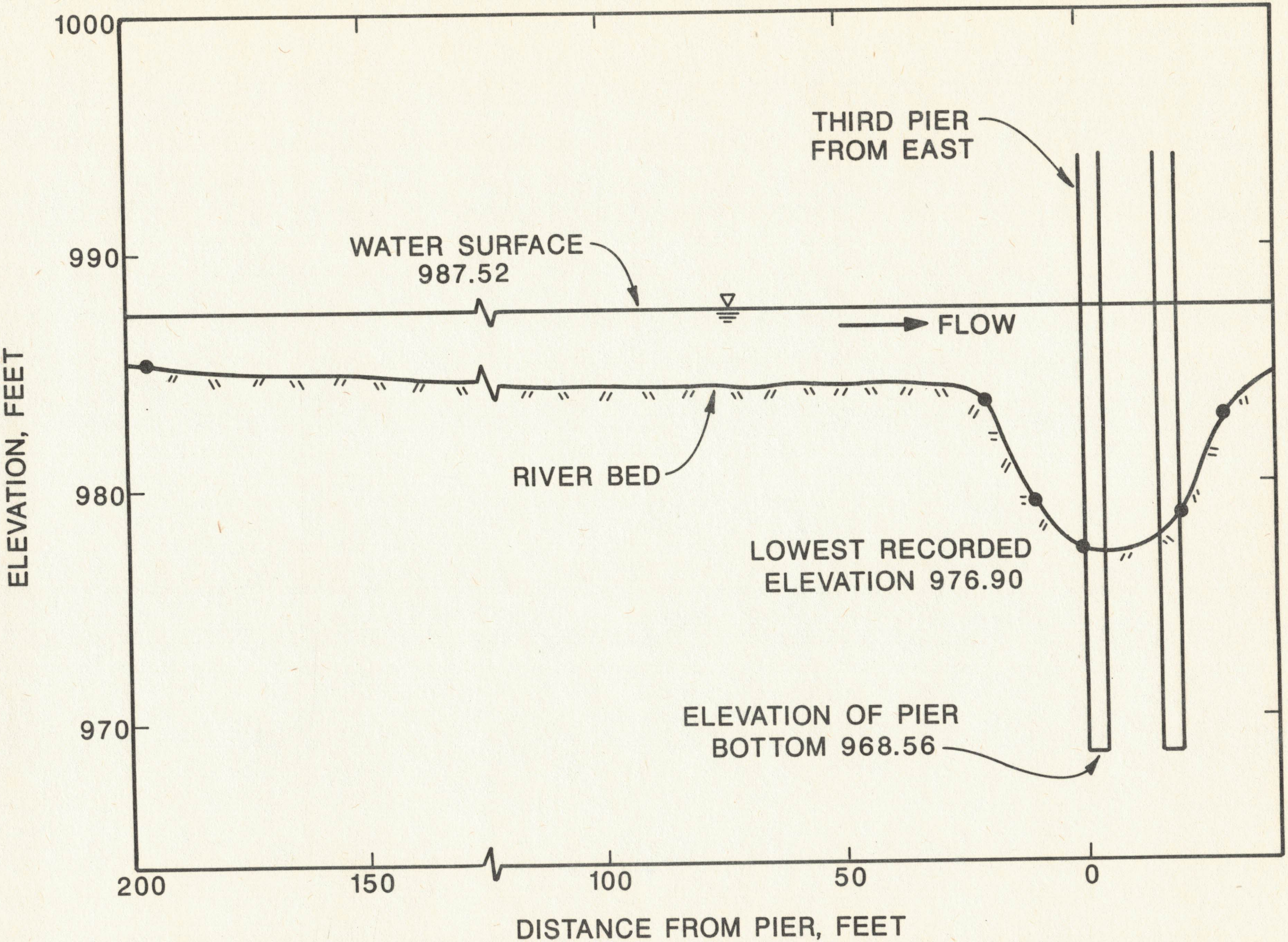

FIGURE 3. CHANNEL PROFILE AT LACEY, HWY 51, CIMARRON RIVER.

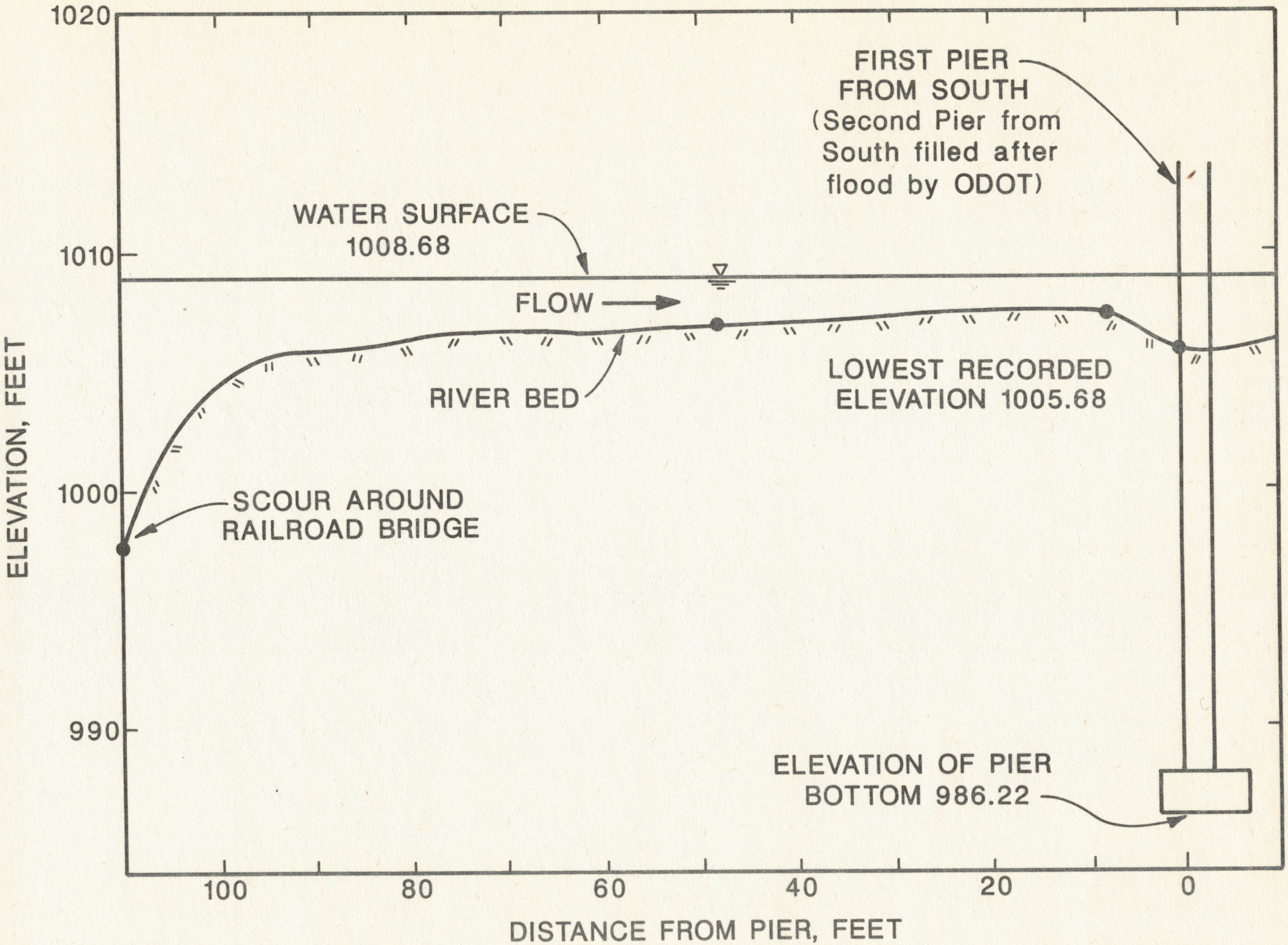

FIGURE 4. CHANNEL PROFILE AT DOVER BRIDGE, HWY 81, CIMARRON RIVER.

