TECHNICAL REPORT H-73-12

HOUSTON SHIP CHANNEL GALVESTON BAY, TEXAS

Report 1

HYDRAULIC AND SALINITY VERIFICATION

Hydraulic Model Investigation

by

W. H. Bobb, R. A. Boland, Jr., A. J. Banchetti

August 1973

Sponsored by U. S. Army Engineer District, Galveston

Conducted by U. S. Army Engineer Waterways Experiment Station
Hydraulics Laboratory
Vicksburg, Mississippi

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ARMY-MRC VICKSBURG, MISS.

FOREWORD

The model investigation of the Houston Ship Channel was approved by the Office, Chief of Engineers, on 13 November 1961 and was authorized by the U. S. Army Engineer District, Galveston, on 30 November 1961. Design and construction of the model were accomplished during the period June 1962-December 1963. Hydraulic and salinity adjustment of the model was carried out during the period January 1964-November 1965.

The model design, construction, and verification were carried out in the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES) under the general supervision of Messrs. E. P. Fortson, Jr. (retired), Chief of the Hydraulics Laboratory, and G. B. Fenwick (retired), Assistant Chief of the Hydraulics Laboratory; and under the direct supervision of H. B. Simmons present Chief of the Hydraulics Laboratory and former Chief of the Estuaries Division, and W. H. Bobb, Chief of the Interior Channel Branch. Messrs. G. M. Fisackerly and R. A. Boland, Jr., were Project Engineers on the model study and were assisted by Messrs. A. J. Banchetti and O. H. Rhodes. This report was prepared by Messrs. Bobb, Boland, and Banchetti. Subsequent reports will describe the various specific studies conducted in the model.

Directors of WES during the design, construction, and verification phases of the study and the preparation and publication of this report were COL E. H. Lang, CE; COL A. G. Sutton, Jr., CE; COL J. R. Oswalt, Jr., CE; COL L. A. Brown, CE; BG E. D. Peixotto, CE; and COL G. H. Hilt, CE. Technical Directors were Messrs. J. B. Tiffany and F. R. Brown.

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CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
miles (U. S. statute)	1.609344	kilometers
square feet	0.092903	square meters
square miles	2.58999	square meters
feet per second	0.3048	meters per second
cubic feet per second	0.02831685	cubic meters per second

SUMMARY

The Houston Ship Channel model, a fixed-bed model constructed to linear scale ratios of 1:600 horizontally and 1:60 vertically, reproduced a portion of the Gulf of Mexico adjacent to the Galveston Harbor Entrance, the Galveston Bay complex, including Trinity Bay in its entirety, East Bay, a portion of West Bay, the Houston Ship Channel to its upstream boundary in the City of Houston, Texas, and Buffalo Bayou from the Houston Ship Channel turning basin to the confluence of White Oak Bayou. The model was equipped with necessary appurtenances for the accurate reproduction and measurement of tides, tidal currents, salinity intrusion, freshwater inflow, density effects, shoaling, and other important prototype phenomena. The purpose of the model study was to determine if the present cost of maintenance dredging can be reduced by proposed plans involving channel realignments, partial or complete diking of connecting bays, sediment traps, dikes in Galveston Bay, local contractions, enlargements, and other remedial measures.

Model verification tests were conducted to make certain that the model hydraulic and salinity regimens were in satisfactory agreement with those of the prototype. The agreements attained between similar model and prototype values were considered satisfactory.

HOUSTON SHIP CHANNEL, GALVESTON BAY, TEXAS

HYDRAULIC AND SALINITY VERIFICATION

Hydraulic Model Investigation

PART I: INTRODUCTION

1. Verification of hydraulic and salinity phenomena in an estuary model is a necessary phase in preparing the model for its ultimate use in evaluating the effects of proposed improvement works. Because of its large size, the wealth of prototype data available for verification purposes, and the high degree of accuracy desired, verification of hydraulic and salinity phenomena in the Houston Ship Channel model required a very elaborate series of tests. No effort was spared in carrying out the verification phase in the most comprehensive manner possible.

2. This report contains all data relative to hydraulic and salinity verification of the model and will be referred to frequently in subsequent reports concerned with other phases of the overall model investigation.

PART II: THE PROTOTYPE

Description

3. The Galveston Bay complex, located in the southeastern part of Texas on the Gulf of Mexico (vicinity map, plate 1), is approximately 60 miles* west of Port Arthur, Texas, and 50 miles south of Houston, Texas. With the exception of the area between Galveston Island and Bolivar Peninsula, known as Bolivar Roads, the bay is relatively shallow and varies generally from 7 to 9 ft** in depth, except for the deepened ship channels that are maintained by dredging. Bolivar Roads is connected to the various ports in or near Galveston Bay by Galveston, Houston Ship, and Texas City Channels and is connected to the Gulf of Mexico by the Galveston Harbor or jetty channel. The Houston Ship Channel is a dredged, deep-draft channel 400 ft wide and 40 ft deep extending north-northwestward from Bolivar Roads across Galveston Bay to Morgan Point, thence in the San Jacinto River to the mouth of Buffalo Bayou, through Buffalo Bayou, and terminating at the Houston Ship Channel turning basin.

Hydraulic Characteristics

4. Normal gulf tides at Pleasure Pier at Galveston are of the diurnal type with a maximum range of about 2.1 ft. Resulting tide ranges throughout Galveston Bay are generally less than 1.5 ft, and maximum tidal currents, excluding currents in the navigation channels, are on the order of 1.0 fps. The total mean freshwater inflow into the bay complex is 11,323 cfs, of which 7,900 cfs enters from Trinity River. A major portion of the remainder enters the ship channel upstream of Morgan Point from the San Jacinto River, Buffalo Bayou, and several minor tributaries.

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* A table of factors for converting British units of measurement to metric units is presented on page vii.

** All depths and elevations (el) in this report are referred to mean sea level datum at Galveston.

Salinity Characteristics

5. Seasonal maximum salinities in the bay and tributaries generally occur in the dry period from September to November and vary between about 29-32 ppt at the bottom in the entrance to about 8-15 ppt at the surface in the ship channel turning basin at Houston. Seasonal minimum salinities occur in conjunction with heavy spring rains and vary between about 26-31 ppt and about 1-3 ppt at the same respective locations. Surface salinities in the shallow bay areas are generally about 2 ppt less than bottom salinities at the same locations. In the Houston Ship Channel, surface salinities can be as much as 14-16 ppt less than corresponding bottom salinities during periods of maximum freshwater inflow.

The Problems

6. The individual problems that will be studied in the model will be described in detail in subsequent reports of one or more complete phases of the overall investigation; however, the most important general problem requiring investigation is the present maintenance dredging requirement in the Houston Ship Channel. Of particular interest is the possibility of shifting the location of some present major shoal areas to other areas where adequate spoil disposal areas are available and where dredging can be performed at appreciably lower unit cost.

PART III: THE MODEL

Description

7. The model was of the fixed-bed type, molded in concrete to conform to 1962 prototype conditions, and was constructed to linear scale ratios, model to prototype, of 1:600 horizontally and 1:60 vertically. Other pertinent scale ratios, which were derived from the linear scale ratios, were: velocity 1:746, time 1:77.46, discharge 1:278,855, volume 1:21,600,000, and slope 10:1. The salinity scale ratio for the study was 1:1. One prototype diurnal tidal cycle of 24 hours and 50 minutes was reproduced in the model in 19.24 minutes. The pertinent portion of the Texas Coordinate System, South Central Zone, reproduced to scale over the model site, was used for the horizontal control system. The model was approximately 540 ft long, 250 ft wide at its widest point, and covered an area of about 57,200 sq ft, reproducing approximately 740 square miles of prototype area. The area reproduced in the model is shown in plate 1 and included that portion of the Texas coast from Rollover Pass on Bolivar Peninsula on the east to Interstate Highway 45 on the west; the portion of the Gulf of Mexico adjacent to the abovementioned coastal area and extending seaward about 11 miles; all interior bays (such as East Bay, Dickinson Bay, Trinity Bay, and a portion of West Bay); all connecting lakes and tributary streams; and the Houston Ship Channel in its entirety. The topographical features of the model were reproduced to scale to the +5 ft contour. All areas influenced by the proposed alignment of the ship channel were molded in concrete with removable blocks so that desired modifications could be readily made.

8. During construction of the model, 3/4-in.-wide metal strips were placed in Galveston Harbor between the jetties, in the Gulf of Mexico near the entrance to the jetties, and in Texas City and Houston Ship Channels in their entirety to act as roughness in those areas of the model. This was required to make possible the proper adjustment of velocity magnitude and distribution, both horizontally and vertically,

which could not be obtained through the use of boundary roughness alone. A general view of the model looking from the gulf area toward Morgan Point is shown in fig. 1.

Appurtenances

9. The model was equipped with the necessary apparatus to satisfactorily reproduce and measure all pertinent phenomena of the prototype. The appurtenances included a tide generator, inflow and outflow measuring devices, gulf saltwater supply system, tide gages, current meters, and salinity and dye sampling and measuring equipment. The rise and fall of the tide in the model, and the resulting flood and ebb currents, were reproduced by maintaining at all times a precise imbalance between a pumped flow of water to the model and a gravity outflow from the model, as required to reproduce the gulf tide with respect to both time and elevation. An electrically controlled automatic valve installed in the gravity outflow line from the model to the saltwater storage sump was adjusted by cut-and-try until prototype tidal heights and times at the control station (T-A, Pleasure Pier) were reproduced to scale. The tide control mechanism was equipped with a continuous tide recorder so that the accuracy of model reproduction of any prototype tide could be visually checked at all times. The desired salinity of the gulf supply was maintained by the addition of salt to the storage sump as required to compensate for the diluting effect of freshwater inflows introduced into the tributaries.

10. All rivers and streams with significant mean freshwater inflows were equipped with a constant-head tank and a flowmeter for precise measurement of the respective flows, and the locations of all such freshwater inflow points are shown in plate 1.

11. Permanent point gages, graduated to 0.001 ft (0.06 ft prototype), were installed in the model at locations corresponding to prototype recording tide gage locations and were used to obtain measurements of tidal heights throughout the model. These gages could be read accurately to within ± 0.0005 ft (0.03 ft prototype).

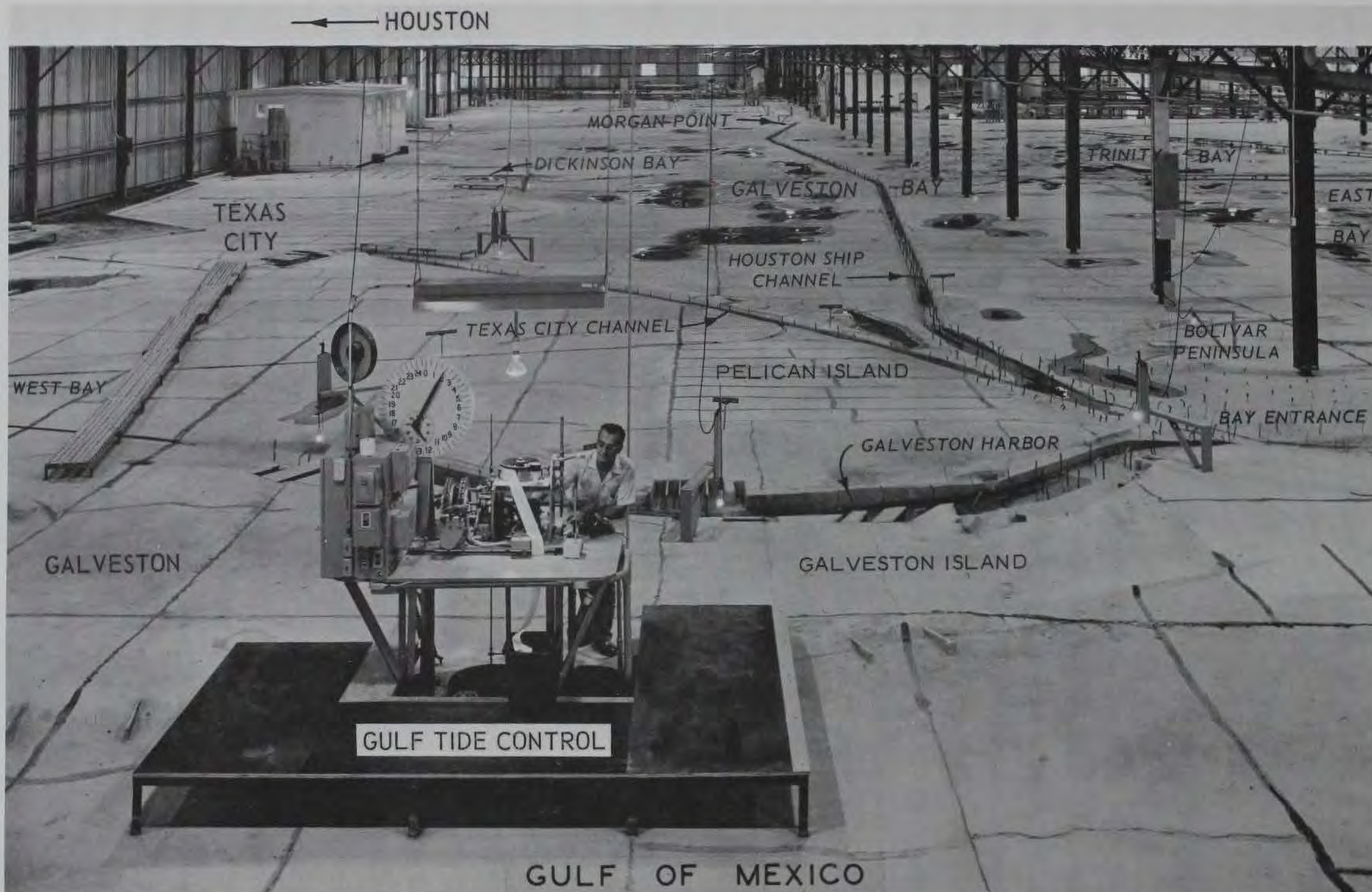


Fig. 1. View of model, looking northward from Gulf of Mexico

12. Current velocity measurements were obtained with miniature Price-type meters, one of which is shown in fig. 2. The five meter cups,

Fig. 2. Model current meter

constructed of a light plastic material, were approximately 0.04 ft in diameter and were mounted on a horizontal wheel about 0.09 ft in diameter; the center of the cups was 0.05 ft from the bottom of the frame. The meters were calibrated frequently to ensure accurate operation and were capable of measuring actual velocities as low as about 0.03 fps (about 0.2 fps prototype).

13. Water samples for determination of salinity concentrations were withdrawn from the model manually with 10-cc pipettes and collected in 5-cc vials. Salinities were determined by conductivity cells especially built and calibrated for this purpose. One cell was used for salinities below 1.5 ppt, a second cell covered the intermediate range of about 1.5 to 20.0 ppt, while the third cell was used for values greater than 20.0 ppt. A salinity meter assembly is shown in fig. 3.

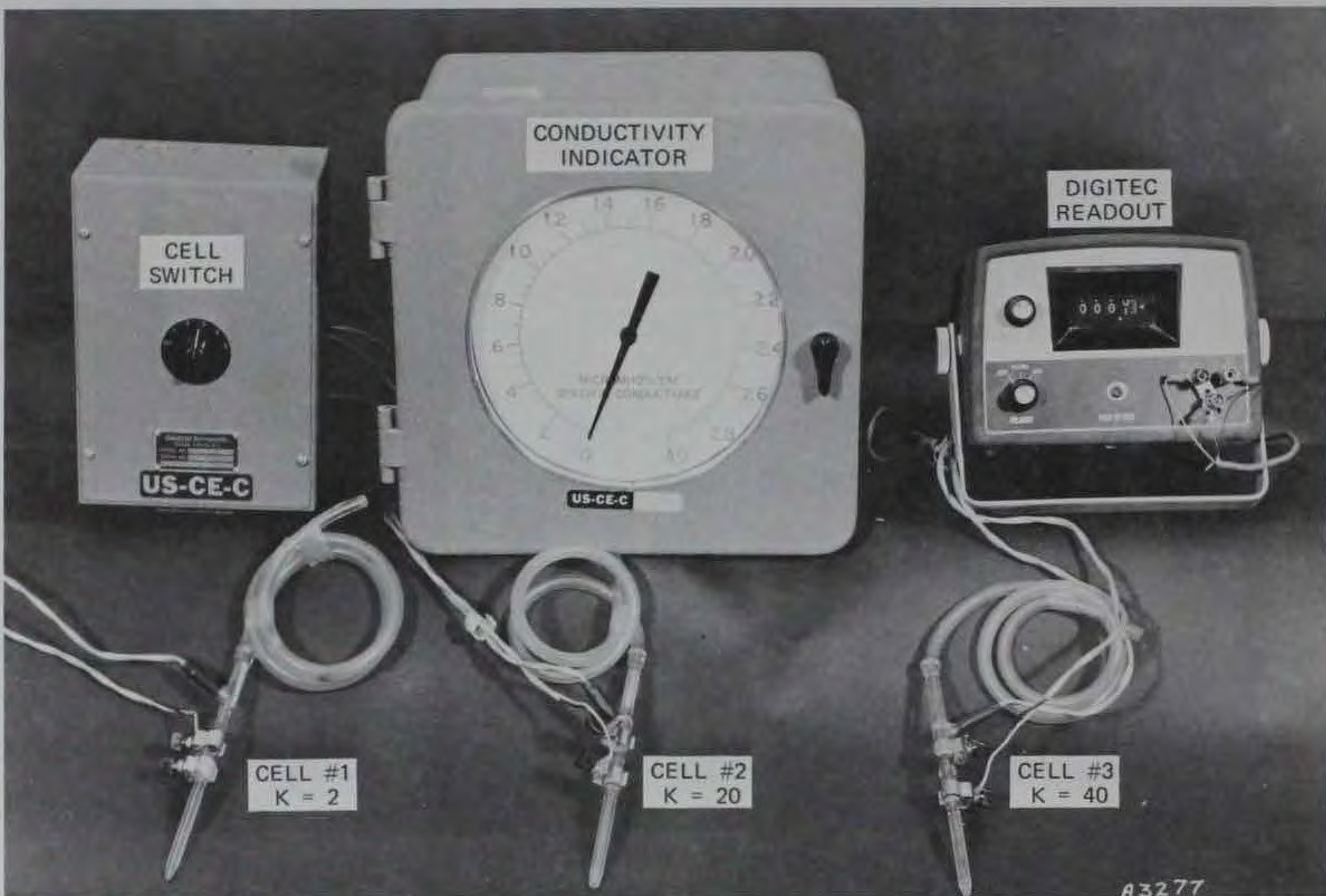


Fig. 3. Salinity meter

PART IV: VERIFICATION OF THE MODEL

14. Verification of the model was accomplished in three phases. Phase 1 involved normal tide verification, which ensured that tidal elevations and phases for normal astronomical tides throughout the model were in proper agreement with corresponding tides in the prototype; phase 2 was the current velocity verification, which ensured that current velocities and directions in the model corresponded to those in the prototype for similar conditions of tide; and phase 3 was the salinity verification, which ensured that salinities in the model corresponded to those in the prototype for similar conditions of tide and freshwater inflow.

Tidal Verification

15. The first step in preparing the model for testing consisted of verifying the accuracy with which an observed normal tide could be reproduced. This was accomplished by adjusting the tide generator to reproduce the observed prototype tide of 26 June 1963 in the model gulf at sta T-A (Pleasure Pier), then observing the accuracy with which this tide was reproduced at other tide gage locations throughout the bay system. Through a trial-and-error procedure, the roughness elements in the model were progressively adjusted until tidal elevations and phases were properly reproduced throughout the system. Prior to undertaking the actual model tests, a search through existing wind data obtained from the Weather Bureau Office, Post Office Building, Galveston, Texas, indicated that tide data obtained on 26 June 1963 would be less affected by wind than other tide data that were available for the Galveston Bay area. For this reason the prototype tide of 26 June 1963 was chosen for use in the first phase of the tidal verification.