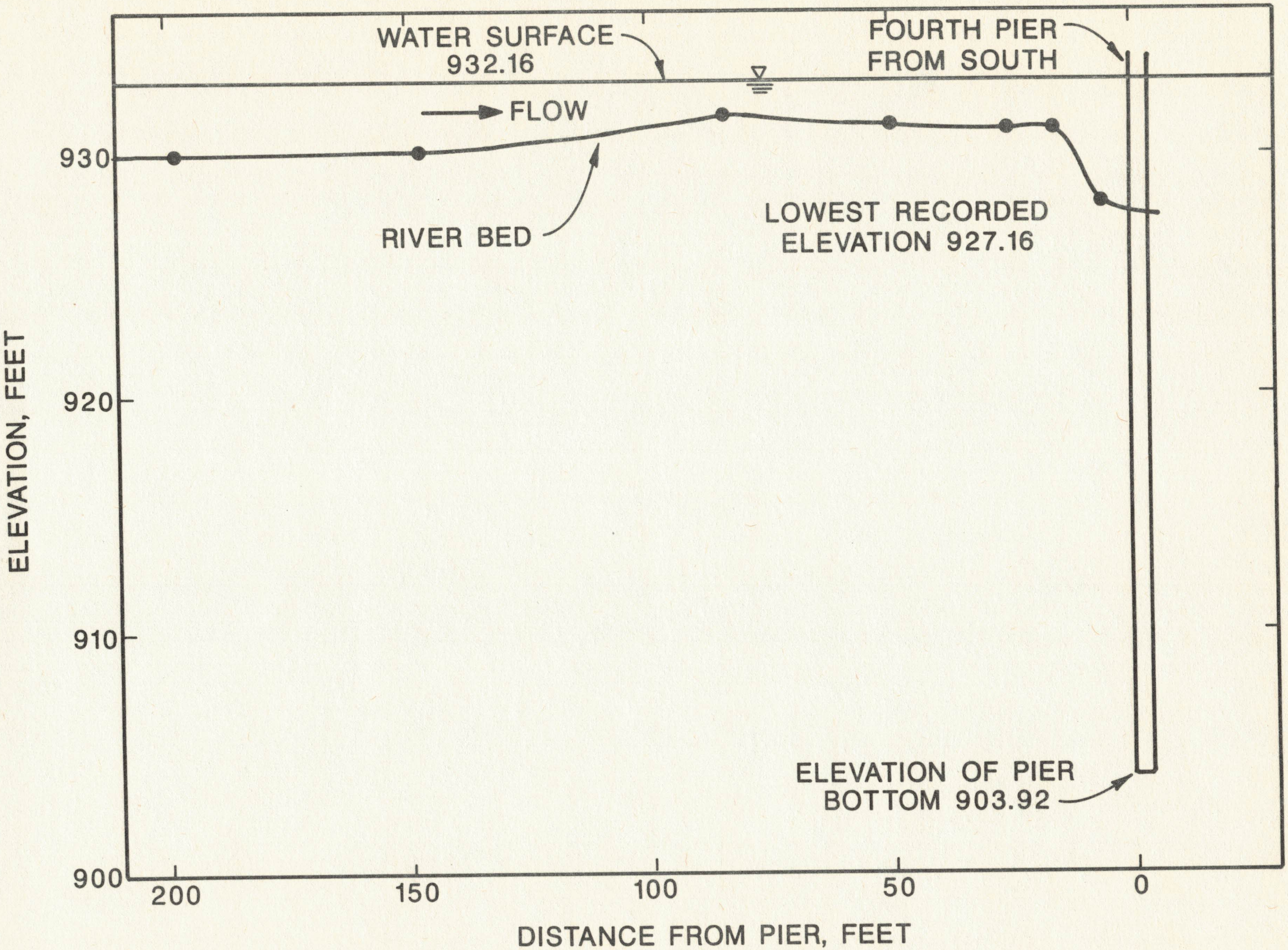

FIGURE 5. CHANNEL PROFILE AT CIMARRON CITY BRIDGE, HWY 74, CIMARRON RIVER.

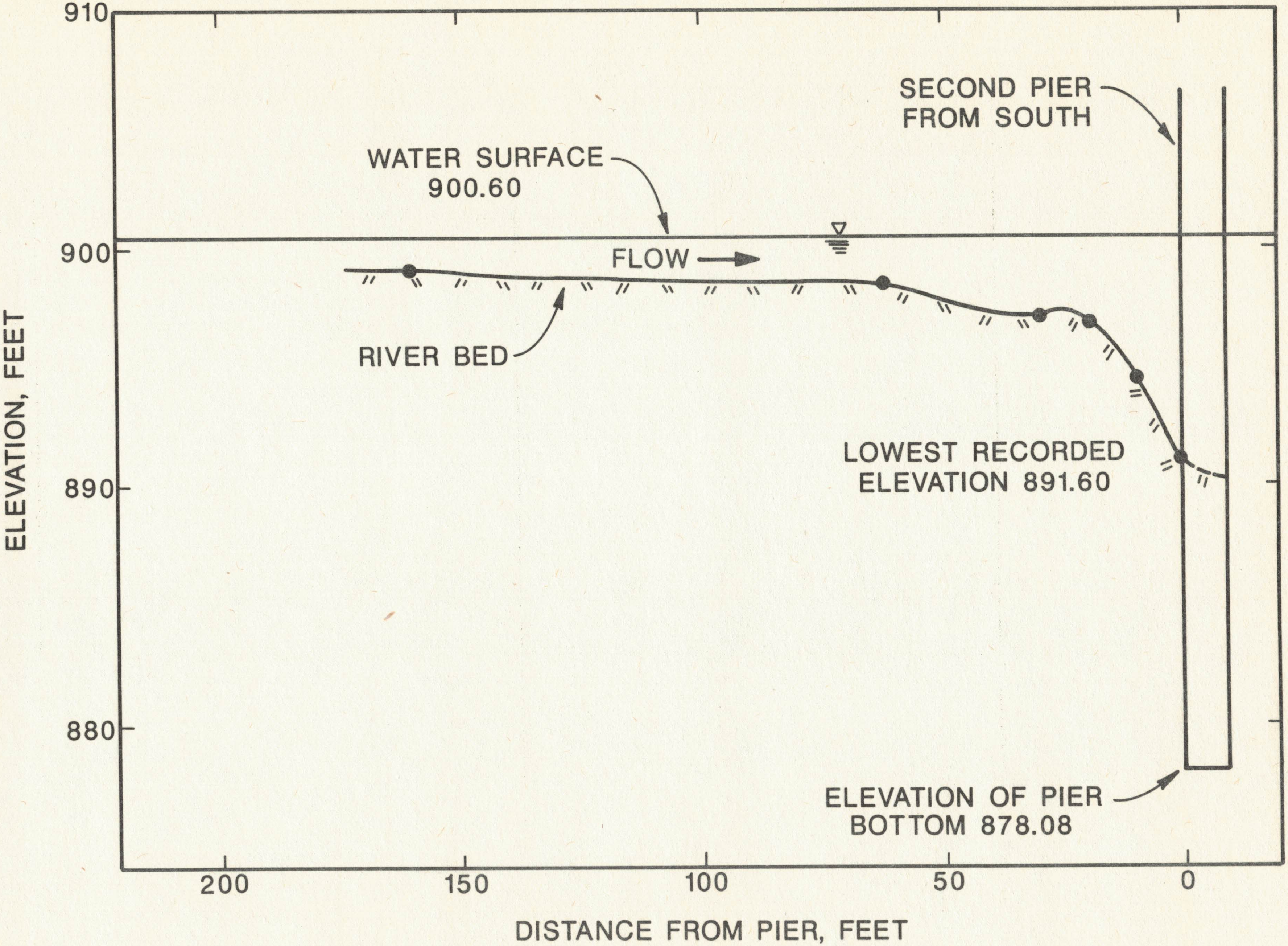

FIGURE 6. CHANNEL PROFILE NORTH OF GUTHRIE, HWY 77, CIMARRON RIVER.

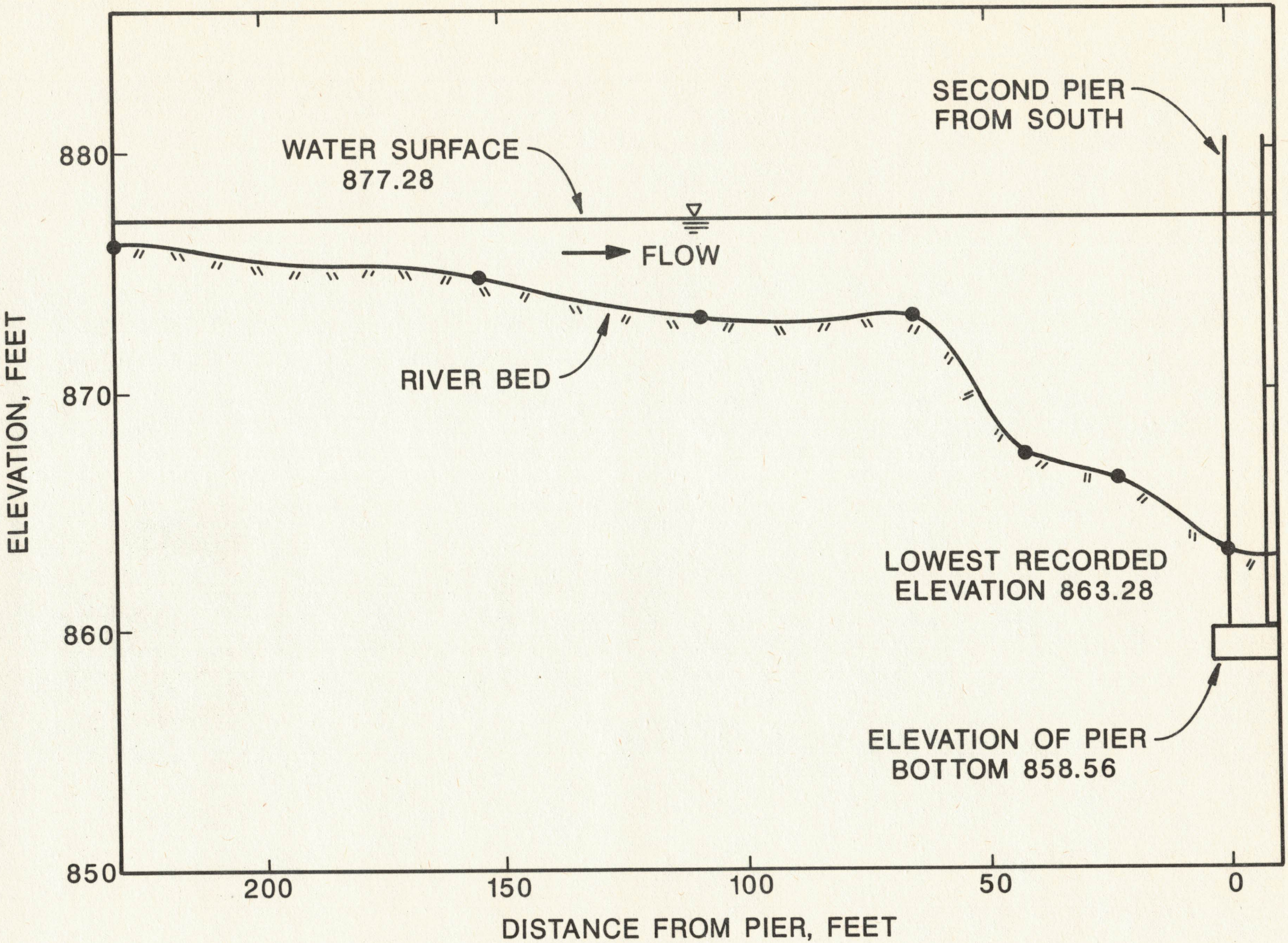

FIGURE 7. CHANNEL PROFILE AT I-35, CIMARRON RIVER.

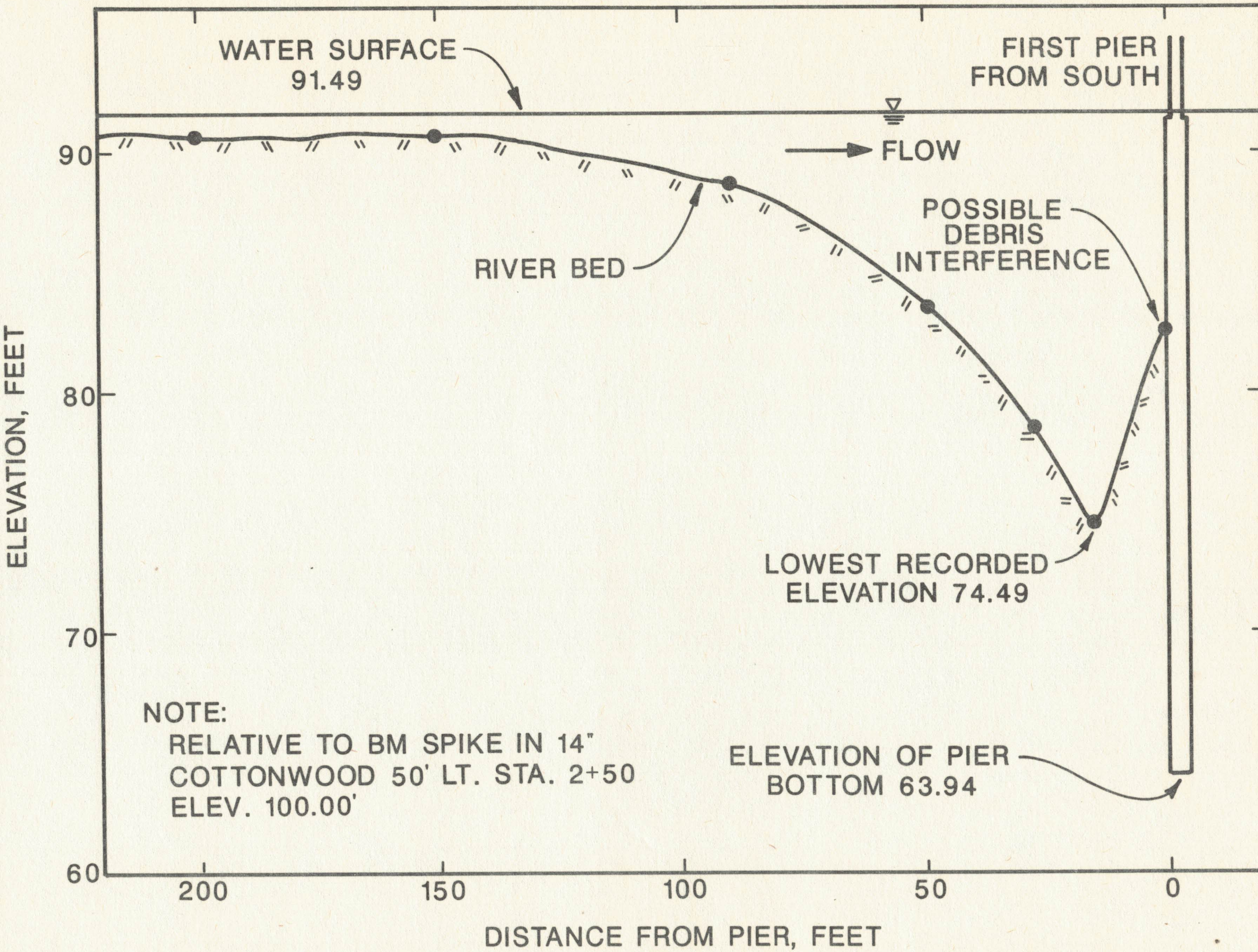

FIGURE 8. CHANNEL PROFILE AT COYLE, HWY 33, CIMARRON RIVER.