16. Locations of the 20 tide stations used during verification are shown in plate 1. The accuracy with which the prototype tide of 26 June 1963 was reproduced in the model is shown in plates 2-6. These data show that maximum and minimum prototype elevations were generally

reproduced within about ±0.2 ft (prototype). At several of the gages there was a slight vertical divergence between model and prototype tidal planes. Repeated efforts involving various model roughness arrangements failed to improve the agreement at several locations; and it was concluded that undefined prototype forces such as upland flow variations, abnormal tidal differences, wind effects, etc., were reflected in the prototype data and that further efforts to improve the agreement at such locations were not justifiable. It is believed that the model tides accurately represent tides which would have occurred in the prototype in the absence of random forces not reproduced in the model, and the comparisons of model and prototype data as shown in these plates indicate that satisfactory agreement was achieved with respect to water-surface elevations and tidal occurrences throughout the model.

17. A second tidal adjustment was required, since the available prototype current velocity and salinity data were not obtained on 26 June 1963, the period used in the initial tidal adjustment. The prototype tide of 26-28 February 1964 was used for the model verification of currents and salinities, and the accuracy with which that tide was reproduced in the model is shown in plates 7-12. Comparisons of model and prototype data as shown in these plates indicate that satisfactory agreement was achieved with respect to water-surface elevations and phases throughout the model.

Current Velocity Verification

18. The objective of the model current adjustment was to obtain an accurate reproduction of the vertical and lateral distributions of prototype currents in the jettied entrance and in the entire Houston Ship Channel. Prototype current velocity data obtained simultaneously with tidal data on 26-28 February 1964 were used as a basis for verifying the accuracy with which the model reproduced prototype current velocities in the Houston Ship Channel. Prototype current velocity data were available for each of the 10 channel stations shown in plate 1 and for the 8 stations in the jettied entrance shown in fig. 4. Following

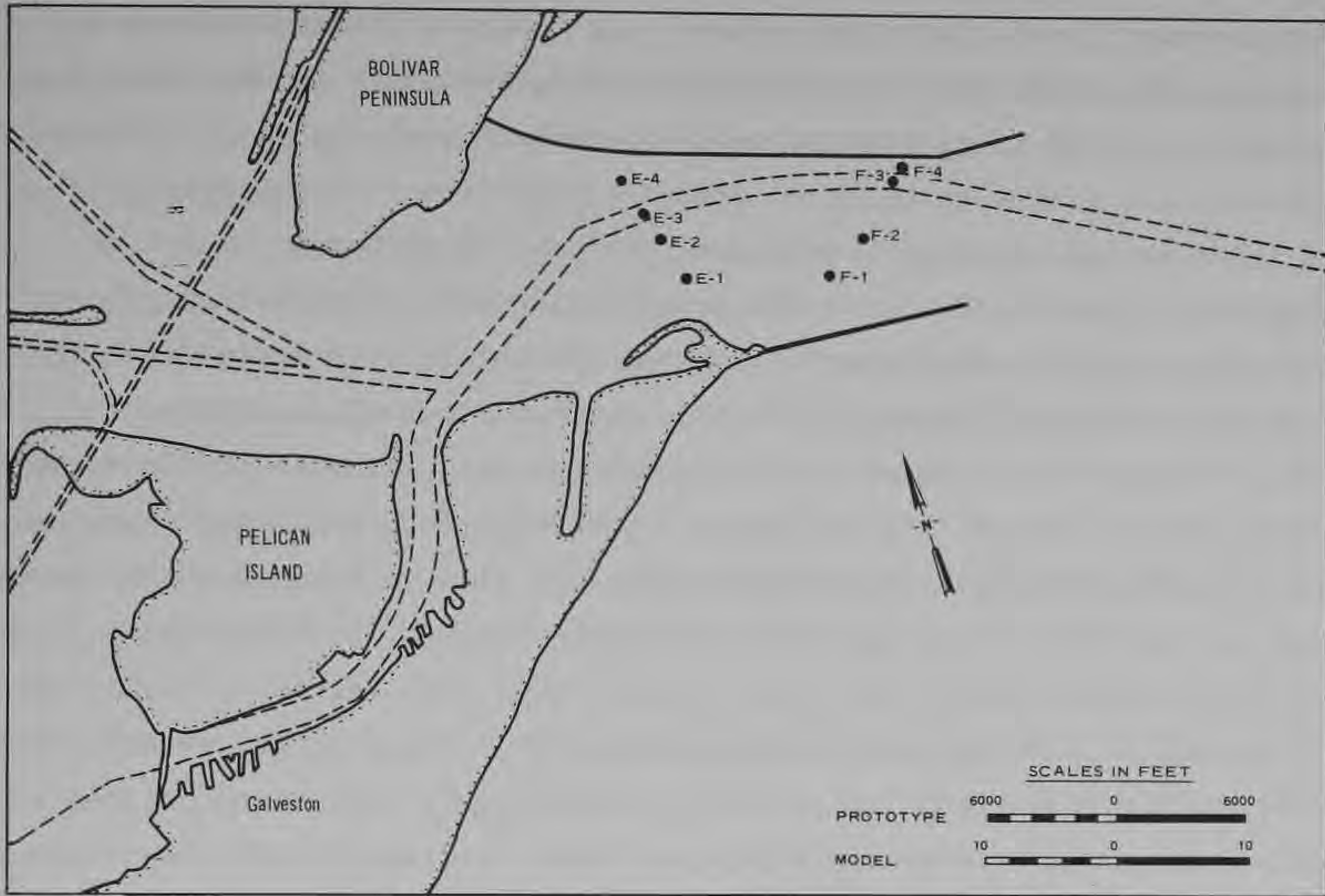


Fig. 4. Location of prototype velocity stations

adjustment of the model to correctly reproduce the desired gulf tide, additional adjustments were made to the model roughness until the distributions and magnitudes of the currents, as measured at each of the prototype stations, were correctly reproduced. The accuracy with which the model reproduced prototype current velocities is shown in plates 13-30. These comparisons indicate that the magnitude and phasing of the velocities at each station were in good agreement with prototype velocity data.

Salinity Verification

19. The results of preliminary adjustment tests indicated that tidal currents throughout the model bay system did not produce vertical mixing of salt and fresh water to the same degree as occurs in the prototype. In general, the model bays tended to be more stratified than

was measured in the prototype; and it was apparent that additional turbulence other than that imparted by the tidal currents in the model was needed to secure an equivalent model-to-prototype mixing ratio. Since surface wave action is known to generate significant mixing energy in all shallow bay systems, it was concluded that such action should be simulated in the model. A method of generating the required turbulence and simulating the mixing action caused by surface wind waves was devised by carefully placing 132 16-in. oscillating fans throughout the entire bay system to impart to the model the wave and wind mixing energy equivalent to that of the prototype. The results of preliminary salinity adjustment tests also indicated that the tidal currents in that portion of the ship channel upstream from Morgan Point did not produce vertical mixing of salt and fresh water to the same degree as occurs in the prototype. The model channel upstream from Morgan Point tended to be more stratified than its prototype counterpart, and it was apparent that again additional energy other than that imparted by the tidal currents was needed to secure equivalent model-to-prototype mixing. Since ship action in this portion of the channel is known to be a significant mixing mechanism, it was concluded that such action should be simulated in the model. The method devised to simulate the mixing of salt and fresh water caused by ships traversing the channel consisted of introducing air bubbles along the center line of the ship channel. The air discharge rate, depth of release, and spacing of the air release points were adjusted by trial and error until the proper mixing of salt and fresh water in the ship channel was obtained.

20. The preliminary tests and the available prototype data indicated that verification of salinities in the Houston Ship Channel model could best be demonstrated by results of a three-phase approach. Surface and bottom measurements throughout the bay complex were used to verify the fact that in general the horizontal and vertical gradients in model and prototype were similar for conditions of a constant discharge. Detailed measurements in the ship channel were used to show that salinity changes throughout a tidal cycle measured in the prototype occurred in the model. Finally, surface and bottom measurements, available at many

locations throughout the system for random times throughout a water year, were used to demonstrate that long-term salinity changes due to variations in upland flow could be reproduced in the model.

Starting procedure

21. The procedure for starting model operation of a tidal model utilizing salt water is developed during the verification phase of the study and thereafter is followed exactly. The initial salinity conditions are artificial, and the model must be operated for a period of time to allow salinities to reach quasi-stable values with respect to time, depth, and location; that is, a condition must be achieved in which salinity concentration at any point does not vary from cycle to cycle, although it will vary during the tidal cycle. In order to accomplish this in the shortest time possible, the model was equipped with a removable watertight barrier across Galveston Bay from Smith Point on the east shore to just upstream of Dickinson Bay on the west shore. That portion of the model downstream from the temporary barrier was filled with gulf salt water (32.5 ppt) from the gulf supply sump, while that portion of the model upstream from the barrier was filled with salt water adjusted to a concentration of 16 ppt (the approximate mean-weighted salinity of the area when salinity stability is reached). Both bodies of water were adjusted to the elevation of high tide at the barrier location; then, simultaneously the barrier was removed, tide reproduction was started, and introduction of fresh water at the 14 inflow points was begun. Model operation was continued until stable salinity conditions were observed throughout the estuary. This initial operating time, or stability time, required about 12 tidal cycles or 4 hours. After establishing salinity stability, model testing could be initiated.

General salinity gradients

22. Comparisons of the vertical gradient and mixing at 24 salinity stations located throughout the model (plate 1) are shown by the bar graph in plate 31. The surface salinity values were divided by the corresponding bottom values at the time of local high-water slack to determine what percent of the bottom value is found at the surface. The comparisons indicate that a proper mixing environment was achieved

throughout the model. The gradual decrease in percentages with distance along the ship channel indicates that the horizontal gradient in the model agrees satisfactorily with the prototype. These tests were made for tidal conditions measured during the period 26-28 February 1964, sustained upland flows totaling 8368 cfs, and a constant source salinity of 32.5 ppt.

Tidal cycle variations

23. Salinity measurements throughout a complete tidal cycle were made in the model at locations, depths, and times of tidal events corresponding to prototype measurements. Prototype salinity measurements throughout a complete tidal cycle were obtained only in the ship channel and are presented along with similar model measurements in plates 32-37. Data presented in these plates indicate that the model variations in salinity with tidal phase were in good agreement with comparable prototype measurements.

Long-period changes

24. After completing the model starting procedure described above and using a mean tide with a gulf range of 2.1 ft, regulation of upland flows to conform to the October 1964-September 1965 hydrographs at the 14 freshwater inflow points was started. The source salinity was maintained at 32.5 ppt. At the time of local high-water slack, every third tidal cycle surface and bottom samples were obtained and the salinities were determined. Smooth curves were drawn through the values and are shown in plates 38-42 along with all available prototype data and an inverted hydrograph of the total upland flow.

25. For the first five months of the long-term salinity verification test, most of the model bay stations were in close agreement with the prototype counterpart. During February of the hydrograph, a number of the Trinity Bay stations indicated a much higher salinity than that of the prototype, which coincided with an appreciable increase in inflow in this area (see plates 38 and 39). During the remaining seven months of the hydrograph, the model salinities in the Trinity Bay area remained slightly higher but exhibited the same degree of change as did the prototype salinities. These same differences occurred generally throughout

the system to a lesser degree in some areas and to a greater degree in others. The model results indicate that the inflow into Trinity Bay during February was not great enough to cause the drop in salinities noted in the prototype data for this period. After this period, the recovery rates of model and prototype salinities were in excellent agreement. In similar situations involving model simulation of a water year, it has been found that the source salinity varies inversely as does the upland flow. Salinity data for the gulf area off Galveston Bay were not available for the test period; therefore, a constant source salinity was maintained throughout the tests. Had such data been available and the source salinity correspondingly adjusted, the agreement between model and prototype during the latter part of the tests would undoubtedly have been much better. It was concluded that the model would satisfactorily reproduce long-term salinity changes brought about by natural seasonal and man-made changes in upland flow.

PART V: LIMITATIONS OF ACCURACY OF MODEL MEASUREMENTS

26. Measurements of tidal elevations in the model are accurate to within ±0.03 ft prototype (0.0005 ft model). Since the maximum error between model and prototype tidal data was of approximately this order of magnitude, the model measurements of tidal elevations are considered accurate and satisfactory.

27. The limitations of the model current meters (see paragraph 12 and fig. 2) should be considered in making close comparison between model and prototype velocity data. The center line of the meter cup wheel is about 0.05 ft from the bottom of the frame; therefore, bottom velocity measurements in the model were actually obtained at a point 3 ft (prototype) above the bottom, instead of 1.0 ft as in the prototype metering program. Also, it was not practical to follow the rise and fall of the model water surface with the meter while measuring surface and middepth velocities as was done in the prototype. For surface measurements in the model, the meter was positioned with the cup wheel barely submerged at low tide, and the meter remained in this position throughout the tidal cycle. Middepth measurements in the model were made at a point midway between the elevation of low tide and bottom. The model velocities were determined by counting the number of revolutions in a 10-sec interval, which represented a period of about 13 min in the prototype, as compared with about a 1-min observation in the prototype. The horizontal spread of the entire meter cup wheel was about 0.11 ft in the model, representing about 66 ft in the prototype, as compared with less than 1.0 ft for the prototype meter. With these limitations in mind, it is believed that current velocity measurements in the model were accurate within ±0.4 fps prototype (0.05 fps in the model).

28. All model salinity measurements presented in this report were made by electrical conductivity and are considered to be accurate within about 0.3 ppt. The accuracy with which the model could be expected to duplicate salinities from cycle to cycle for identical conditions appears to be about ±3 percent.

PART VI: CONCLUSIONS

29. The results of the model verification tests reported herein have demonstrated the ability of the model to reproduce all pertinent hydraulic and salinity phenomena (including fresh- and saltwater mixing) of the prototype in a quantitative manner. It therefore follows that the model may be relied upon to provide quantitative data as to the effects of proposed improvement works on hydraulic and salinity phenomena. In addition, it will be possible to conduct quantitative studies of salinity intrusion and distribution as affected by freshwater discharge, tide range, and other parameters which may influence salinity conditions.

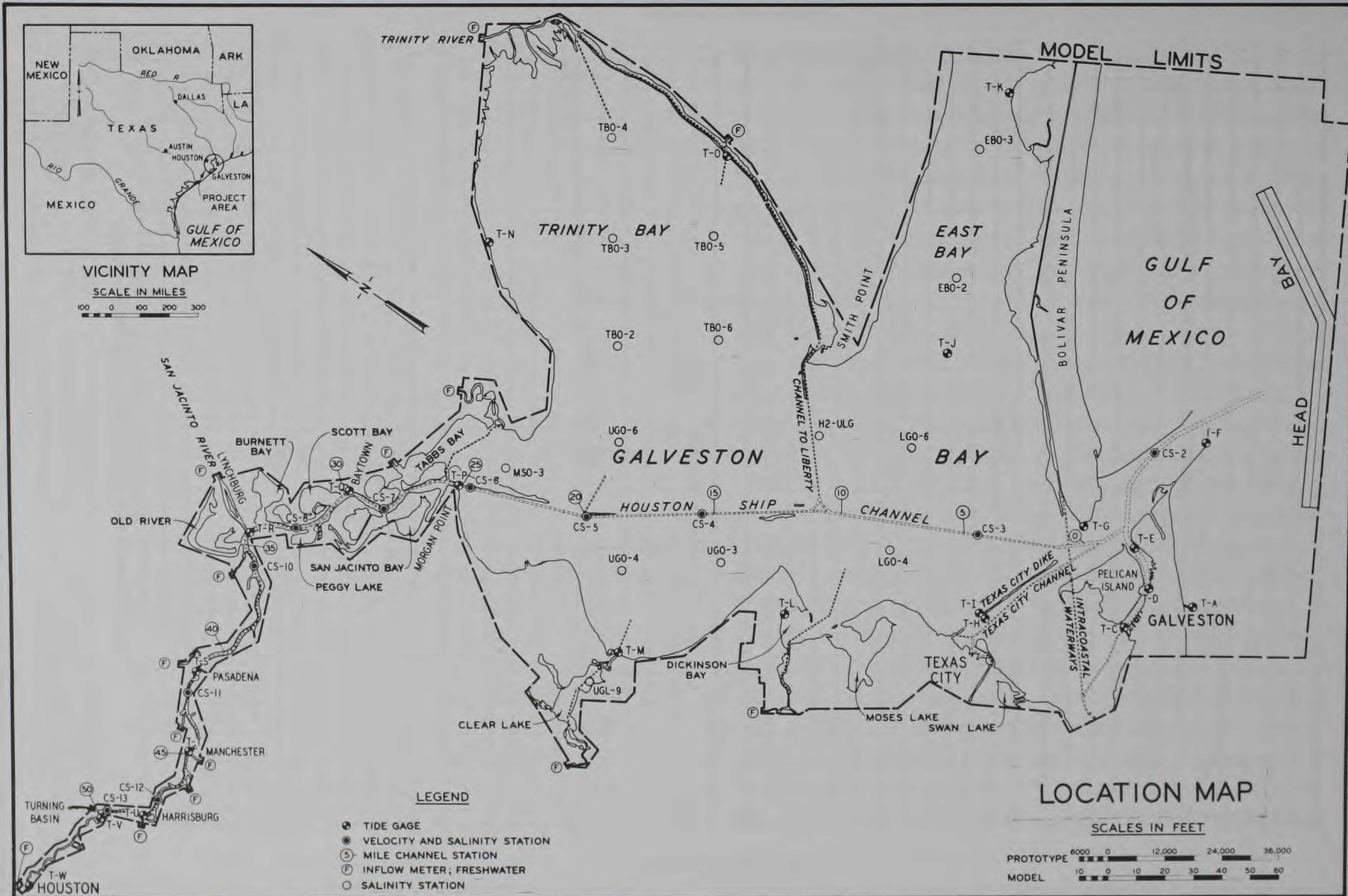
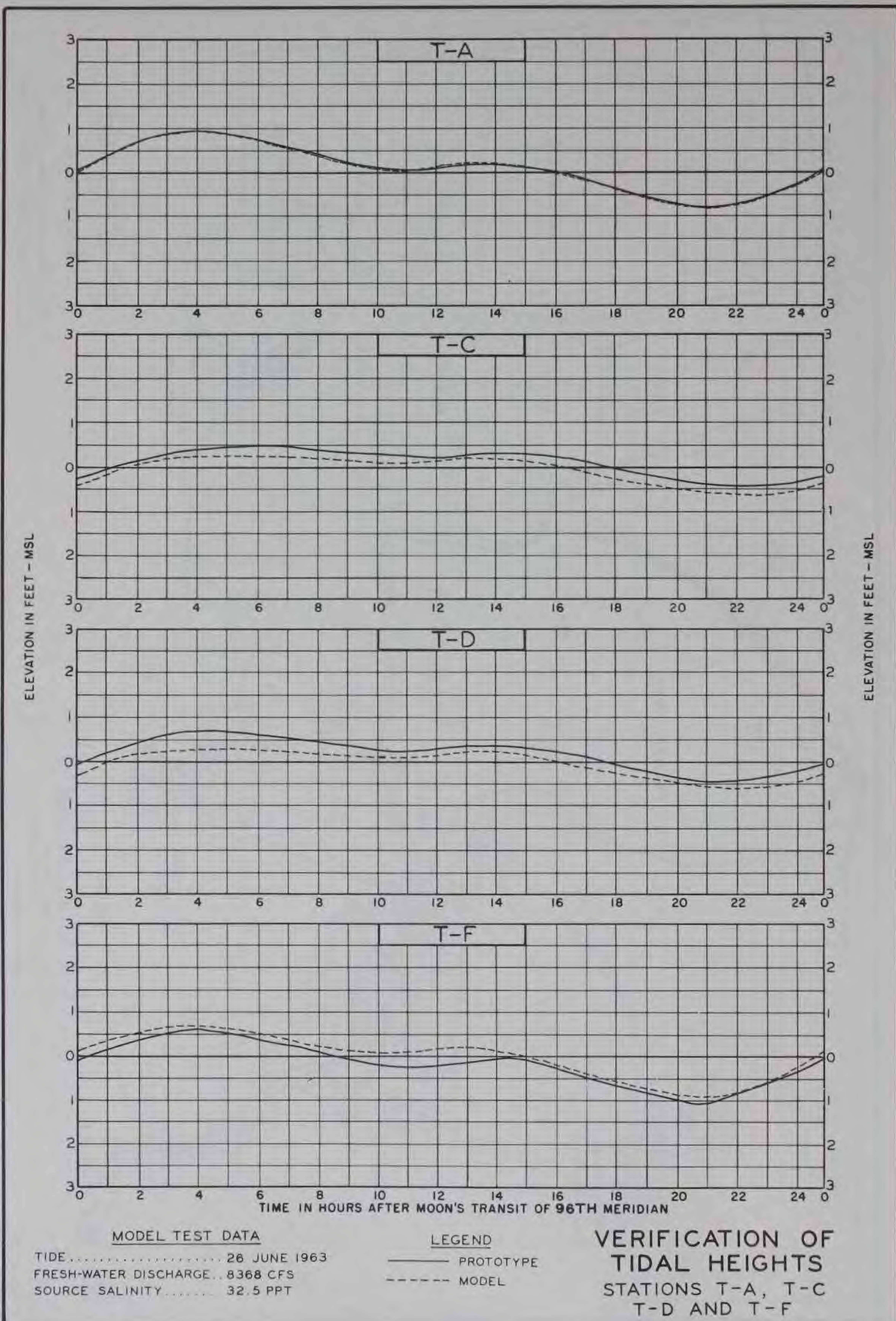
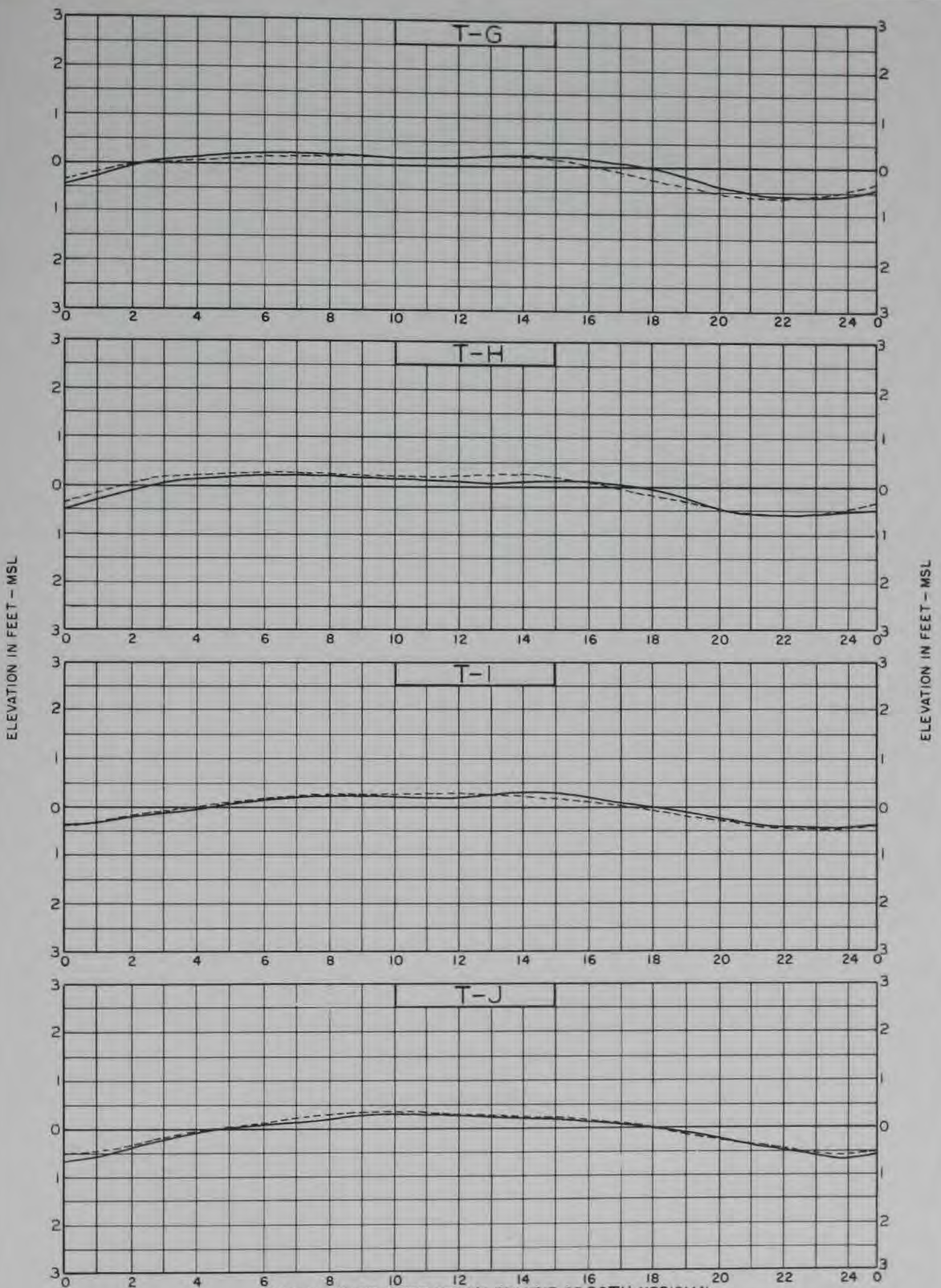