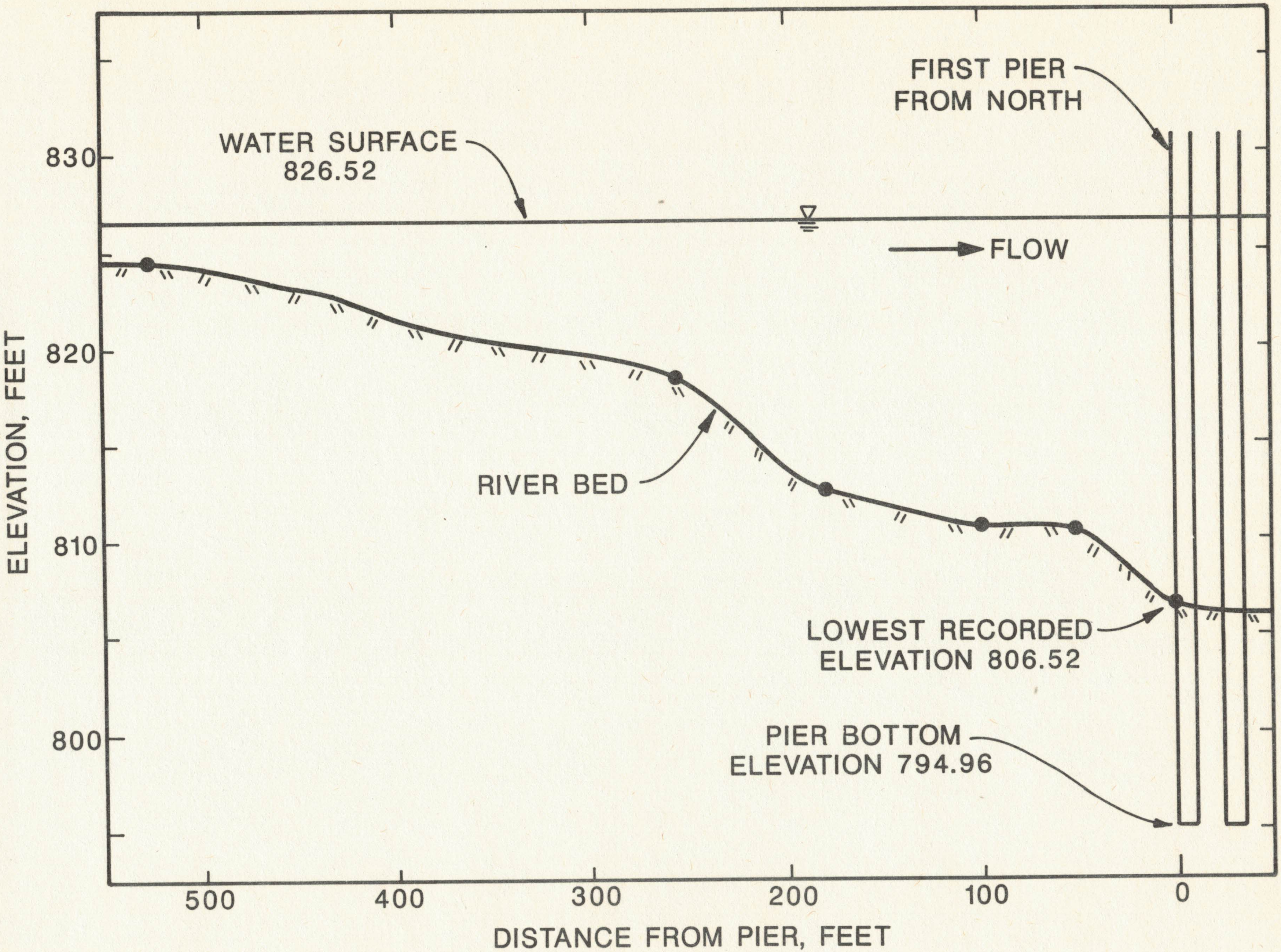

FIGURE 9. CHANNEL PROFILE AT PERKINS, HWY 177, CIMARRON RIVER.

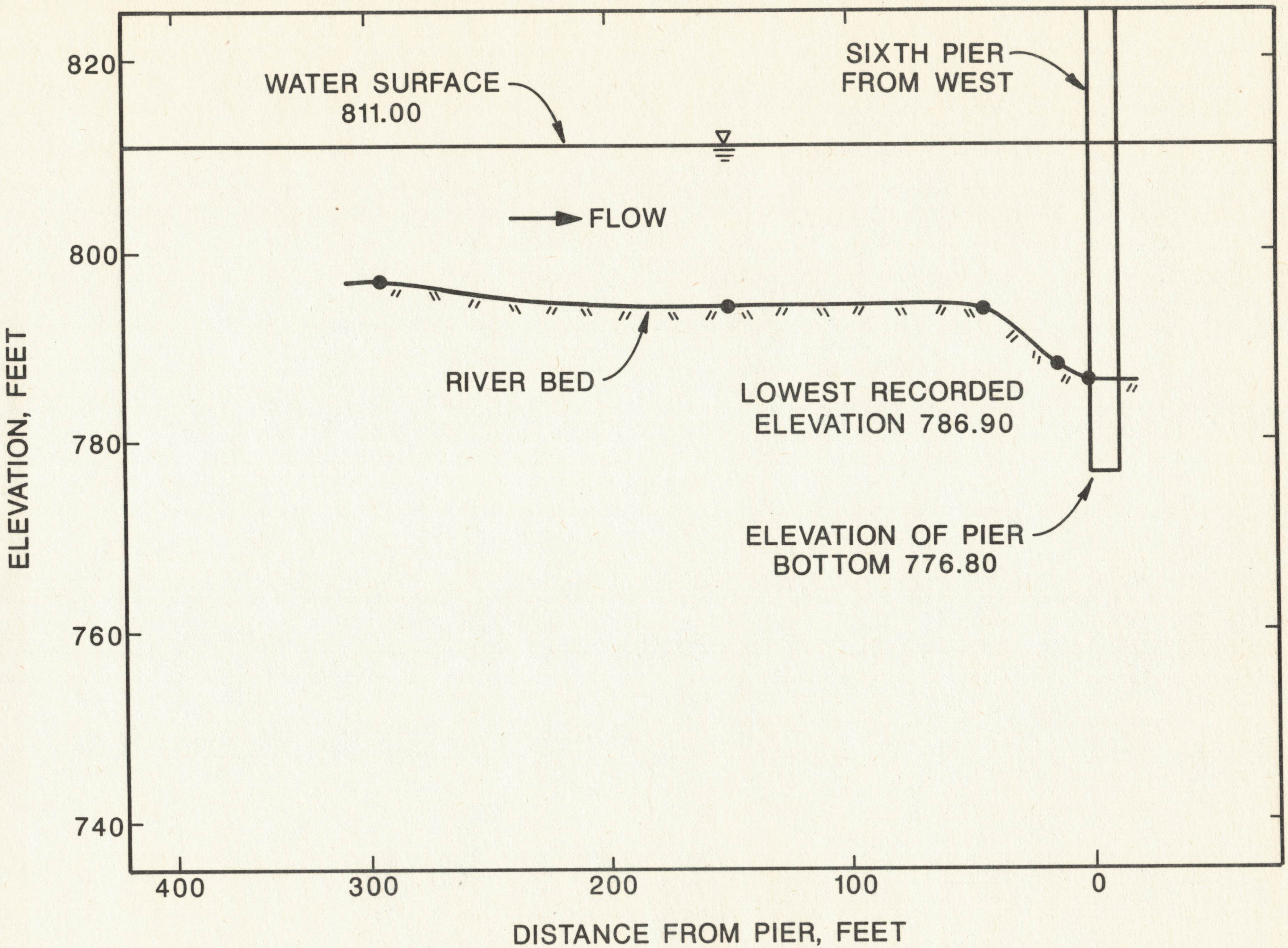

FIGURE 10. CHANNEL PROFILE BETWEEN PERKINS AND CUSHING, HWY 33, CIMARRON RIVER.

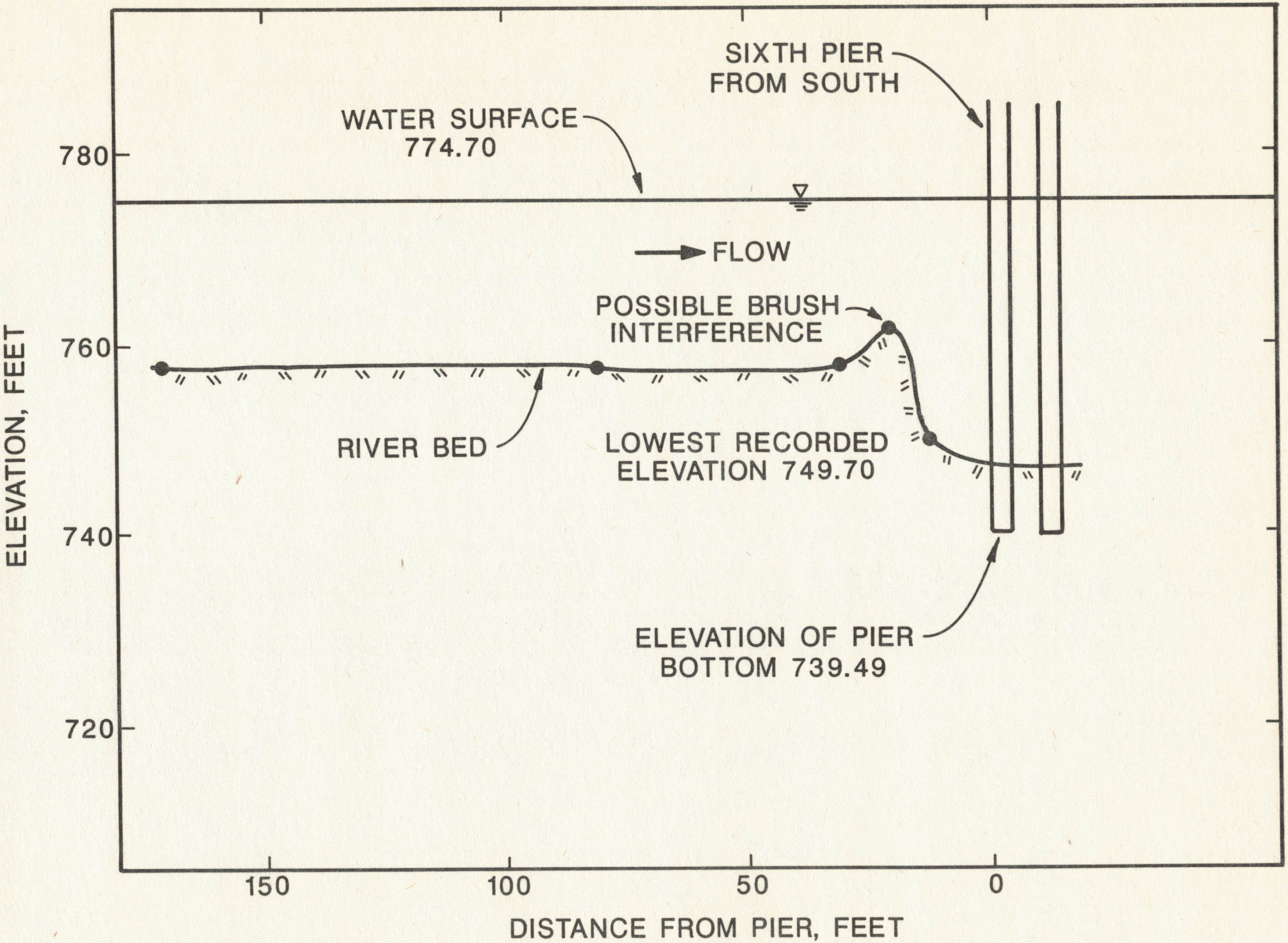

FIGURE 11. CHANNEL PROFILE, NORTH OF CUSHING, HWY 18, CIMARRON RIVER.

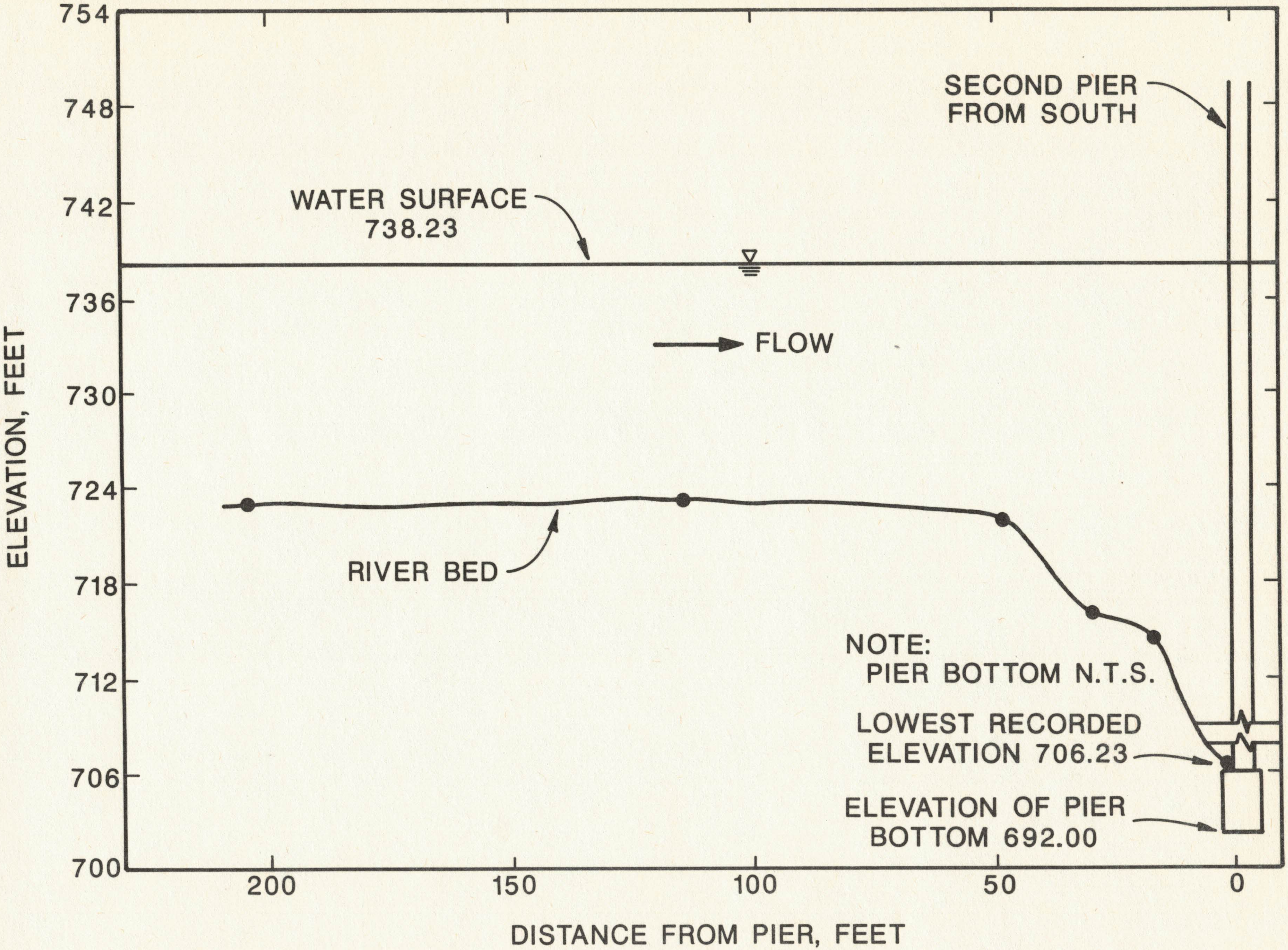

FIGURE 12. CHANNEL PROFILE AT OILTON, HWY 99, CIMARRON RIVER.