VICINITY MAP
SCALE IN MILES
100 0 100 200 300
NEW MEXICO
OKLAHOMA
ARK
LA
RED R
DALLAS
TEXAS
AUSTIN
HOUSTON
GALVESTON
RIO GRANDE
MEXICO
PROJECT AREA
GULF OF MEXICO
N
TRINITY RIVER
MODEL LIMITS
TRINITY BAY
EAST BAY
GULF OF MEXICO
BOLIVAR PENINSULA
SMITH POINT
CHANNEL TO LIBERTY
GALVESTON BAY
HOUSTON SHIP CHANNEL
BAY HEAD
SAN JACINTO RIVER
LYNCHBURG
BURNETT BAY
SCOTT BAY
BAYTOWN
TABBS BAY
MORGAN POINT
OLD RIVER
SAN JACINTO BAY
PEGGY LAKE
PASADENA
MANCHESTER
HARRISBURG
TURNING BASIN
HOUSTON
CLEAR LAKE
DICKINSON BAY
TEXAS CITY
MOSES LAKE
SWAN LAKE
TEXAS CITY DIKE
TEXAS CITY CHANNEL
INTRACOASTAL WATERWAYS
PELICAN ISLAND
GALVESTON
TBO-4
TBO-3
TBO-5
TBO-2
TBO-6
EBO-3
EBO-2
UGO-6
UGO-4
UGO-3
H2-ULG
LGO-6
LGO-4
MSO-3
UGL-9
T-K
T-O
T-N
T-J
T-P
T-Q
T-R
T-S
T-T
T-U
T-V
T-W
T-M
T-L
T-I
T-H
T-G
T-E
T-D
T-C
T-A
T-F
CS-2
CS-3
CS-4
CS-5
CS-6
CS-7
CS-8
CS-10
CS-11
CS-12
CS-13
LEGEND
TIDE GAGE
VELOCITY AND SALINITY STATION
MILE CHANNEL STATION
INFLOW METER; FRESHWATER
SALINITY STATION
LOCATION MAP
SCALES IN FEET
PROTOTYPE 6000 0 12,000 24,000 36,000
MODEL 10 0 10 20 30 40 50 60

PLATE 1



T-A
T-C
T-D
T-F
ELEVATION IN FEET - MSL
TIME IN HOURS AFTER MOON'S TRANSIT OF 96TH MERIDIAN
MODEL TEST DATA
TIDE .... 26 JUNE 1963
FRESH-WATER DISCHARGE .. 8368 CFS
SOURCE SALINITY .... 32.5 PPT
LEGEND
PROTOTYPE
MODEL
VERIFICATION OF TIDAL HEIGHTS
STATIONS T-A, T-C T-D AND T-F

PLATE 2



MODEL TEST DATA

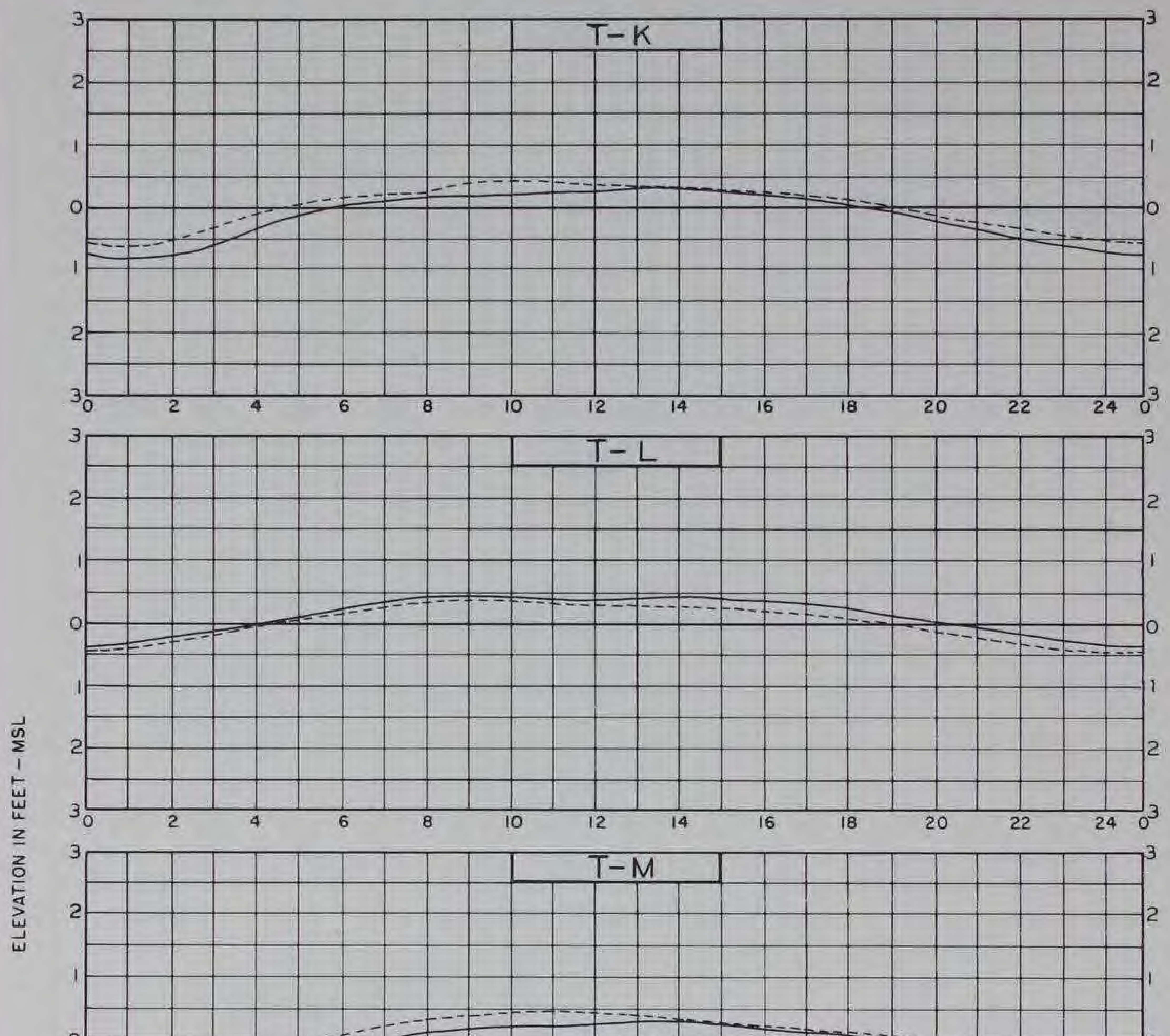
TIDE .... 26 JUNE 1963
FRESH-WATER DISCHARGE .. 8368 CFS
SOURCE SALINITY .... 32.5 PPT

LEGEND

——— PROTOTYPE
------ MODEL

VERIFICATION OF TIDAL HEIGHTS

STATIONS T-G, T-H
T-I AND T-J



MODEL TEST DATA

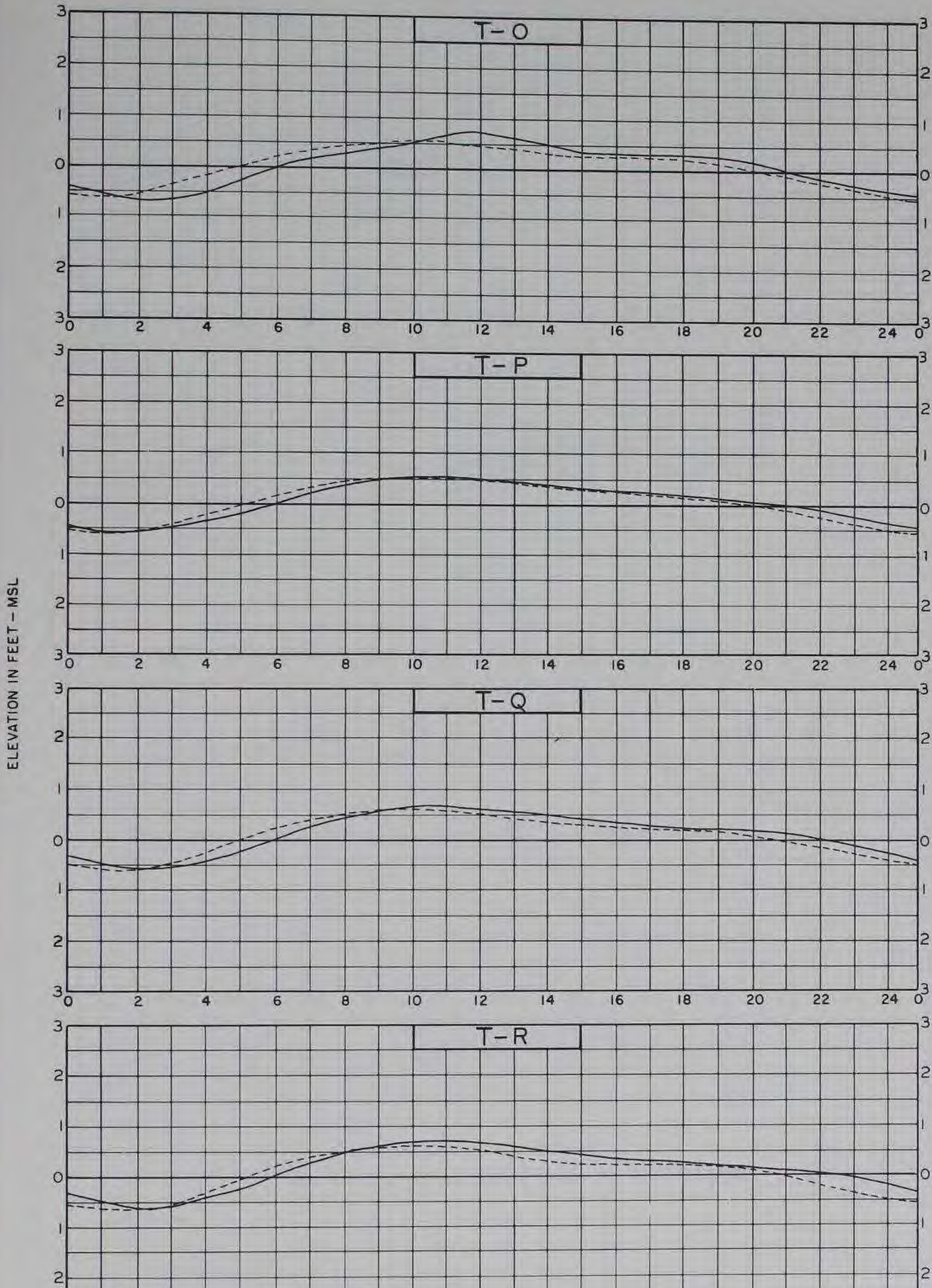
TIDE .... 26 JUNE 1963
FRESH-WATER DISCHARGE .. 8368 CFS
SOURCE SALINITY .... 32.5 PPT