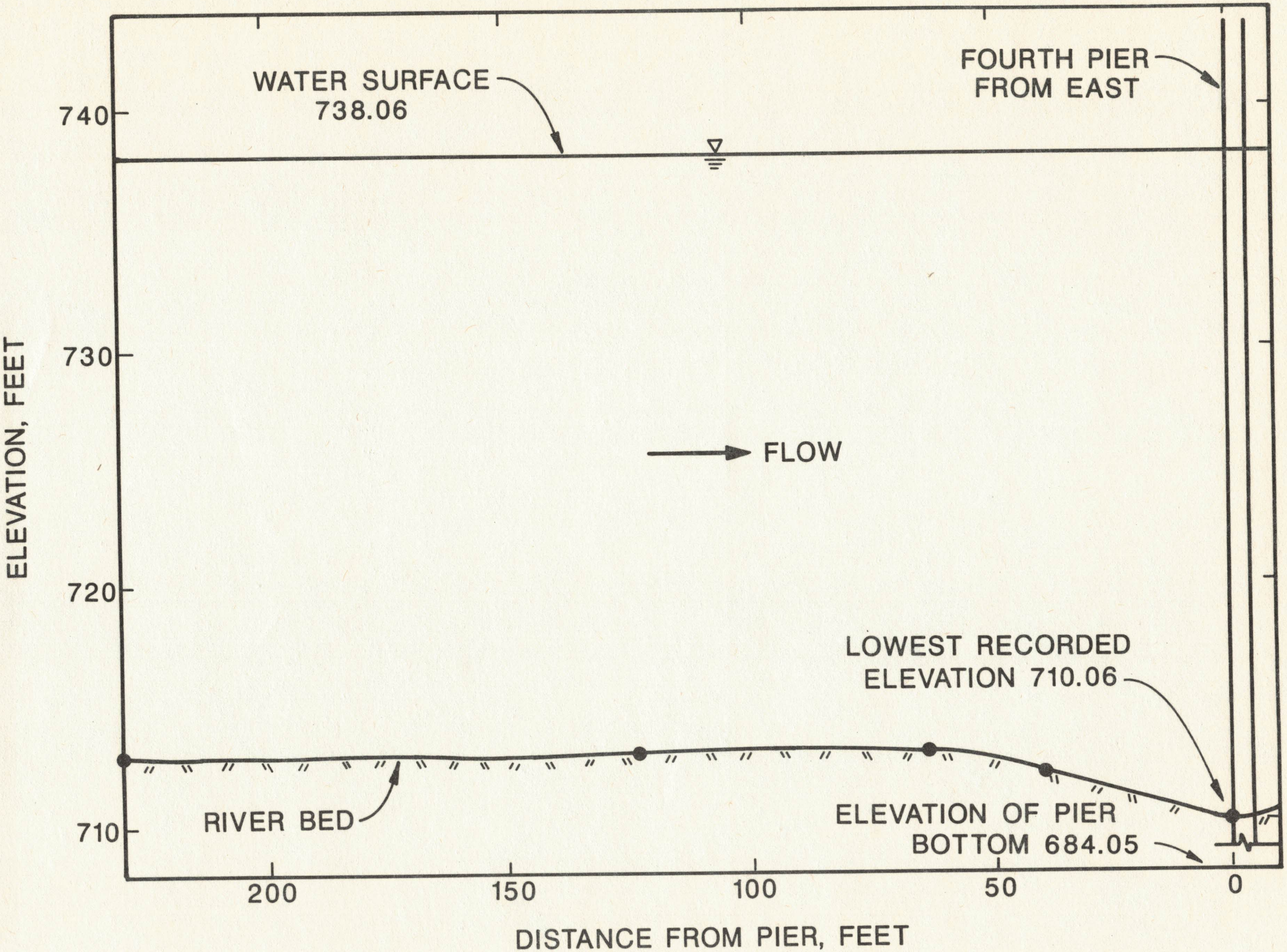

FIGURE 13. CHANNEL PROFILE AT OILTON, HWY 51, CIMARRON RIVER.

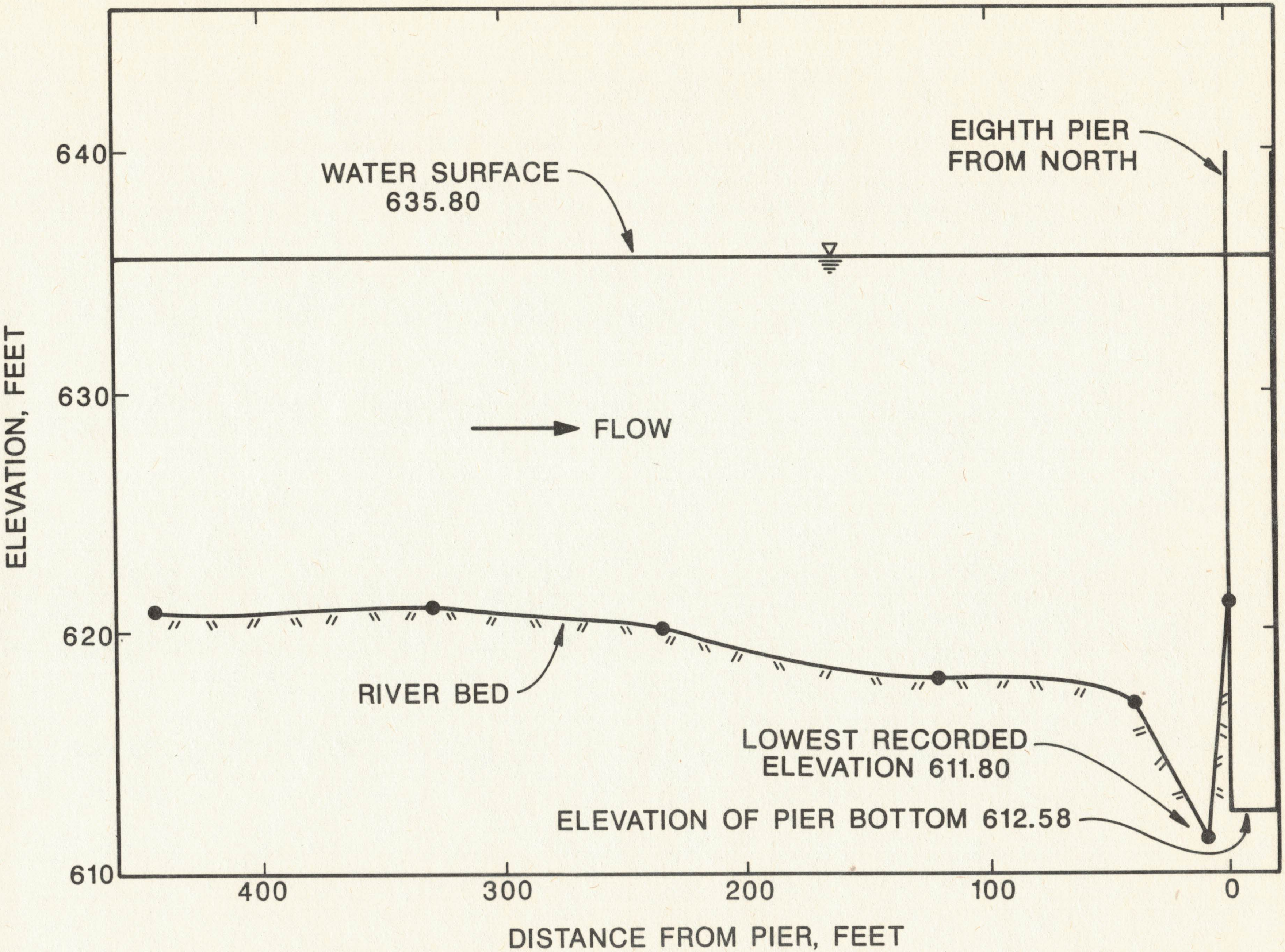

FIGURE 14. CHANNEL PROFILE AT SAND SPRINGS, HWY 97, ARKANSAS RIVER.

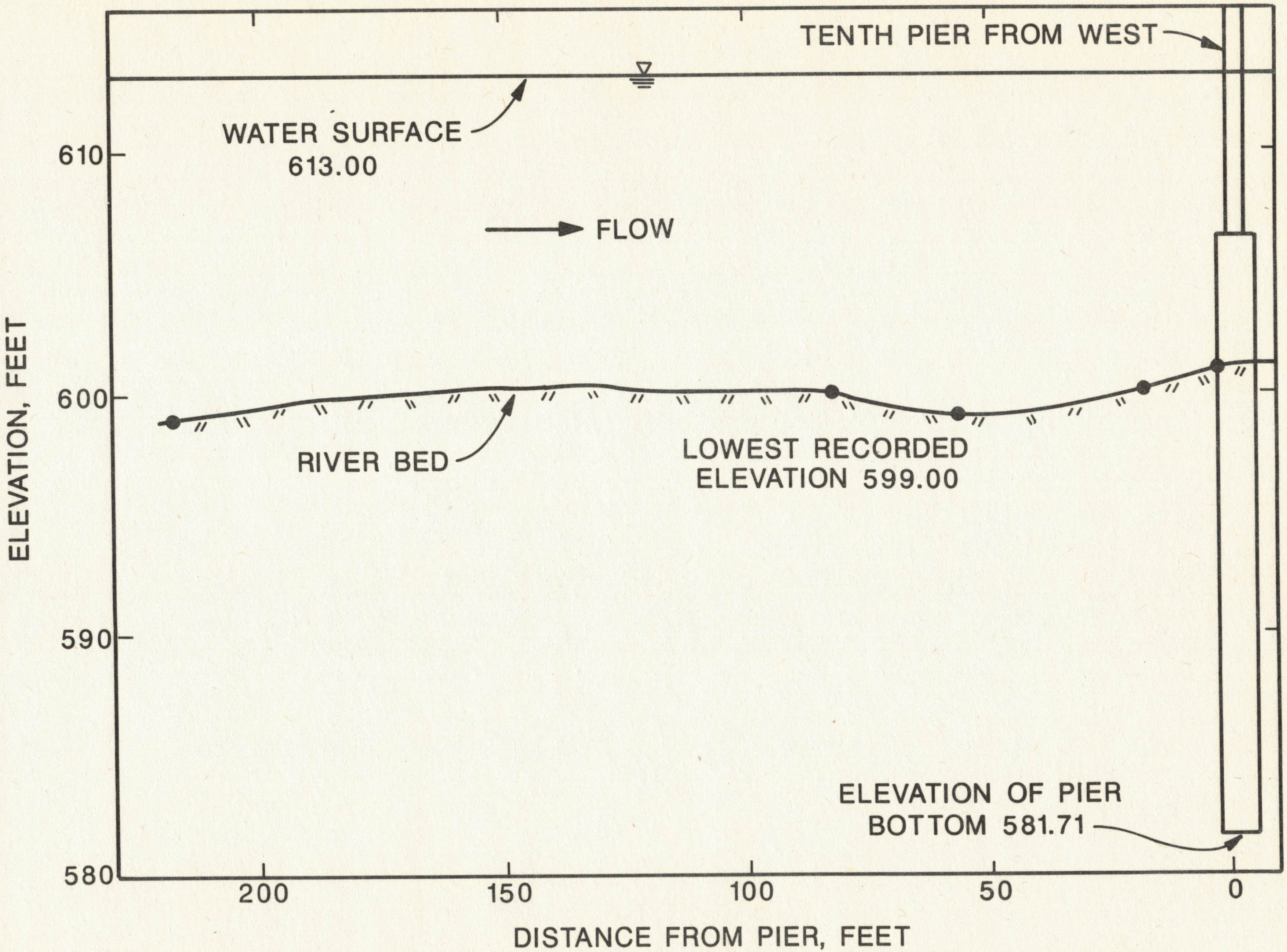

FIGURE 15. CHANNEL PROFILE AT TULSA, HWY 33, ARKANSAS RIVER

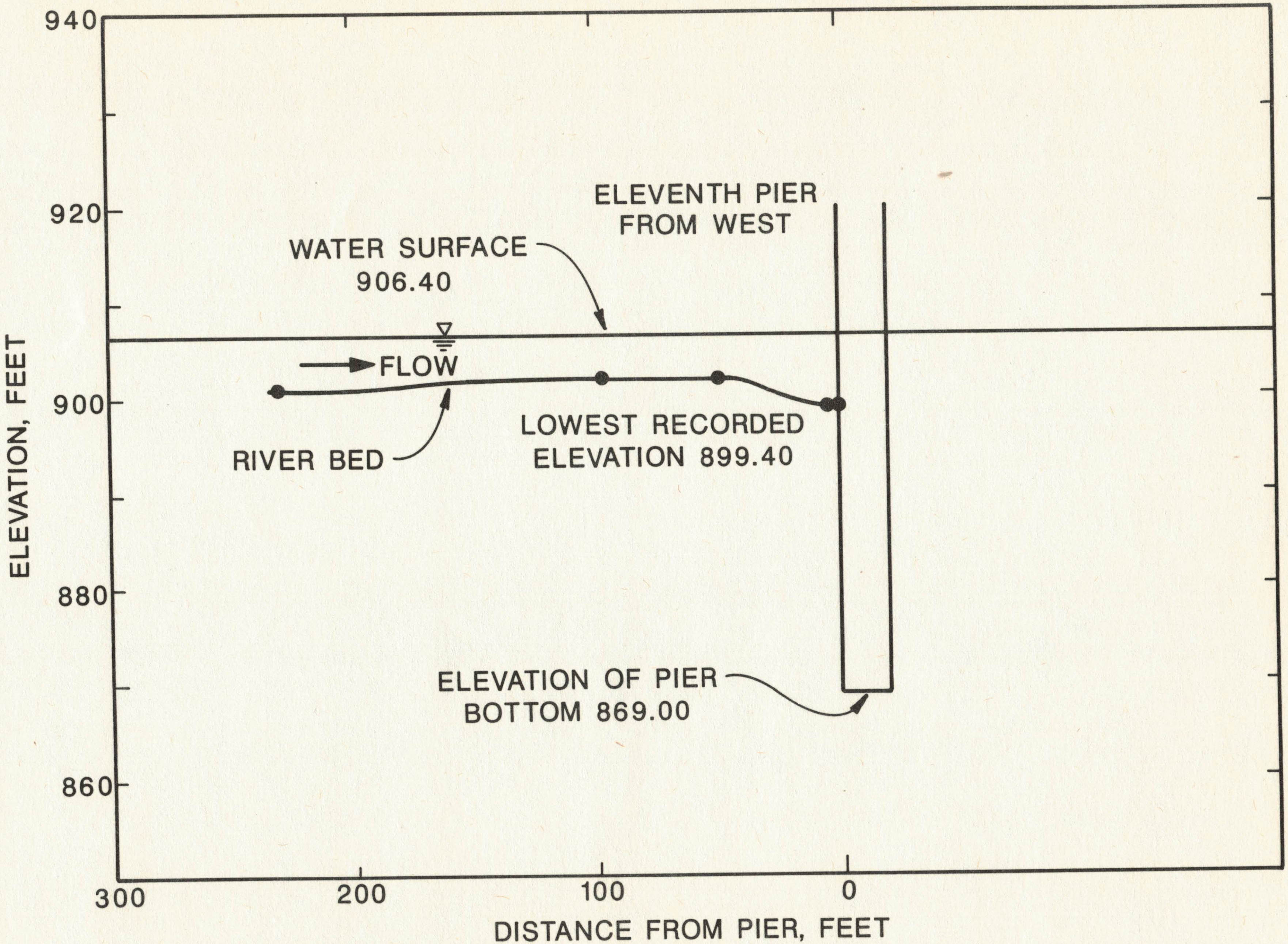

FIGURE 16. CHANNEL PROFILE AT PONCA CITY, HWY 60, ARKANSAS RIVER.