LEGEND

——— PROTOTYPE
- - - - - - MODEL

VERIFICATION OF TIDAL HEIGHTS

STATIONS T-K, T-L T-M AND T-N

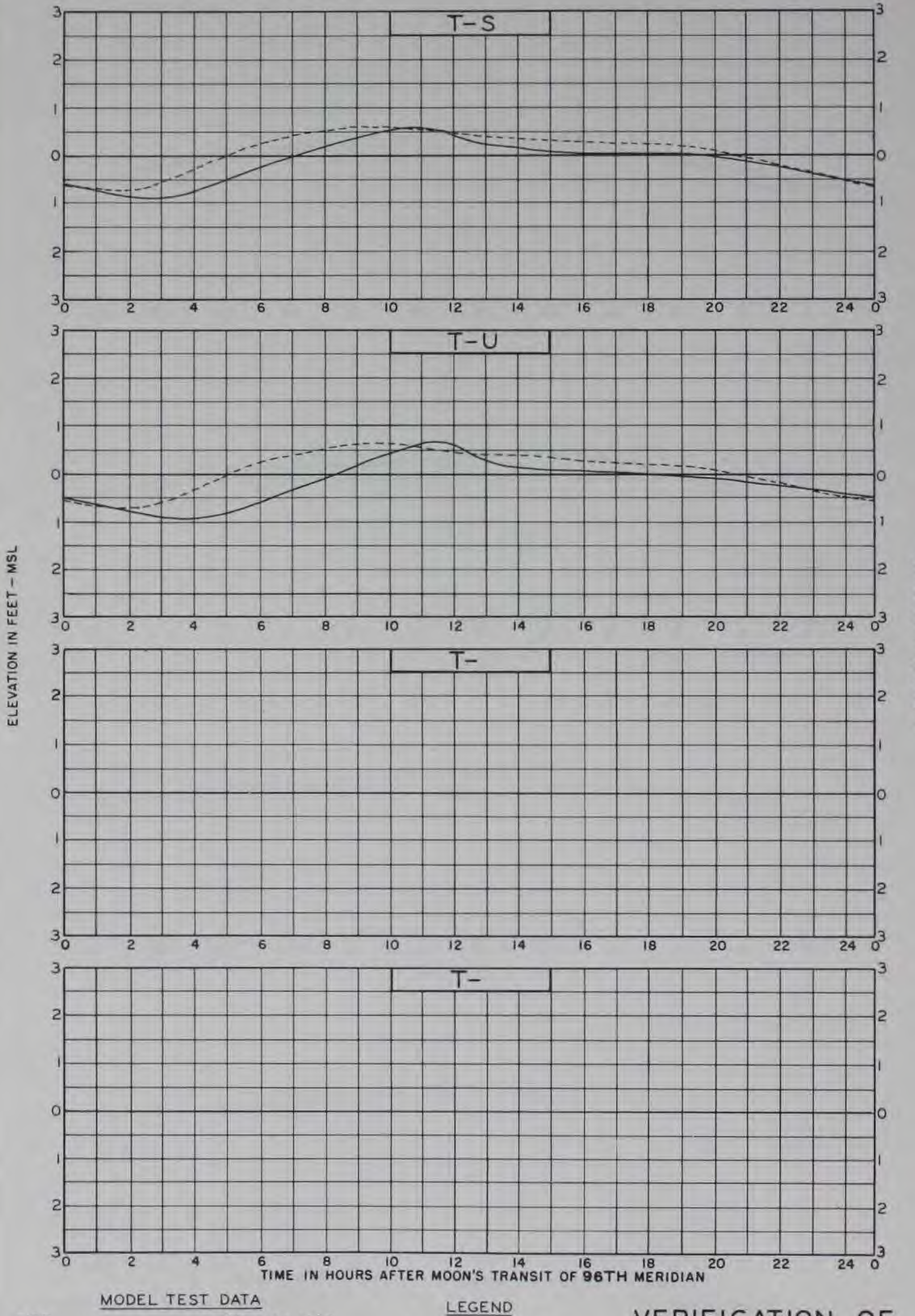


MODEL TEST DATA

TIDE .... 26 JUNE 1963
FRESH-WATER DISCHARGE .. 8368 CFS
SOURCE SALINITY .... 32.5 PPT

VERIFICATION OF TIDAL HEIGHTS

STATIONS T-O, T-P
T-Q AND T-R



MODEL TEST DATA

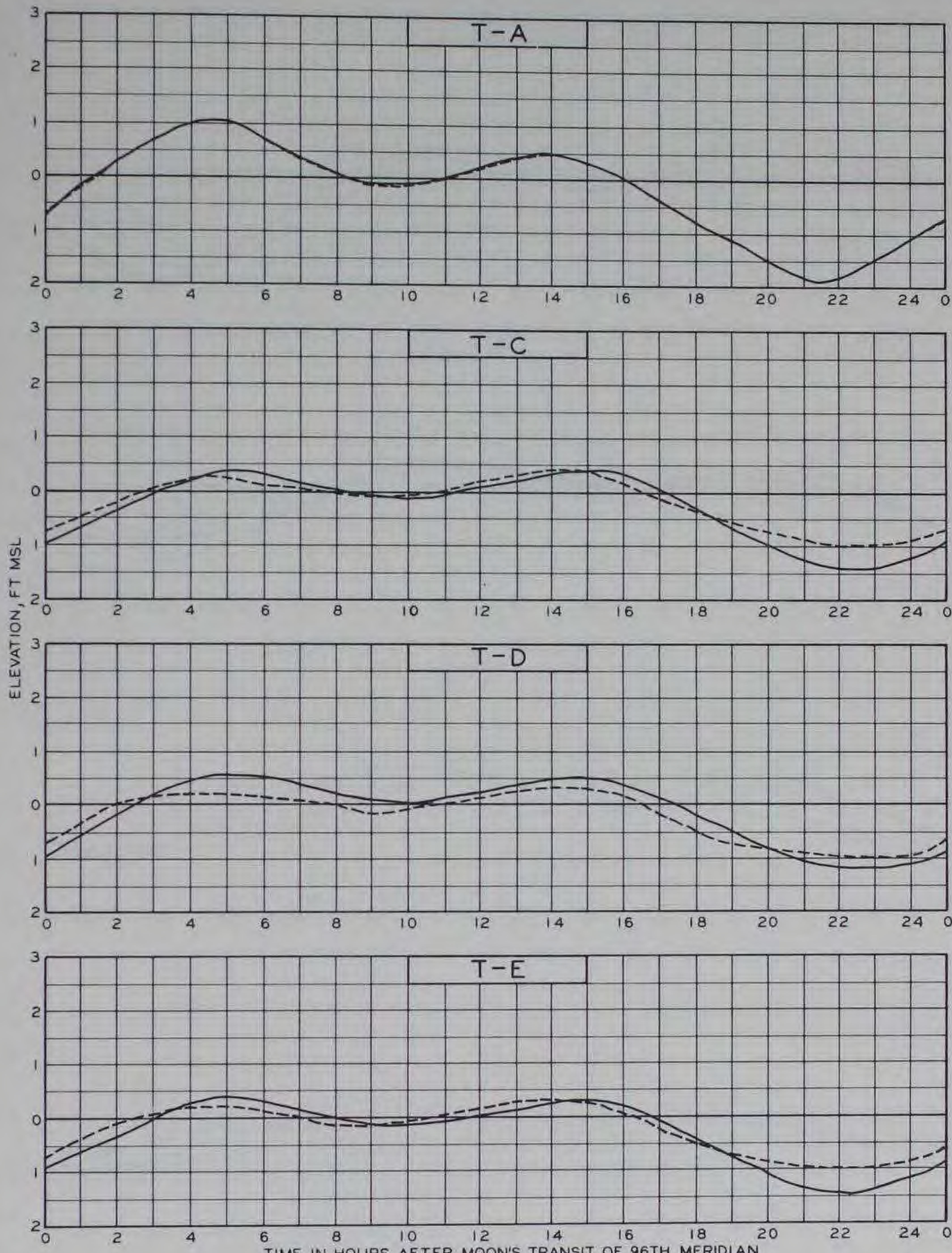
TIDE .... 26 JUNE 1963
FRESH-WATER DISCHARGE .. 8368 CFS
SOURCE SALINITY .... 32.5 PPT

LEGEND

——— PROTOTYPE
------ MODEL

VERIFICATION OF TIDAL HEIGHTS

STATIONS T-S AND T-U



MODEL TEST DATA

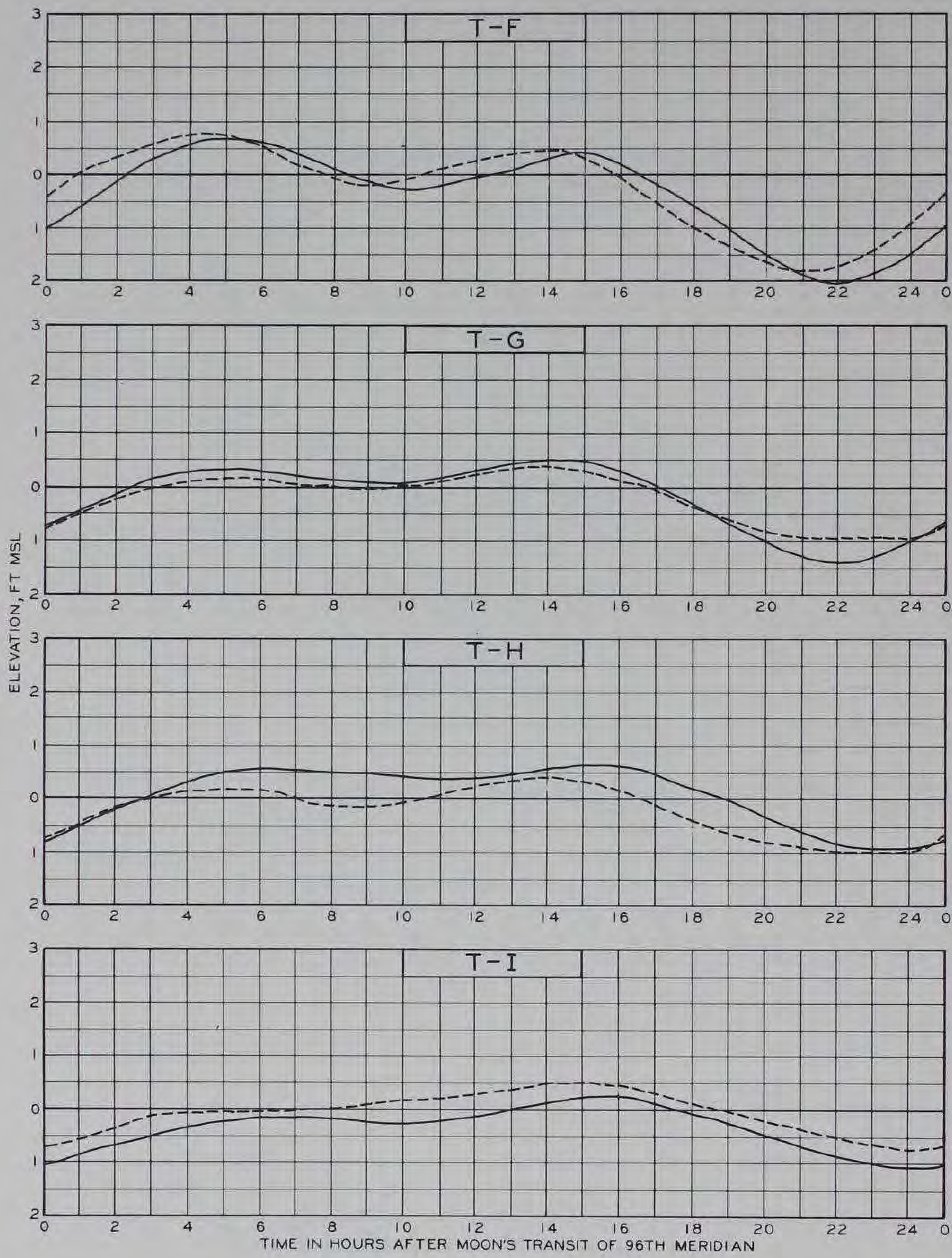
TIDE .... 26-28 FEB 1964
FRESH-WATER DISCHARGE .. 8368 CFS
SOURCE SALINITY .... 32.5 PPT

LEGEND

——— PROTOTYPE
- - - - - MODEL

VERIFICATION OF TIDAL HEIGHTS

STATIONS T-A, T-C
T-D AND T-E



MODEL TEST DATA

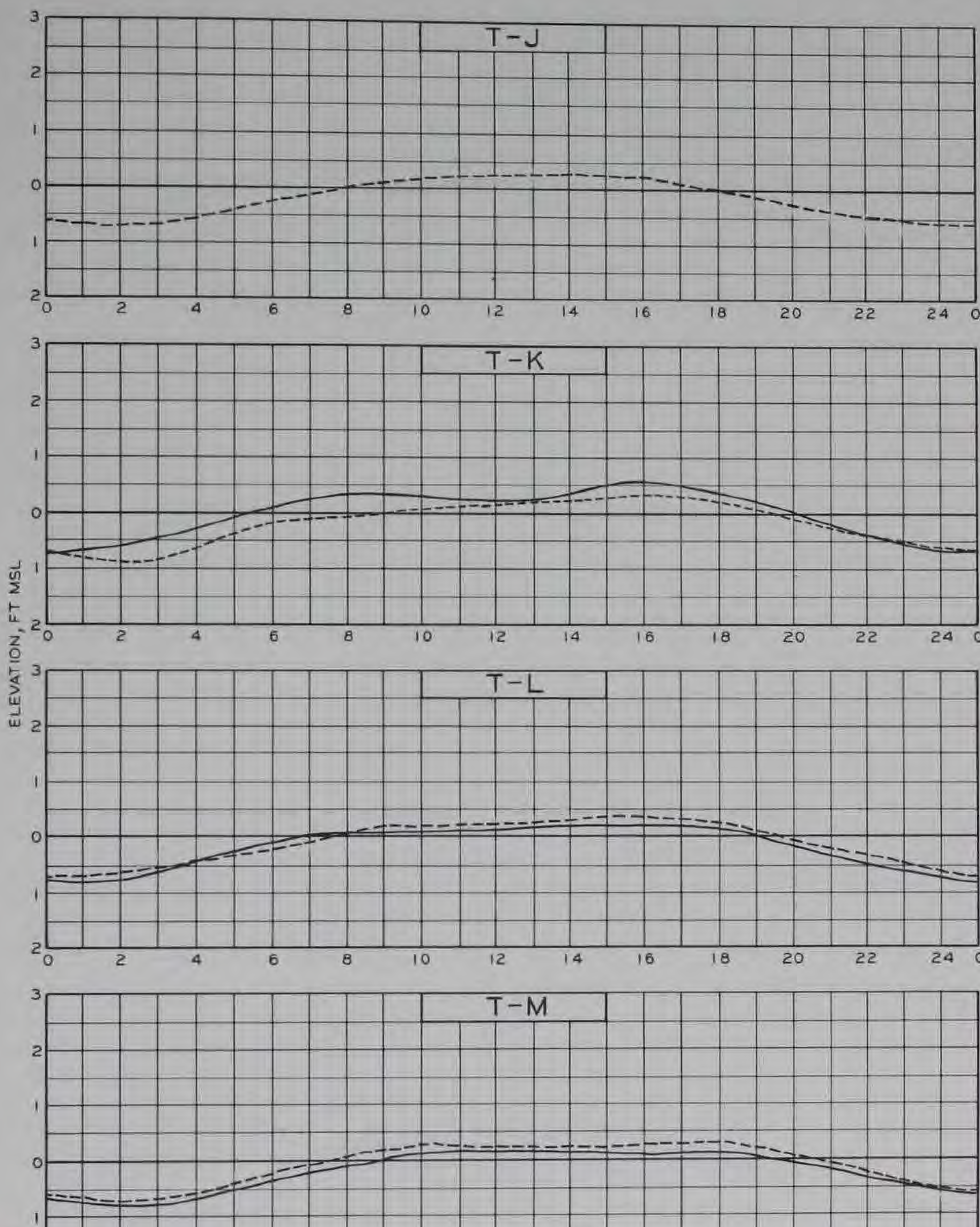
TIDE.................... 26-28 FEB 1964
FRESH-WATER DISCHARGE.. 8368 CFS
SOURCE SALINITY........ 32.5 PPT

LEGEND

——— PROTOTYPE
- - - - - MODEL

VERIFICATION OF TIDAL HEIGHTS

STATIONS T-F, T-G
T-H AND T-I



MODEL TEST DATA

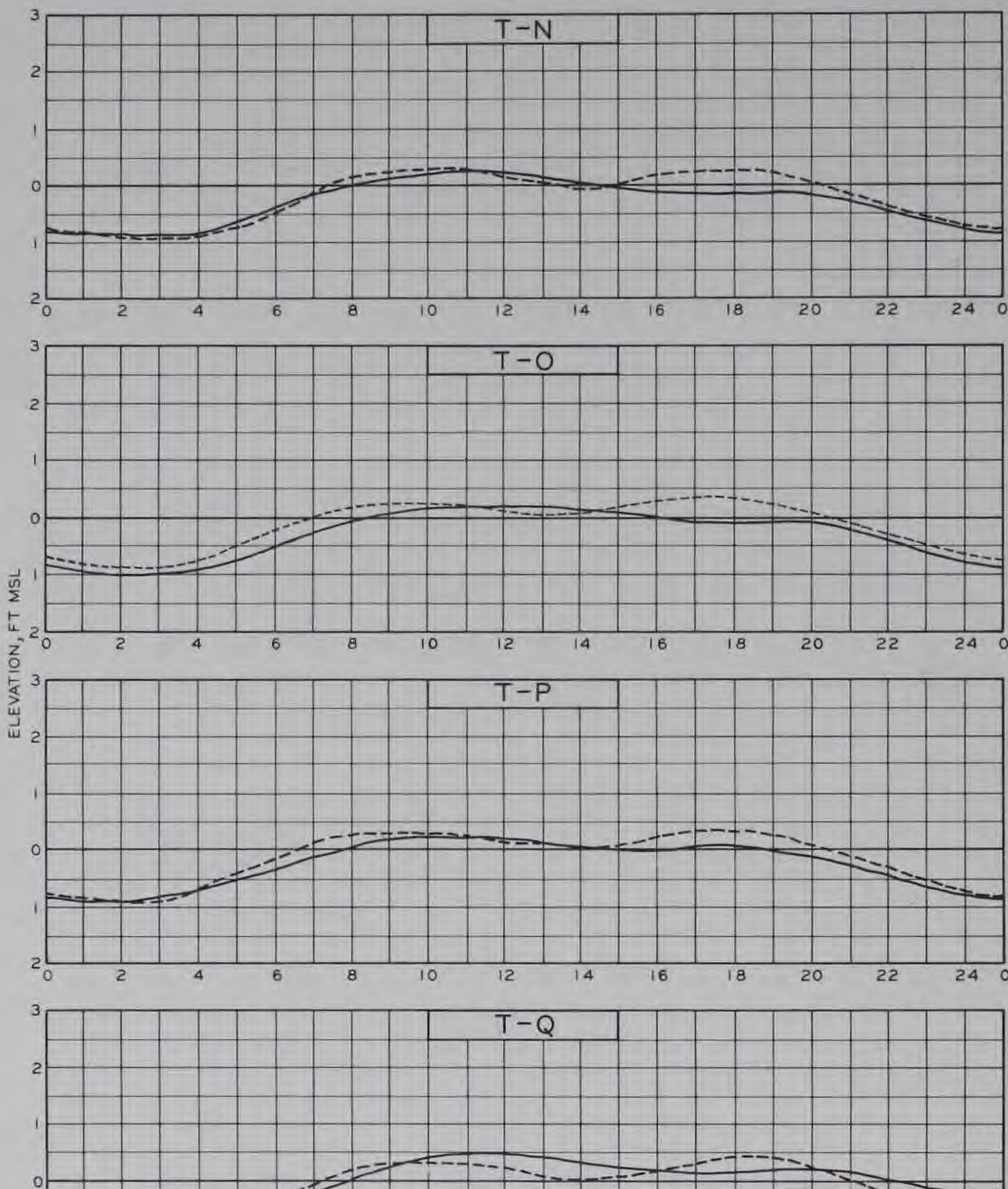
TIDE .... 26-28 FEB 1964
FRESH-WATER DISCHARGE .. 8368 CFS
SOURCE SALINITY .... 32.5 PPT

LEGEND

——— PROTOTYPE
------ MODEL

VERIFICATION OF TIDAL HEIGHTS

STATIONS T-J, T-K
T-L AND T-M



MODEL TEST DATA

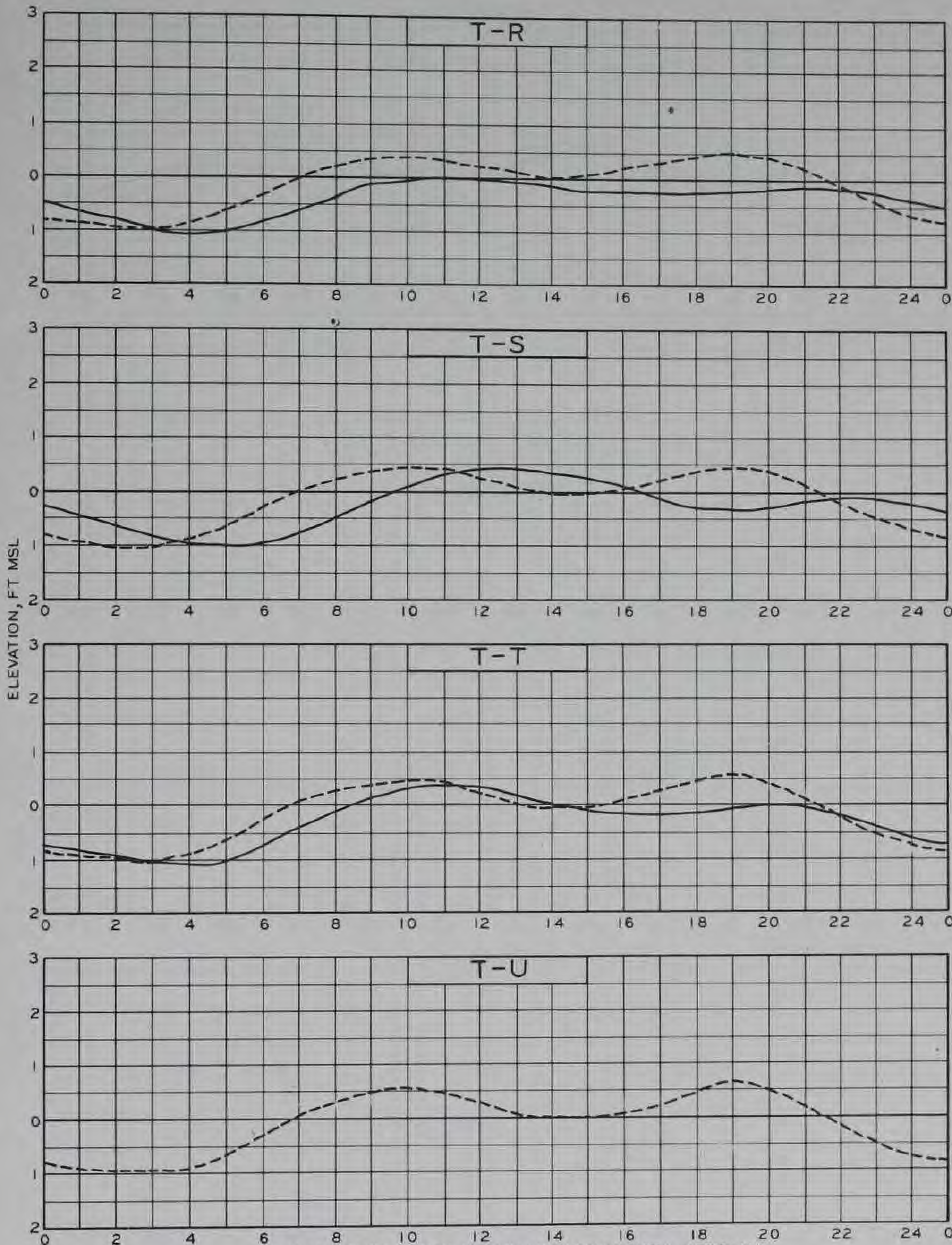
TIDE .... 26-28 FEB 1964
FRESH-WATER DISCHARGE .. 8368 CFS
SOURCE SALINITY .... 32.5 PPT

LEGEND

——— PROTOTYPE
- - - - - - MODEL

VERIFICATION OF TIDAL HEIGHTS

STATIONS T-N, T-O
T-P AND T-Q



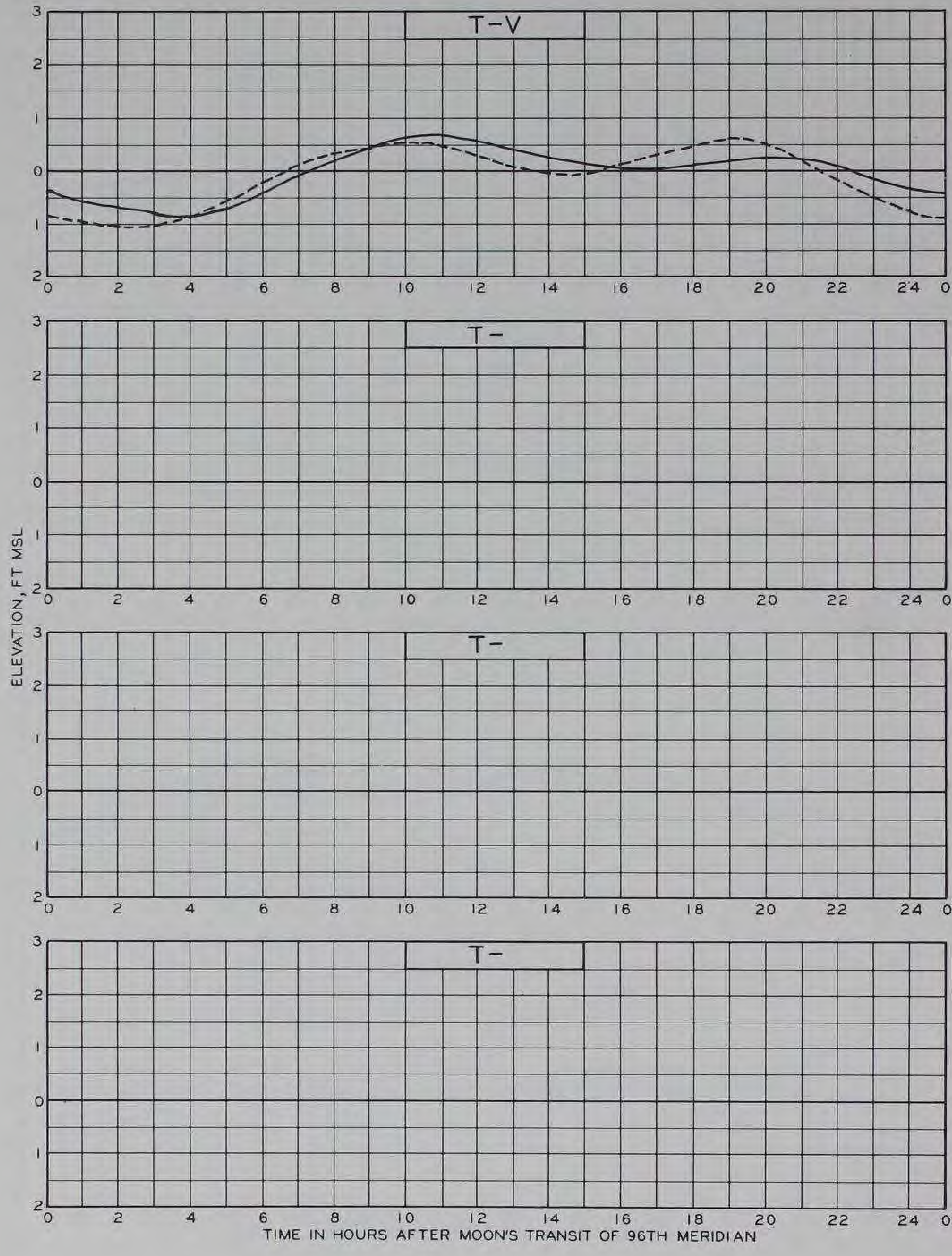
MODEL TEST DATA

TIDE .... 26-28 FEB 1964
FRESH-WATER DISCHARGE .. 8368 CFS
SOURCE SALINITY .... 32.5 PPT

LEGEND

——— PROTOTYPE
- - - - - - MODEL

VERIFICATION OF TIDAL HEIGHTS
STATIONS T-R, T-S T-T AND T-U



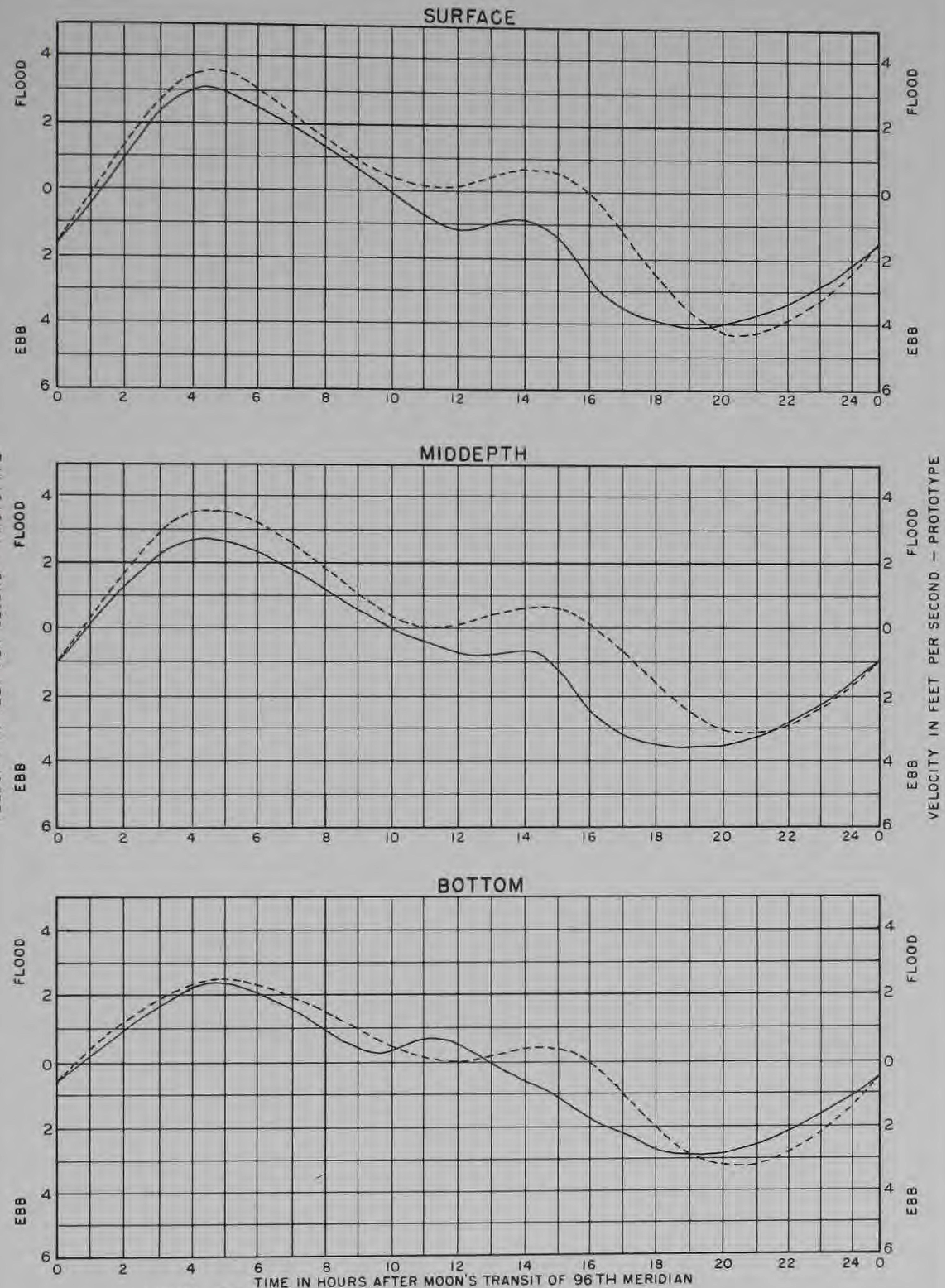
MODEL TEST DATA

TIDE.................... 26-28 FEB 1964
FRESH-WATER DISCHARGE.. 8368 CFS
SOURCE SALINITY........ 32.5 PPT

LEGEND

——— PROTOTYPE
------ MODEL

VERIFICATION OF TIDAL HEIGHTS
STATION T-V



MODEL TEST DATA

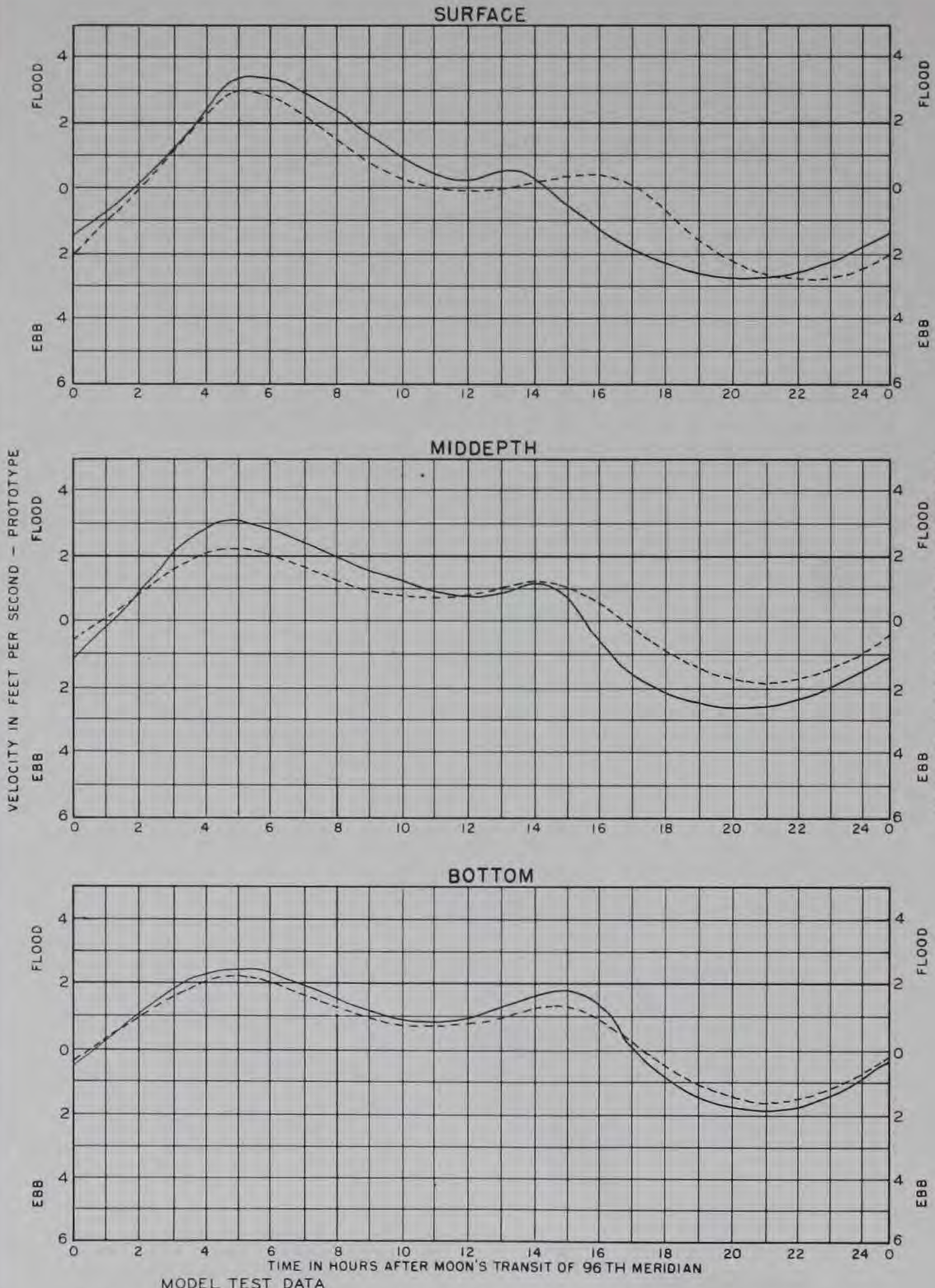
TIDE .... 26-28 FEB 1964
FRESH-WATER DISCHARGE .. 8368 CFS
SOURCE SALINITY .... 32.5 PPT

LEGEND

——— PROTOTYPE
------ MODEL

VERIFICATION OF VELOCITY OBSERVATIONS

STATION CS-2



MODEL TEST DATA

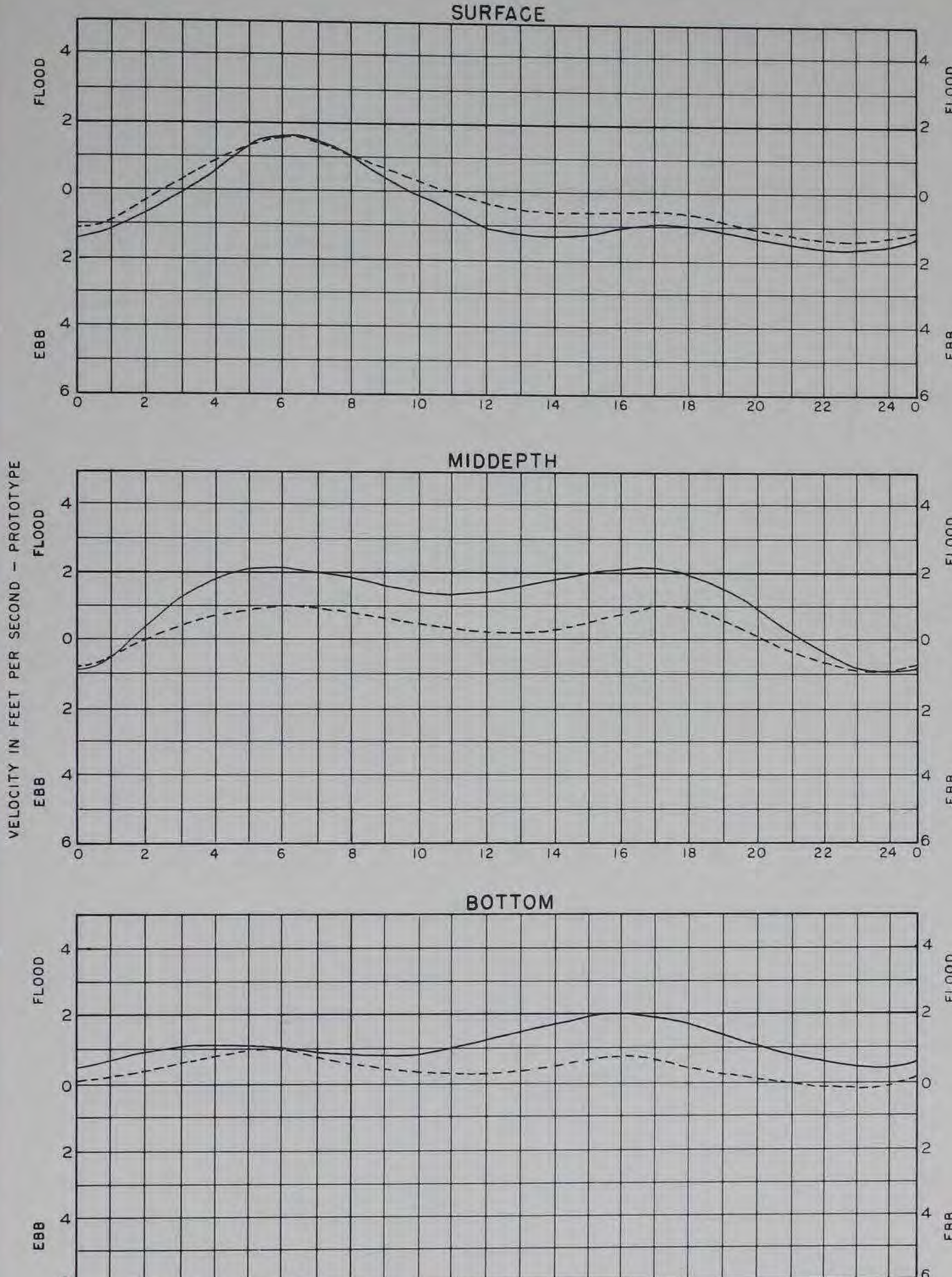
TIDE .... 26-28 FEB 1964
FRESH-WATER DISCHARGE .. 8368 CFS
SOURCE SALINITY ...... 32.5 PPT

LEGEND

——— PROTOTYPE
------ MODEL

VERIFICATION OF VELOCITY OBSERVATIONS

STATION CS-3



MODEL TEST DATA

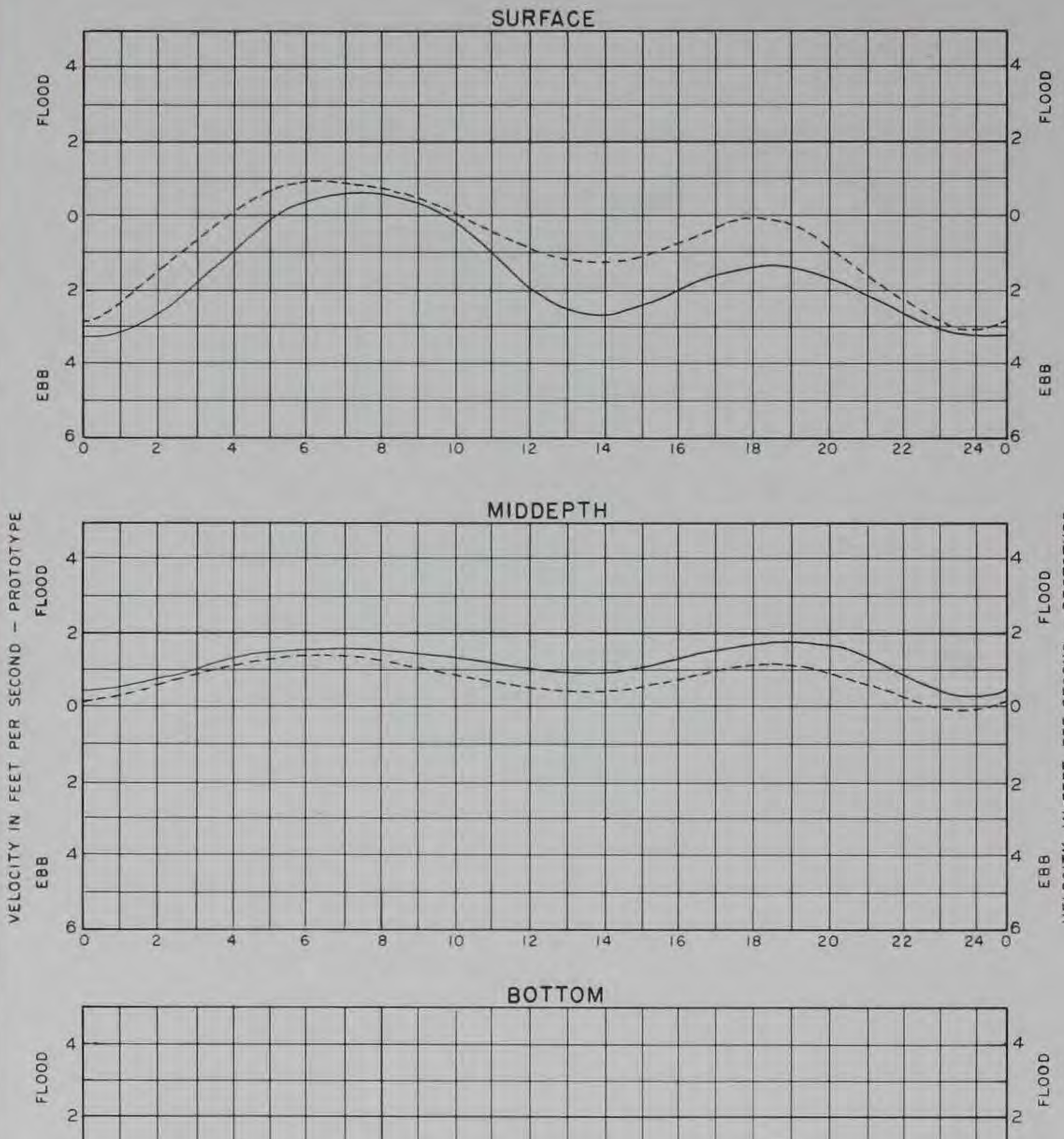
TIDE .... 26-28 FEB 1964
FRESH-WATER DISCHARGE .. 8368 CFS
SOURCE SALINITY .... 32.5 PPT