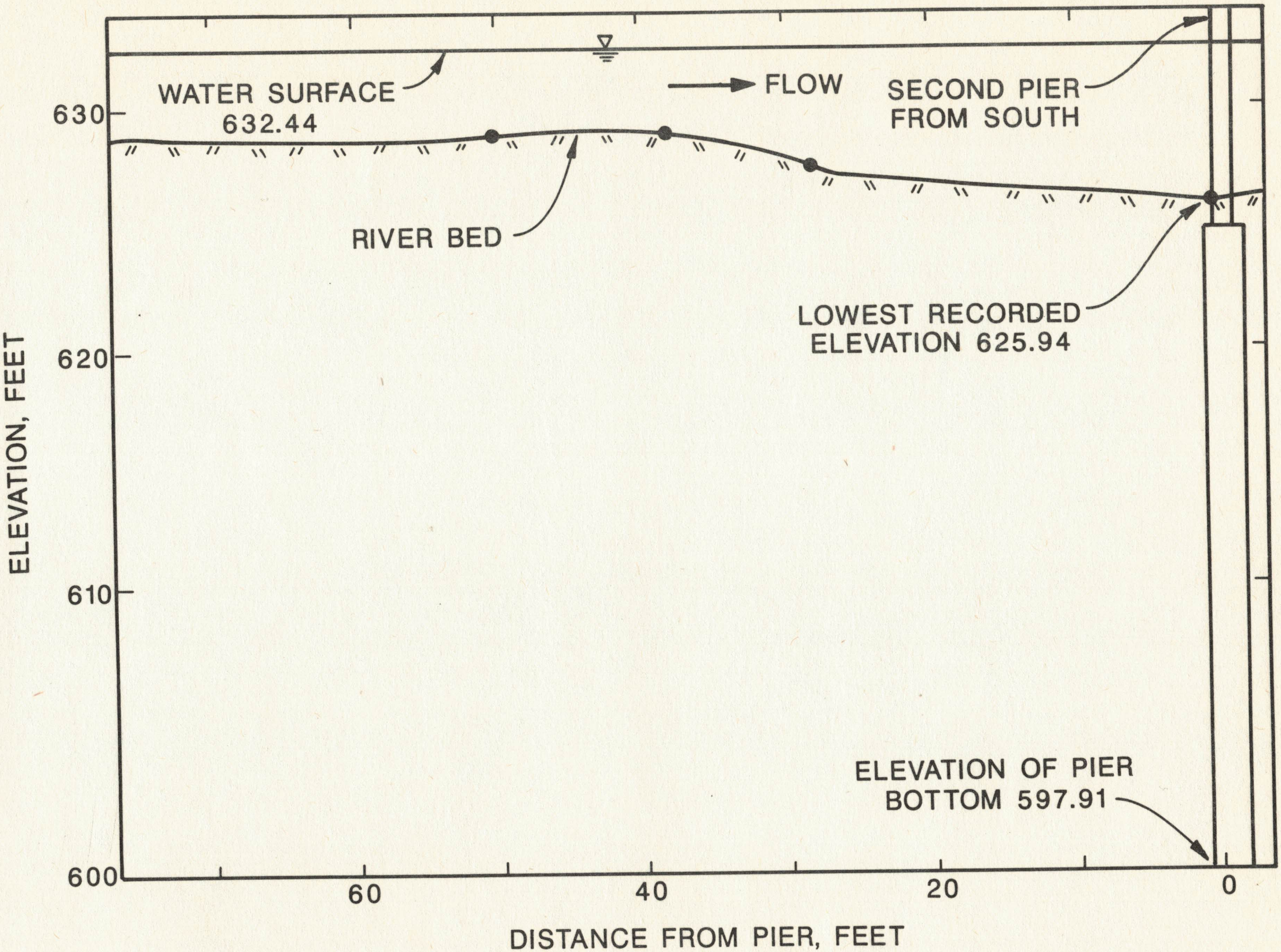

FIGURE 17. CHANNEL PROFILE AT BARTLESVILLE, HWY 75, CANEY RIVER.

IV. RESULTS

Scour profiles and maximum scour depths were measured at thirteen bridges on the Cimarron River, three on the Arkansas River, and two on the Caney River. Table I presents the bridge location, highway name, depth of flow, and maximum scour depth at various piers. The depth of flow varied from 0.75 to 25 feet and the maximum scour depth varied from 0.60 to 18 feet. Figures 1 through 17 show details of scour profiles and degradation of the river bed.

A visual survey of sediments in river beds indicated that the Cimarron River has three reaches of different sediment composition. In the upper reach down to Ringwood bridge, the Cimarron is composed of boulders in the river bed. From there to the Ripley bridge, the Cimarron has a wide floodplain and coarse sand in its bed. In the final reach before joining the Arkansas River, the Cimarron becomes a well-defined river. The river bed is primarily of fine sand.

In the Arkansas River, the river sediment is composed mostly of fine sand to silt, whereas the Caney River bed is composed of clay sediment. This is an important finding that signals the need for further investigation to determine how river sediment influences maximum scour depth.

In rivers that have wide flood plains, overflow structures are built. In Oklahoma, piles are driven to support these structures. In October 1986, maximum damage to overflow structures occurred. Aerial photographs show the elongated shape of the scour holes. This phenomenon may be due to different sediments of flood plains which are generally clayey in nature.

TABLE I

Maximum Scour Depths at Bridge Sites

Bridge Sites	Highway	River	Depth of flow, feet	Scour Depth feet
Cleo Springs	60	Cimarron	2.0	0.6
Ringwood	58	Cimarron	0.75	0.75
Lacey	51	Cimarron	1.7	8.9
Dover*	81	Cimarron	1.5	1.5 (4.5)**
Cimarron City	74	Cimarron	2.0	3.0
Guthrie	77	Cimarron	1.0	8.0
I-35	35	Cimarron	1.0	13.0
Coyle	33	Cimarron	1.0	16.0
Perkins	177	Cimarron	2.0	18.0
Ripley	33	Cimarron	14.0	11.0
Cushing	18	Cimarron	17.0	8.0
Oilton	99	Cimarron	15.0	17.0
Oilton	51	Cimarron	25.0	3.0
Sand Springs	97	Arkansas	15.0	9.0
Tulsa	33	Arkansas	14.0	2.0
Ponca City	60	Arkansas	4.0	3.0
Bartlesville	75	Caney	3.7	2.8
Collinsville	169	Caney	***	2.8

* Piers filled with stones

** Maximum scour at another pier

*** Piers out of water

V. RECOMMENDATIONS

1. Perform hydrographic surveys to determine the maximum scour depth at piers four times a year for a period of four years. Bridge sites on Oklahoma rivers should be selected. Develop an equation based on field data for predicting scour depth and compare with available laboratory data from literature.
2. From the files of ODOT and USGS, collect historical data of scour depth, depth of flow, and discharge on selected bridge sites. Also, obtain stratigraphic data from ODOT files on layers of sand, silt, and shale in the river bed.
3. Collect soil samples from different sites to classify river-bed sediments and correlate with scour depths.
4. Use EDM and sonar to obtain scour profile, maximum scour depth and degradation of river bed near selected piers.
5. Explore automation of recorders that can digitize collected field data in computer-readable format. Develop software to plot this data on the IBM-AT computer.
6. Select a package, such as, LOTUS 1-2-3, DBASEIII, SAS and others, for analyzing, reducing and plotting the field data collected in Oklahoma streams.
7. Perform laboratory experiments using sediments existing in the field at selected bridge sites, and measure the maximum scour around cylindrical piles in flood plains overflow structures and streamlined piers in main stream bridge sections. Laboratory scour experiments use both cohensionless (sandy and silty) and cohesive (clayey) soils.