LEGEND

——— PROTOTYPE
- - - - - MODEL

VERIFICATION OF VELOCITY OBSERVATIONS

STATION CS - 4



MODEL TEST DATA

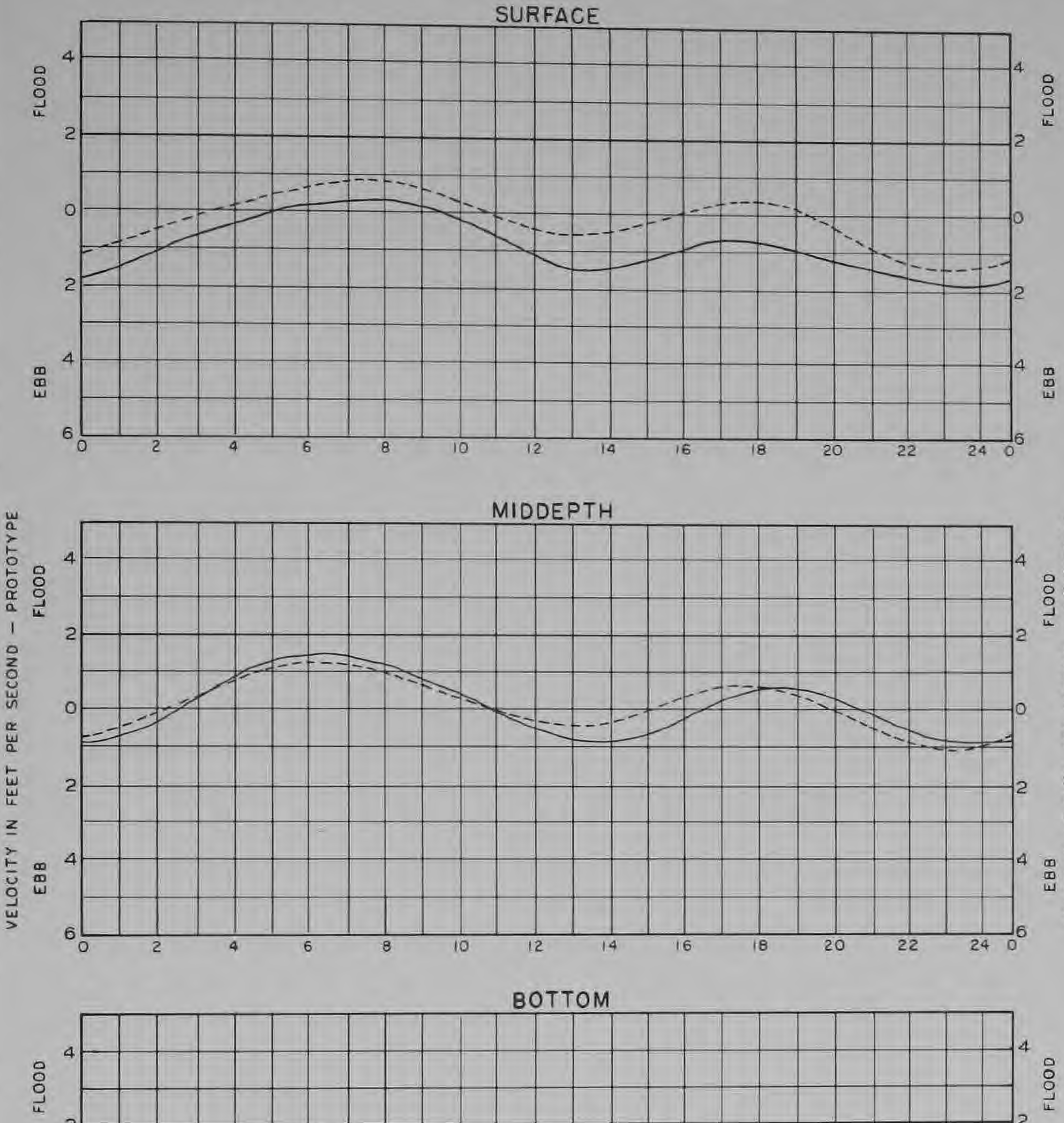
TIDE .... 26-28 FEB 1964
FRESH-WATER DISCHARGE .. 8368 CFS
SOURCE SALINITY ...... 32.5 PPT

LEGEND

——— PROTOTYPE
– – – – – – MODEL

VERIFICATION OF VELOCITY OBSERVATIONS

STATION CS – 6



MODEL TEST DATA

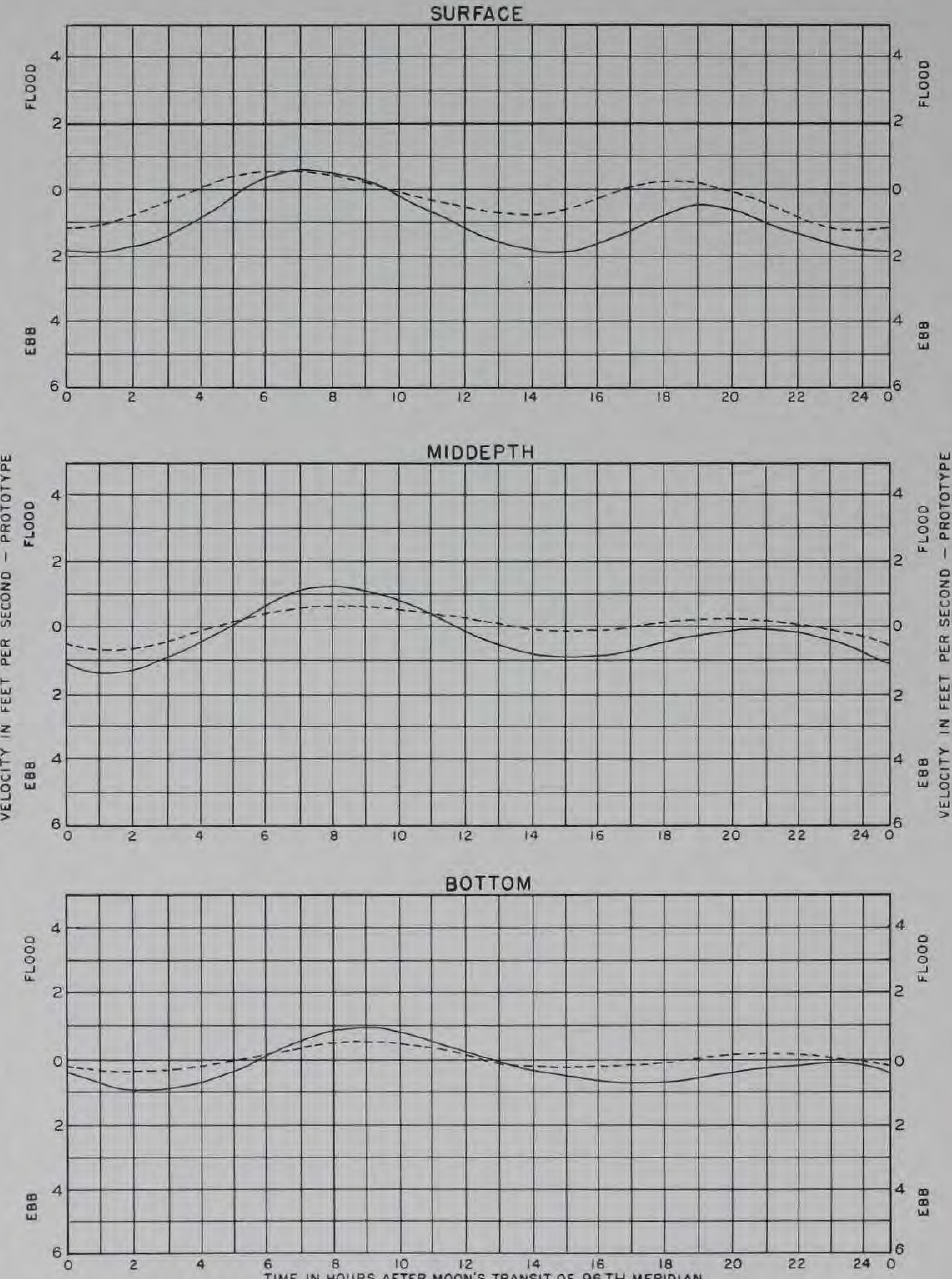
TIDE . . . . 26-28 FEB 1964
FRESH-WATER DISCHARGE . . 8368 CFS
SOURCE SALINITY . . . . . . 32.5 PPT

LEGEND

——— PROTOTYPE
- - - - - - MODEL

VERIFICATION OF VELOCITY OBSERVATIONS

STATION CS - 7



MODEL TEST DATA

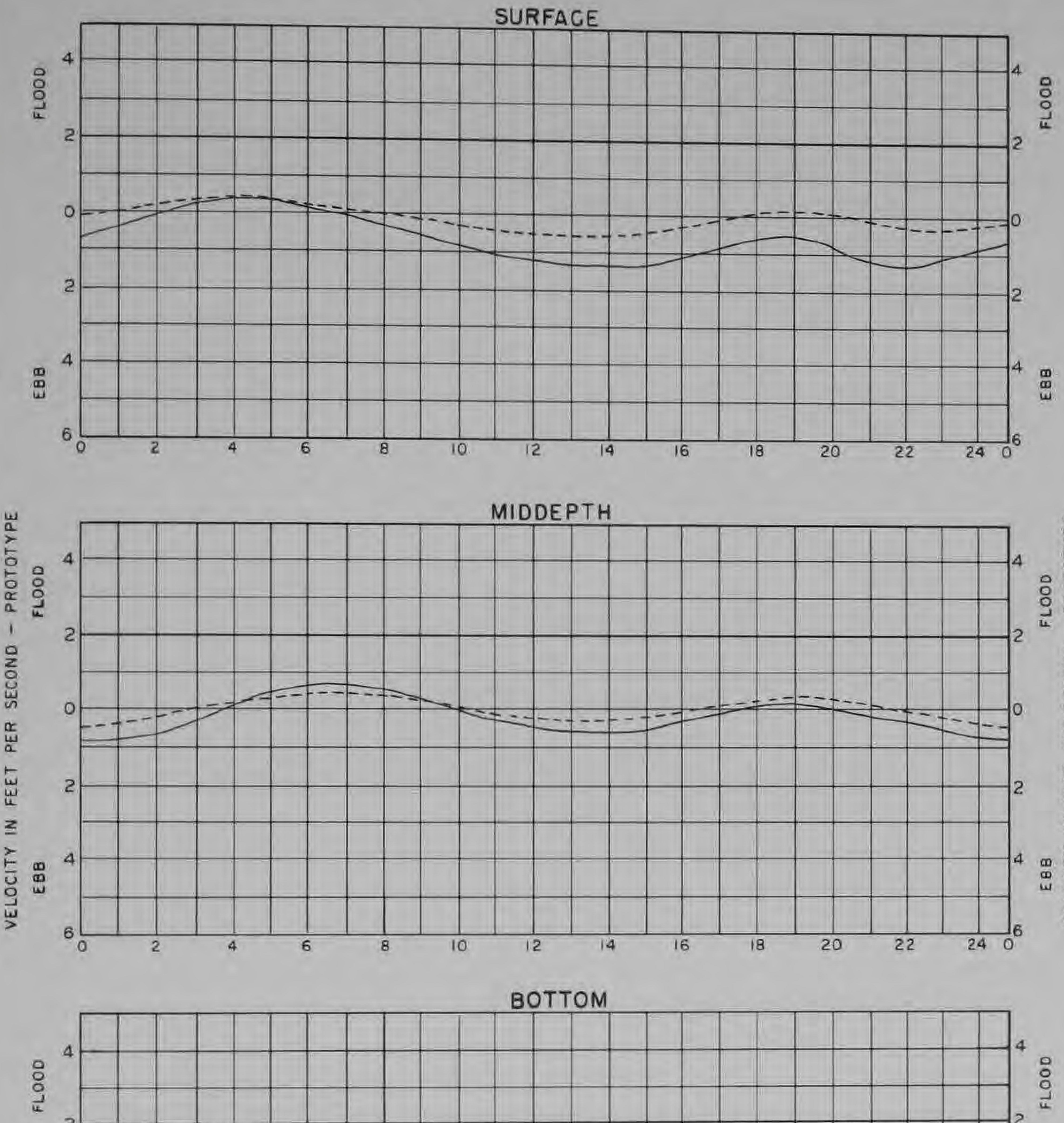
TIDE .... 26-28 FEB 1964
FRESH-WATER DISCHARGE .. 8368 CFS
SOURCE SALINITY .... 32.5 PPT

LEGEND

——— PROTOTYPE
------ MODEL

VERIFICATION OF VELOCITY OBSERVATIONS

STATION CS-8



MODEL TEST DATA

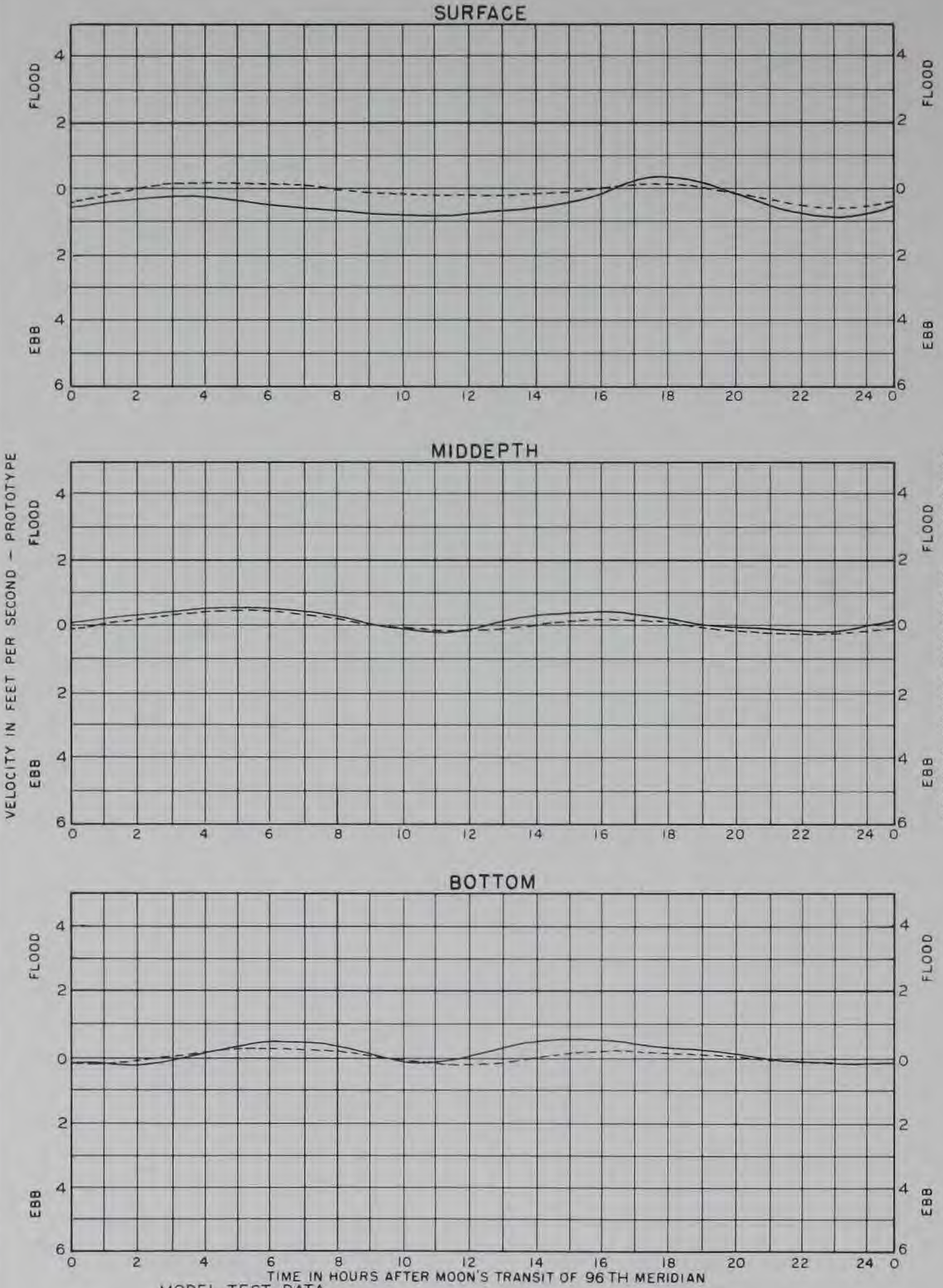
TIDE .... 26-28 FEB 1964
FRESH-WATER DISCHARGE .. 8368 CFS
SOURCE SALINITY .... 32.5 PPT

LEGEND

——— PROTOTYPE
------ MODEL

VERIFICATION OF VELOCITY OBSERVATIONS

STATION CS – 10



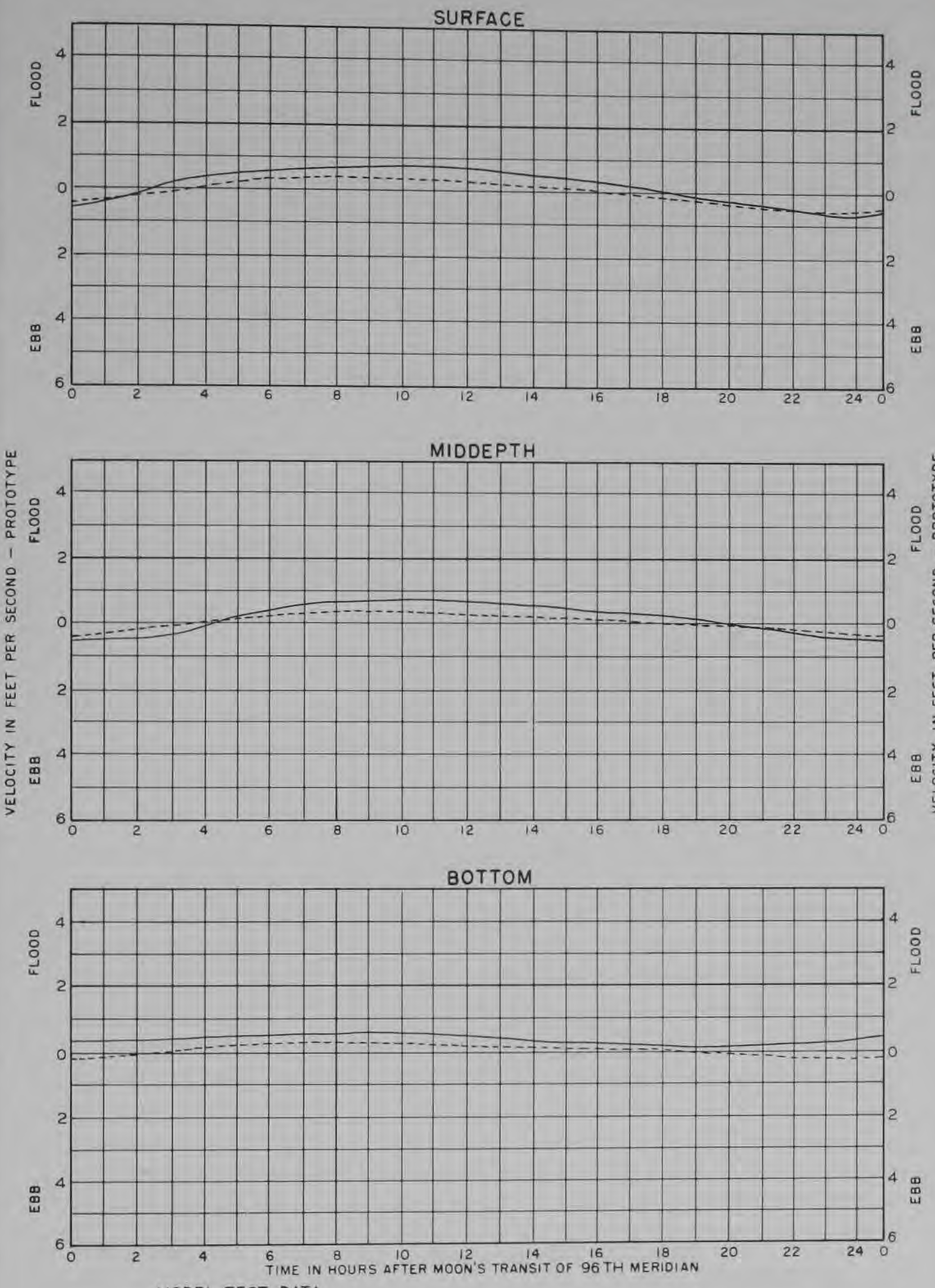
MODEL TEST DATA

TIDE . . . . 26-28 FEB 1964
FRESH-WATER DISCHARGE . . 8368 CFS
SOURCE SALINITY . . . . 32.5 PPT

LEGEND

——— PROTOTYPE
- - - - - - MODEL

VERIFICATION OF
VELOCITY OBSERVATIONS
STATION CS-11



MODEL TEST DATA

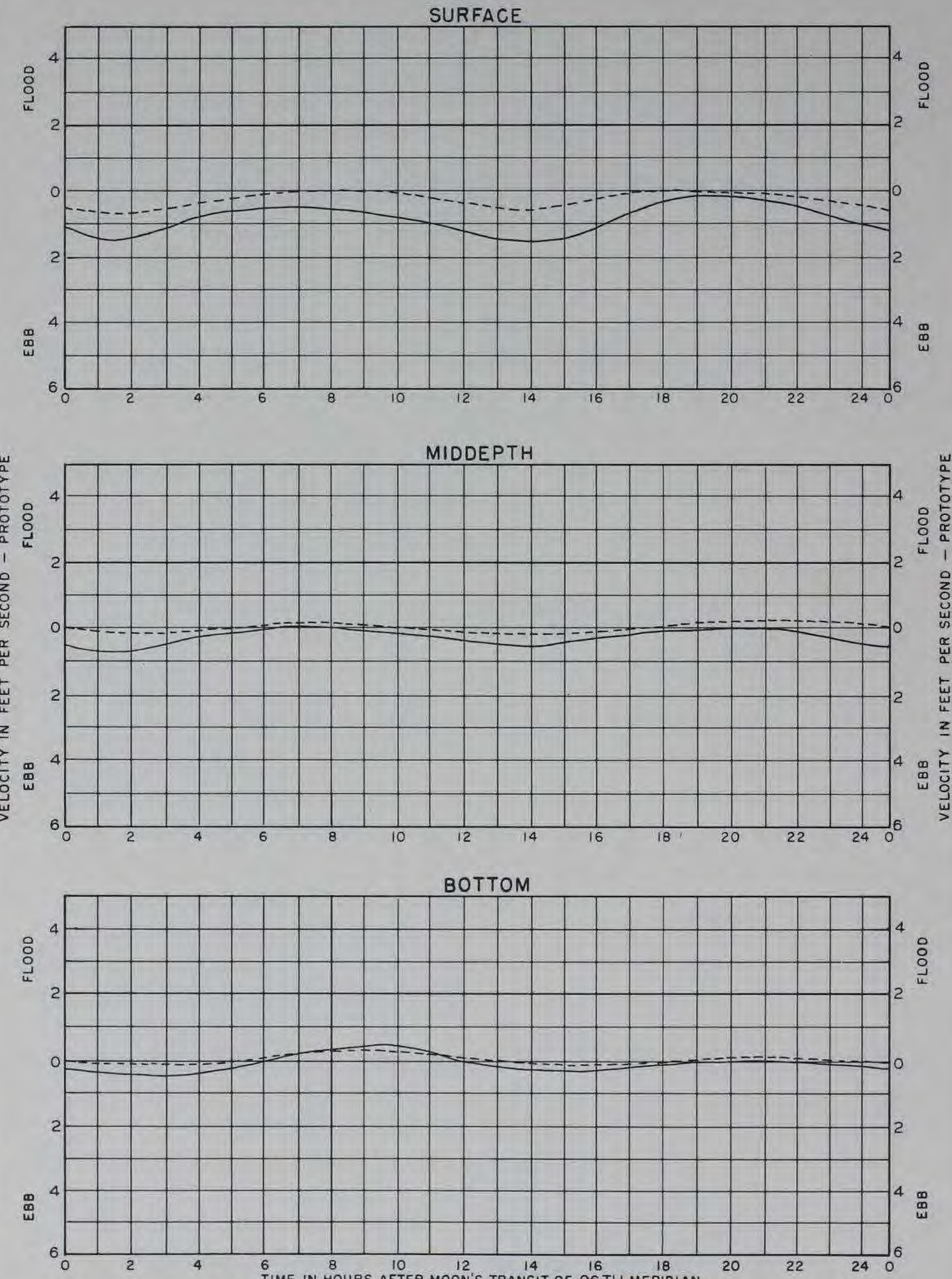
TIDE .... 26-28 FEB 1964
FRESH-WATER DISCHARGE .. 8368 CFS
SOURCE SALINITY .... 32.5 PPT

LEGEND

——— PROTOTYPE
------ MODEL

VERIFICATION OF VELOCITY OBSERVATIONS

STATION CS-12



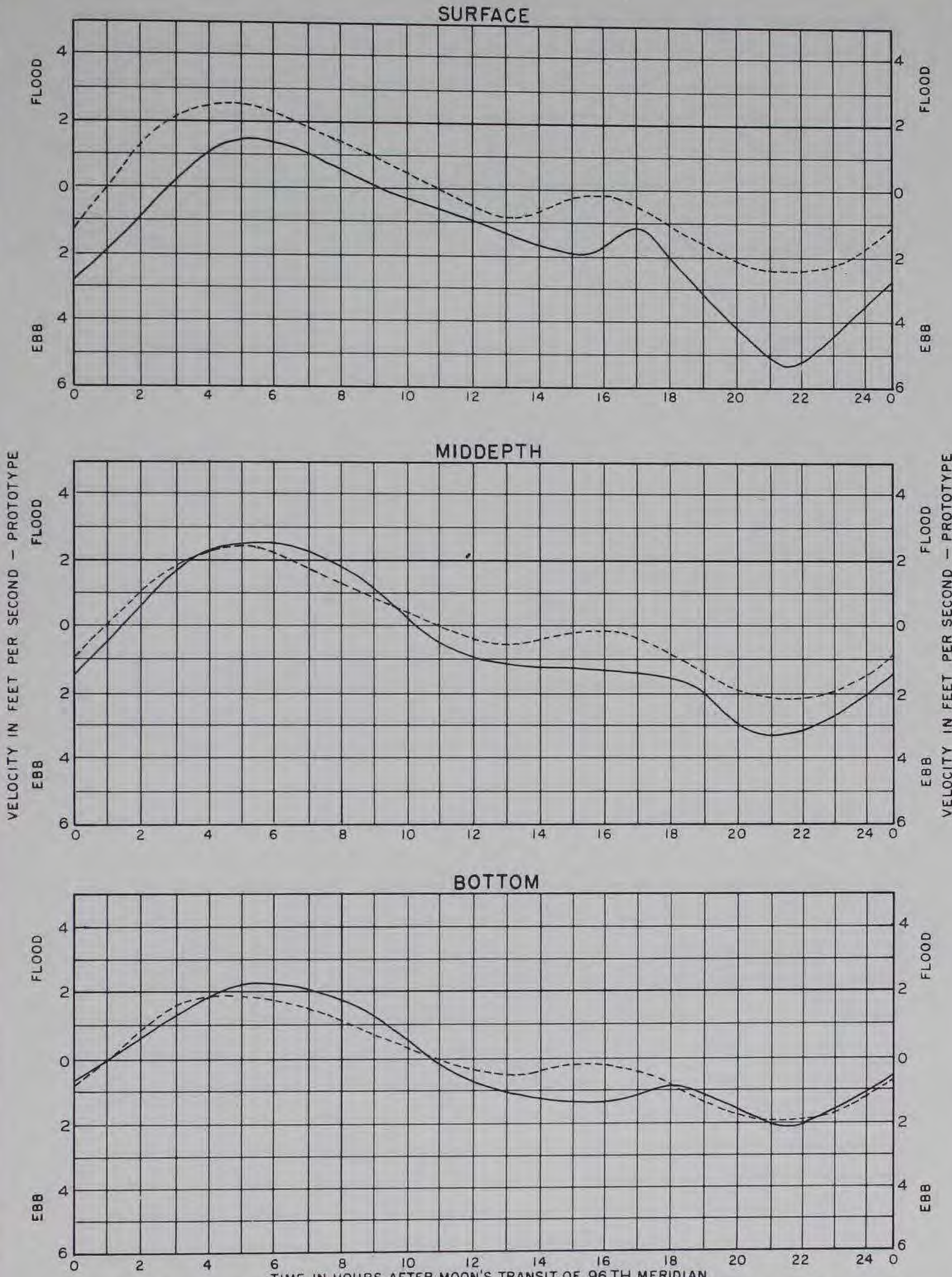
MODEL TEST DATA

TIDE.................... 26-28 FEB 1964
FRESH-WATER DISCHARGE.. 8368 CFS
SOURCE SALINITY........ 32.5 PPT

LEGEND

——— PROTOTYPE
------ MODEL

VERIFICATION OF
VELOCITY OBSERVATIONS
STATION CS-13



MODEL TEST DATA

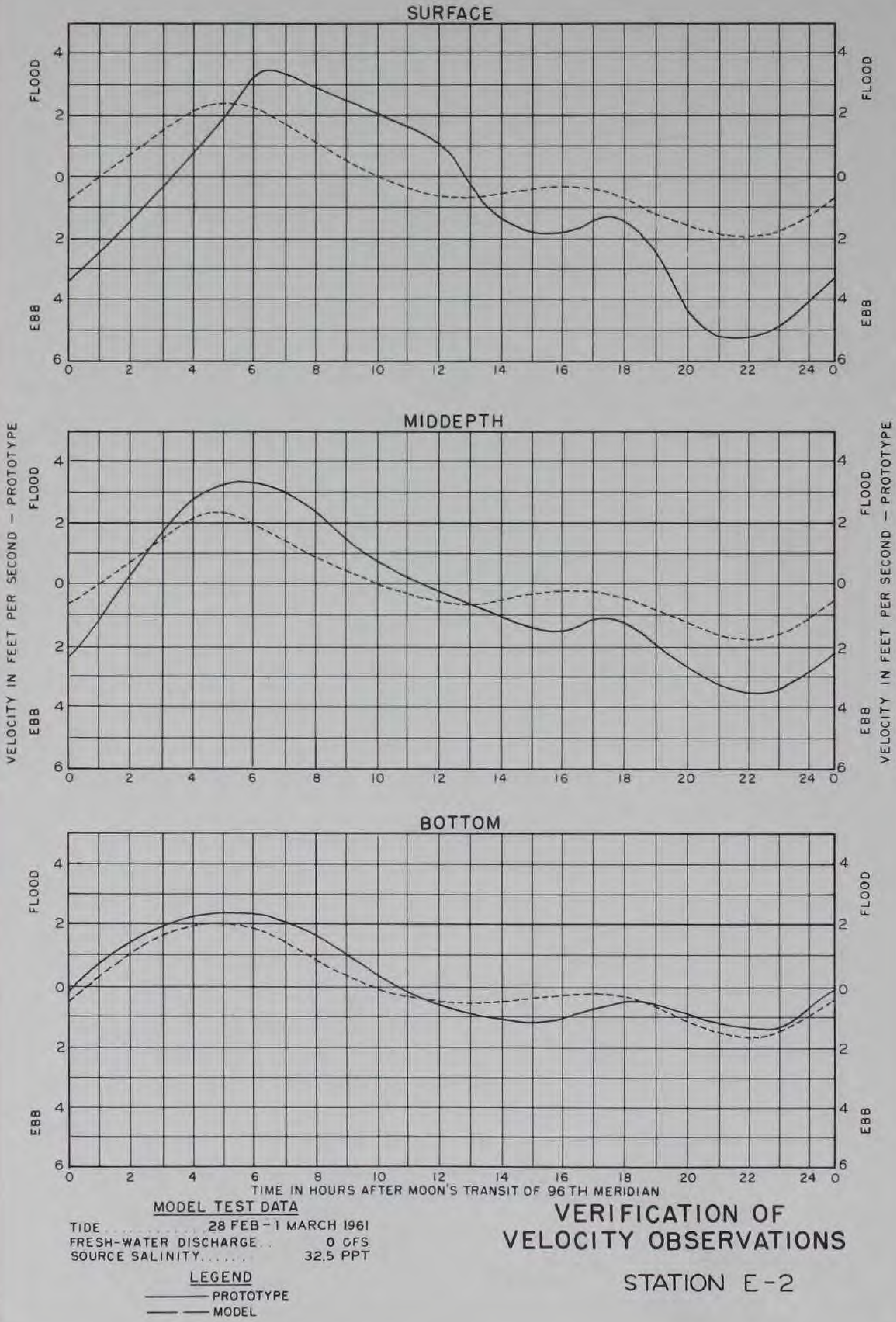
TIDE . . . . 28 FEB - 1 MARCH 1961
FRESH-WATER DISCHARGE . . 0 CFS
SOURCE SALINITY. . . . . . . 32.5 PPT

LEGEND

——— PROTOTYPE
— — MODEL

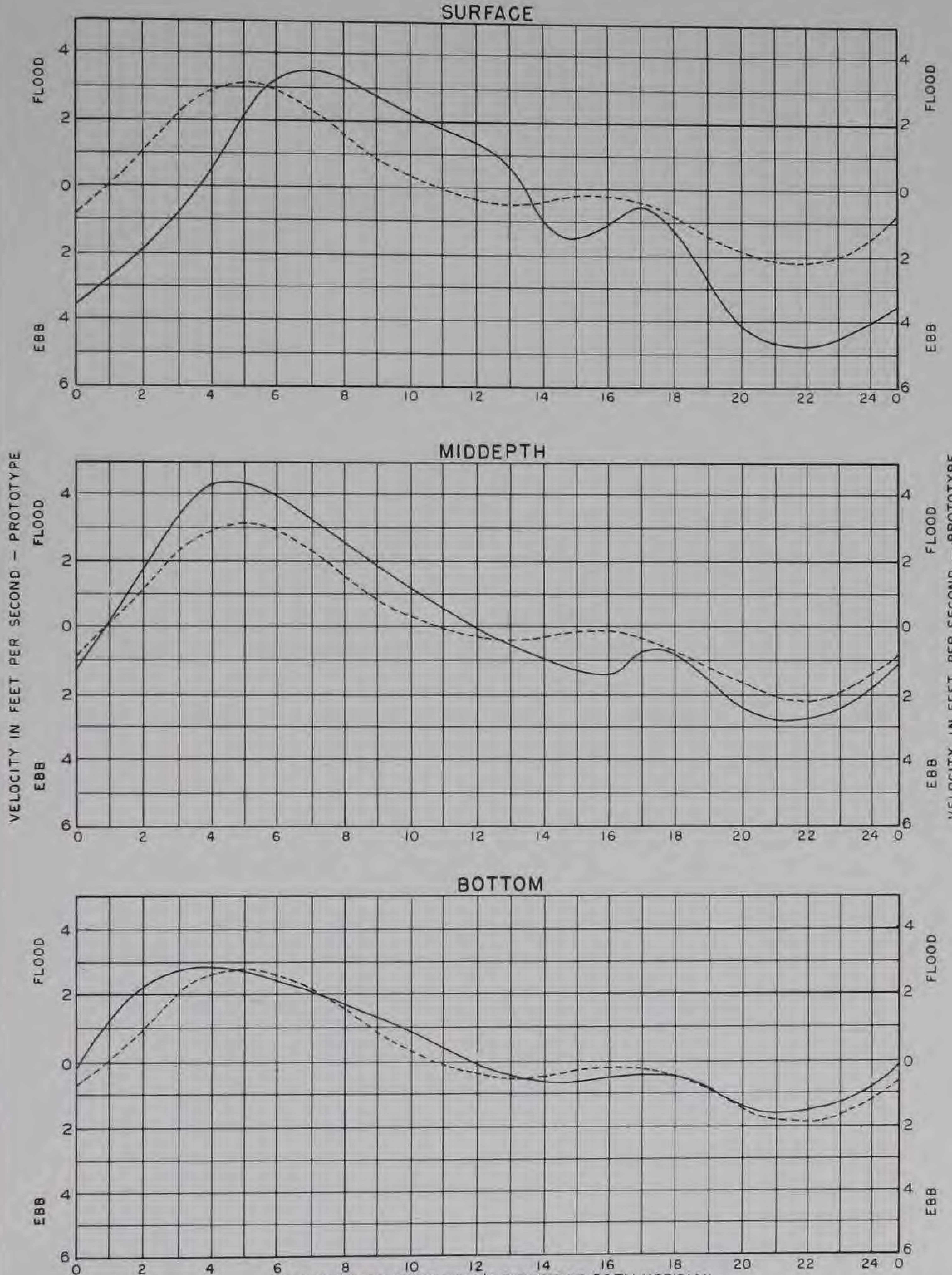
VERIFICATION OF VELOCITY OBSERVATIONS

STATION E-1



VERIFICATION OF VELOCITY OBSERVATIONS

STATION E-2



MODEL TEST DATA

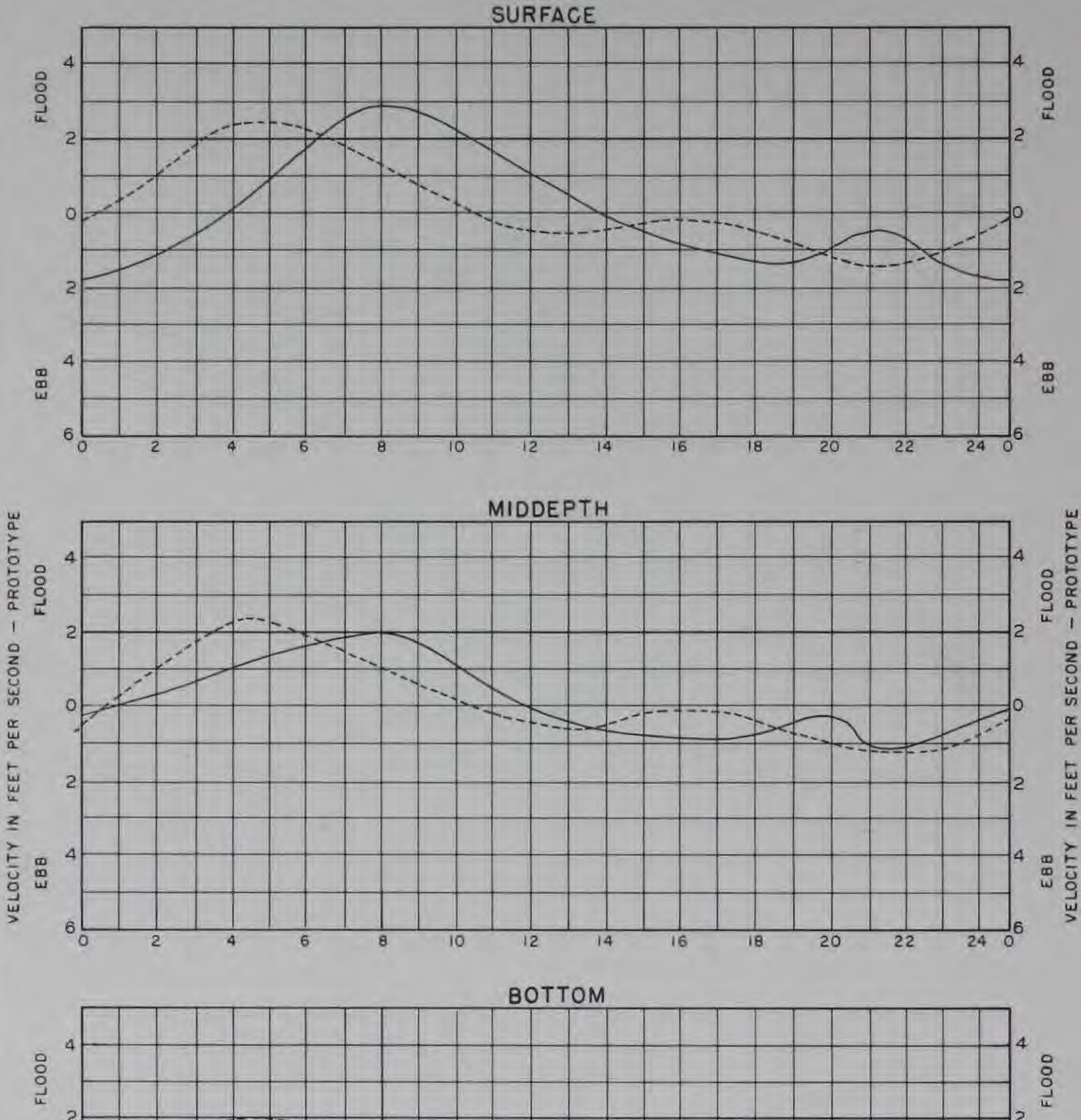
TIDE . . . . 28 FEB - 1 MARCH 1961
FRESH-WATER DISCHARGE . 0 CFS
SOURCE SALINITY. . . . . . . 32.5 PPT

LEGEND

——— PROTOTYPE
— — MODEL

VERIFICATION OF VELOCITY OBSERVATIONS

STATION E-3



MODEL TEST DATA

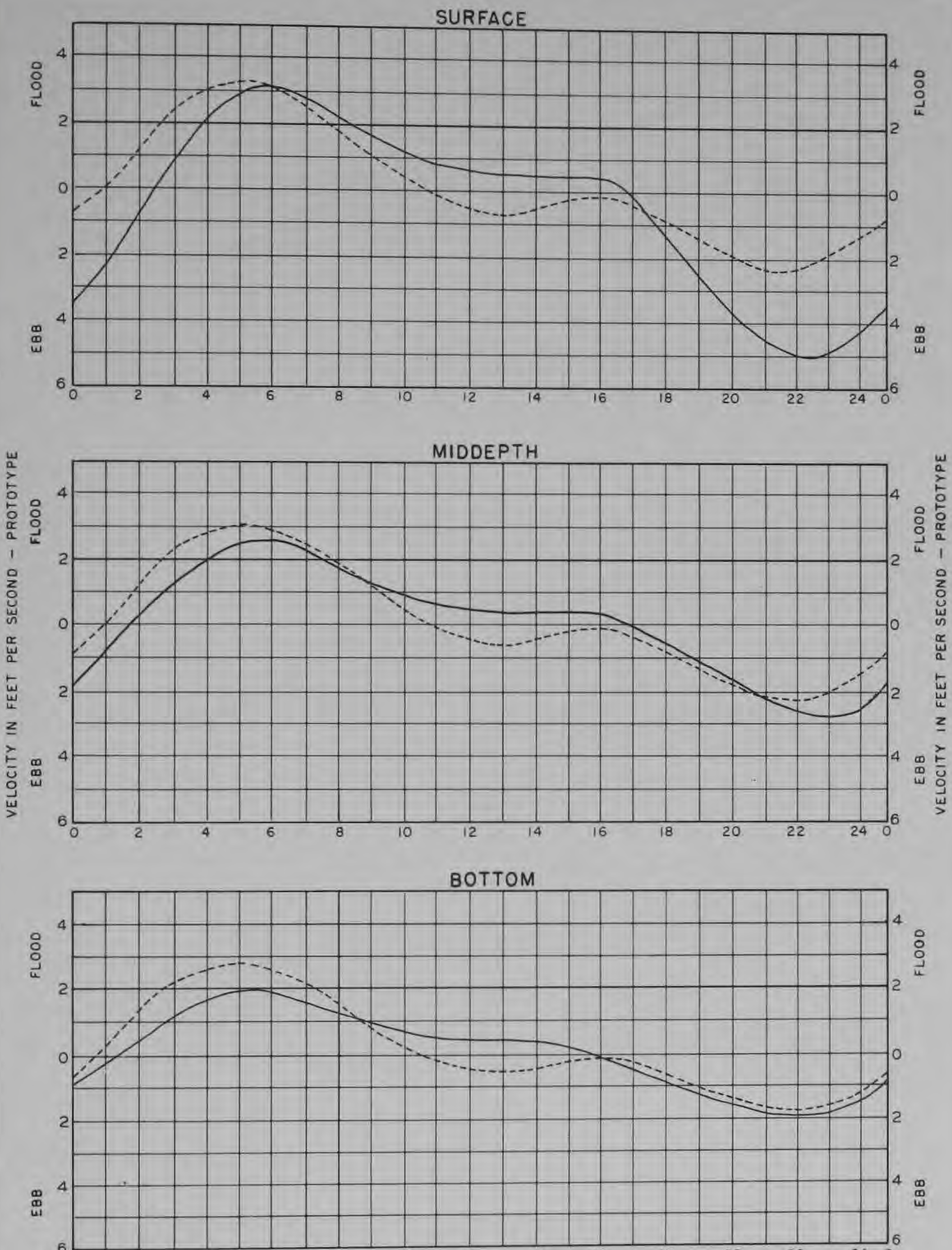
TIDE . . . . 28 FEB – 1 MARCH 1961
FRESH-WATER DISCHARGE . . . 0 CFS
SOURCE SALINITY. . . . . 32.5 PPT

LEGEND

——— PROTOTYPE
— — MODEL

VERIFICATION OF VELOCITY OBSERVATIONS

STATION E-4



MODEL TEST DATA

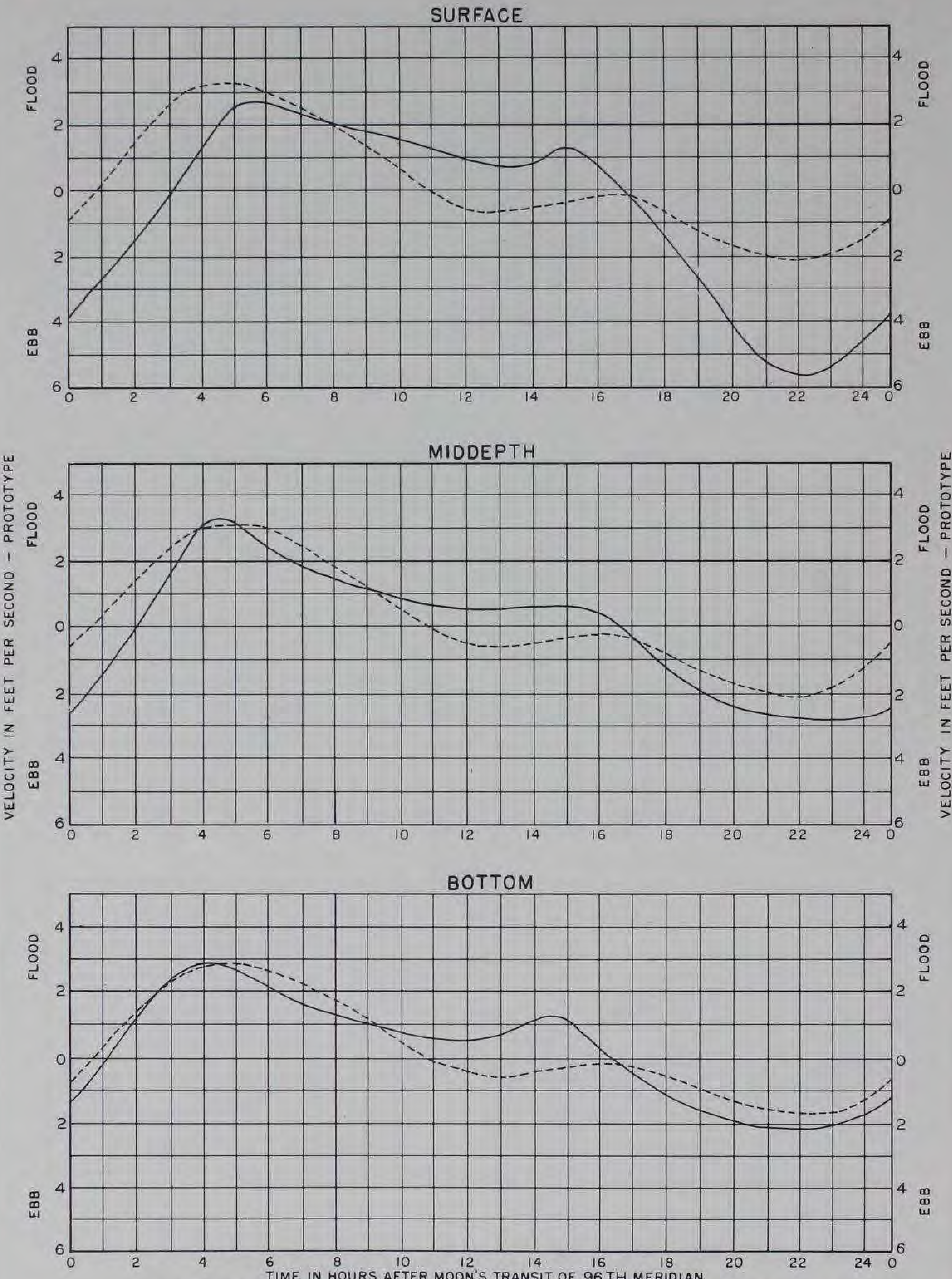
TIDE . . . . 28 FEB - 1 MARCH 1961
FRESH-WATER DISCHARGE . . 0 CFS
SOURCE SALINITY. . . . . . 32.5 PPT

LEGEND

——— PROTOTYPE
— — MODEL

VERIFICATION OF VELOCITY OBSERVATIONS

STATION F-1



MODEL TEST DATA

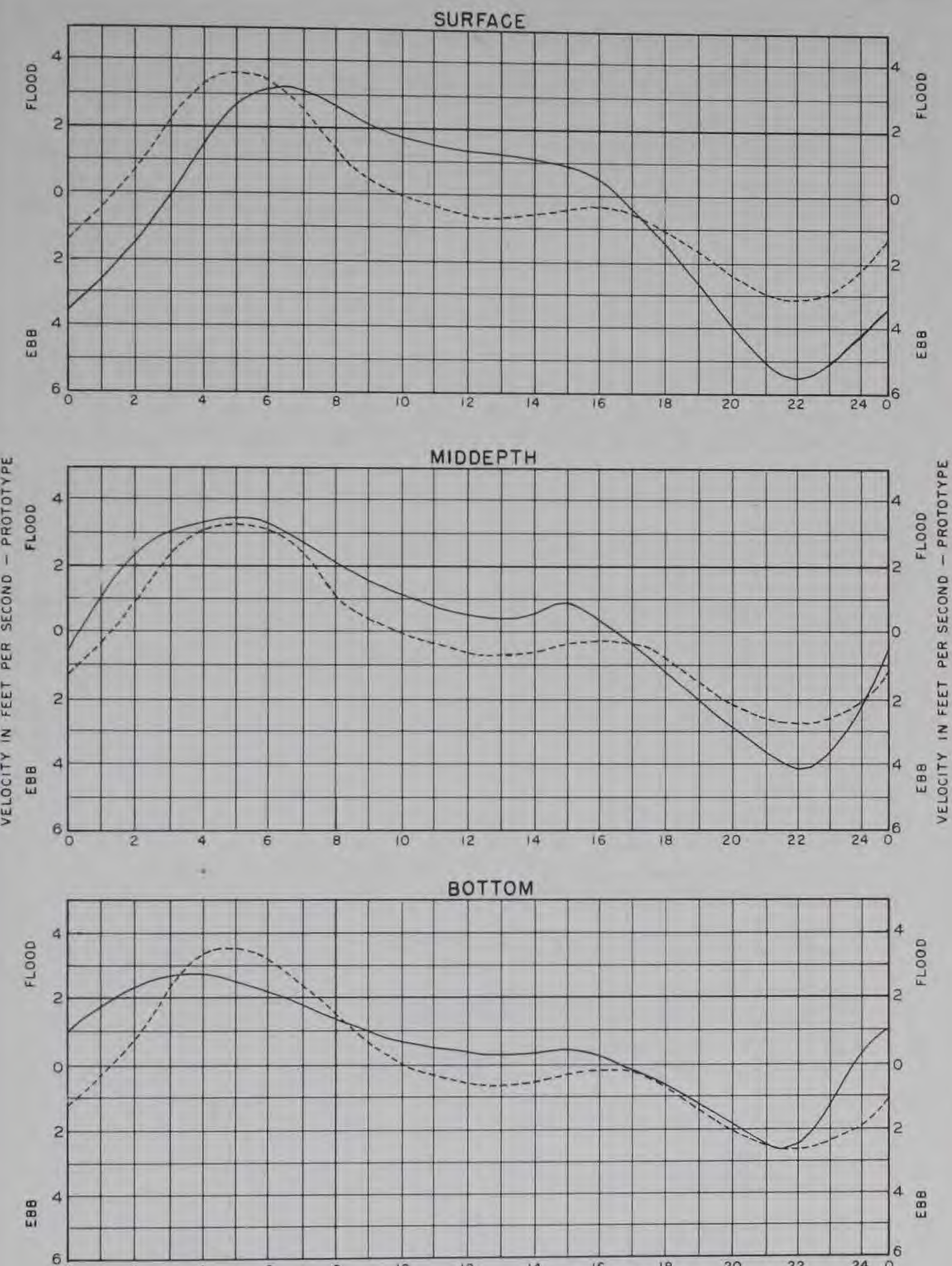
TIDE . . . . 28 FEB - 1 MARCH 1961
FRESH-WATER DISCHARGE . . 0 CFS
SOURCE SALINITY . . . . 32.5 PPT

LEGEND

——— PROTOTYPE
— — MODEL

VERIFICATION OF VELOCITY OBSERVATIONS

STATION F-2



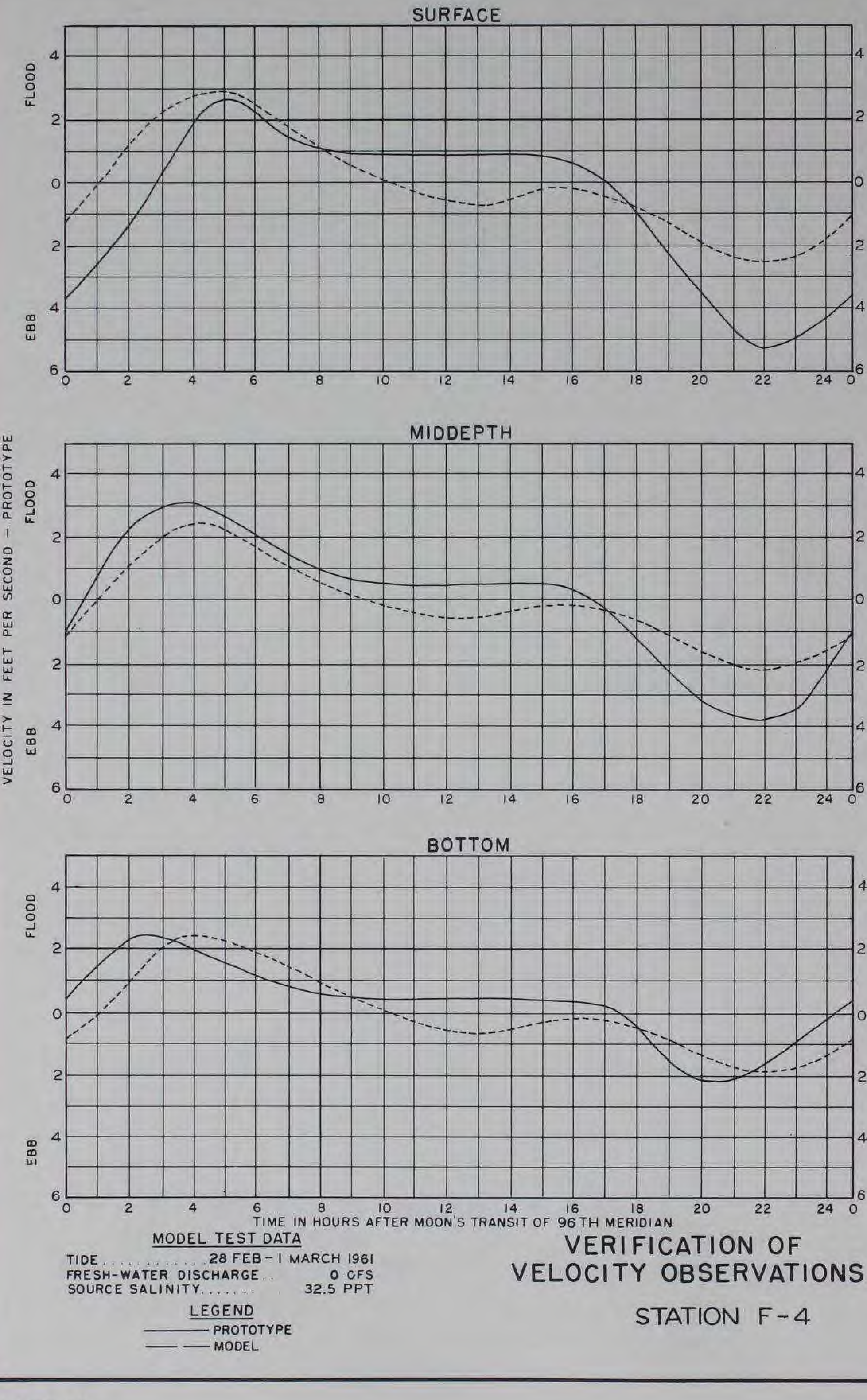
MODEL TEST DATA

TIDE . . . . 28 FEB – 1 MARCH 1961
FRESH-WATER DISCHARGE . . 0 CFS
SOURCE SALINITY . . . . . . 32.5 PPT

LEGEND
——— PROTOTYPE
— — MODEL

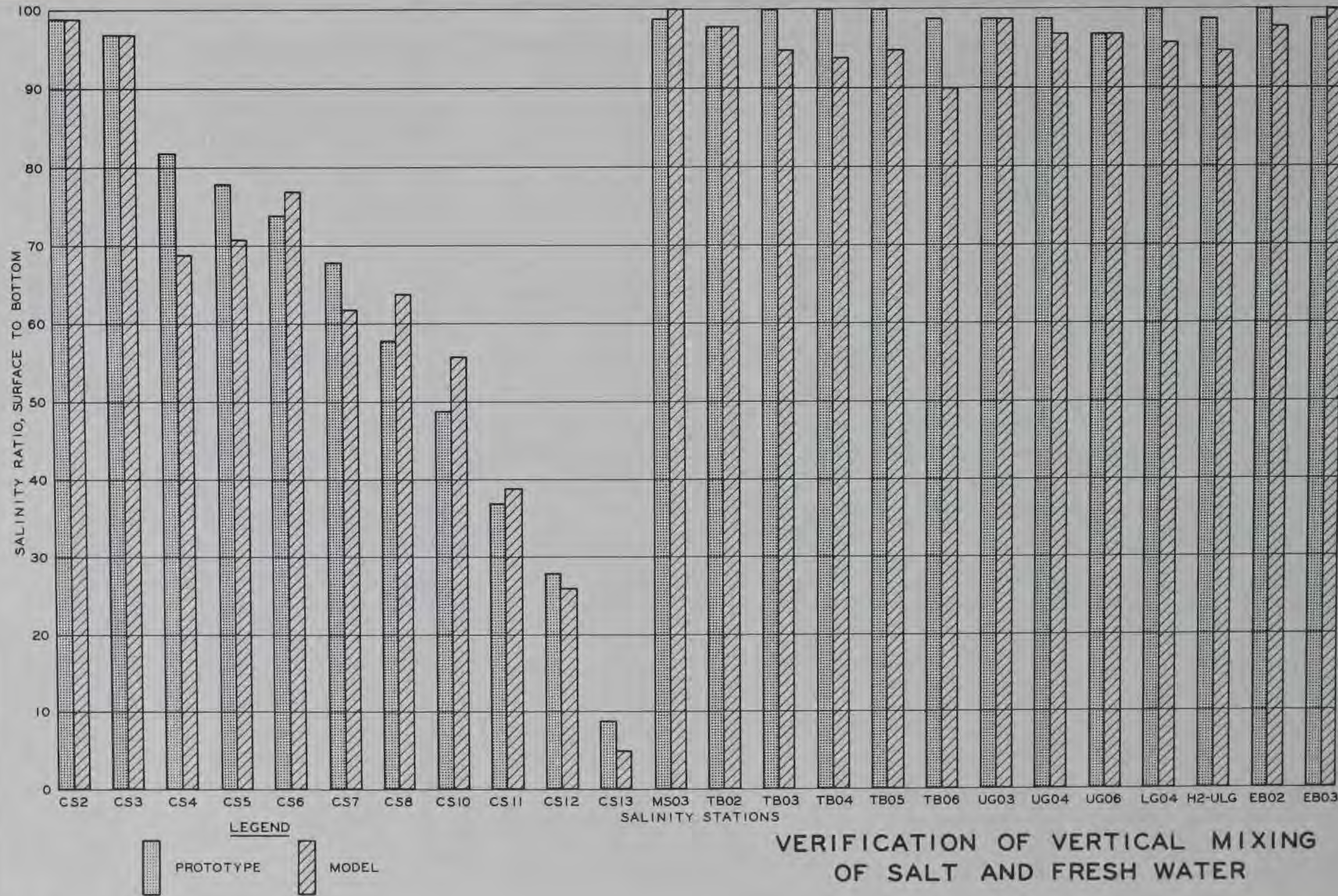
VERIFICATION OF VELOCITY OBSERVATIONS

STATION F-3

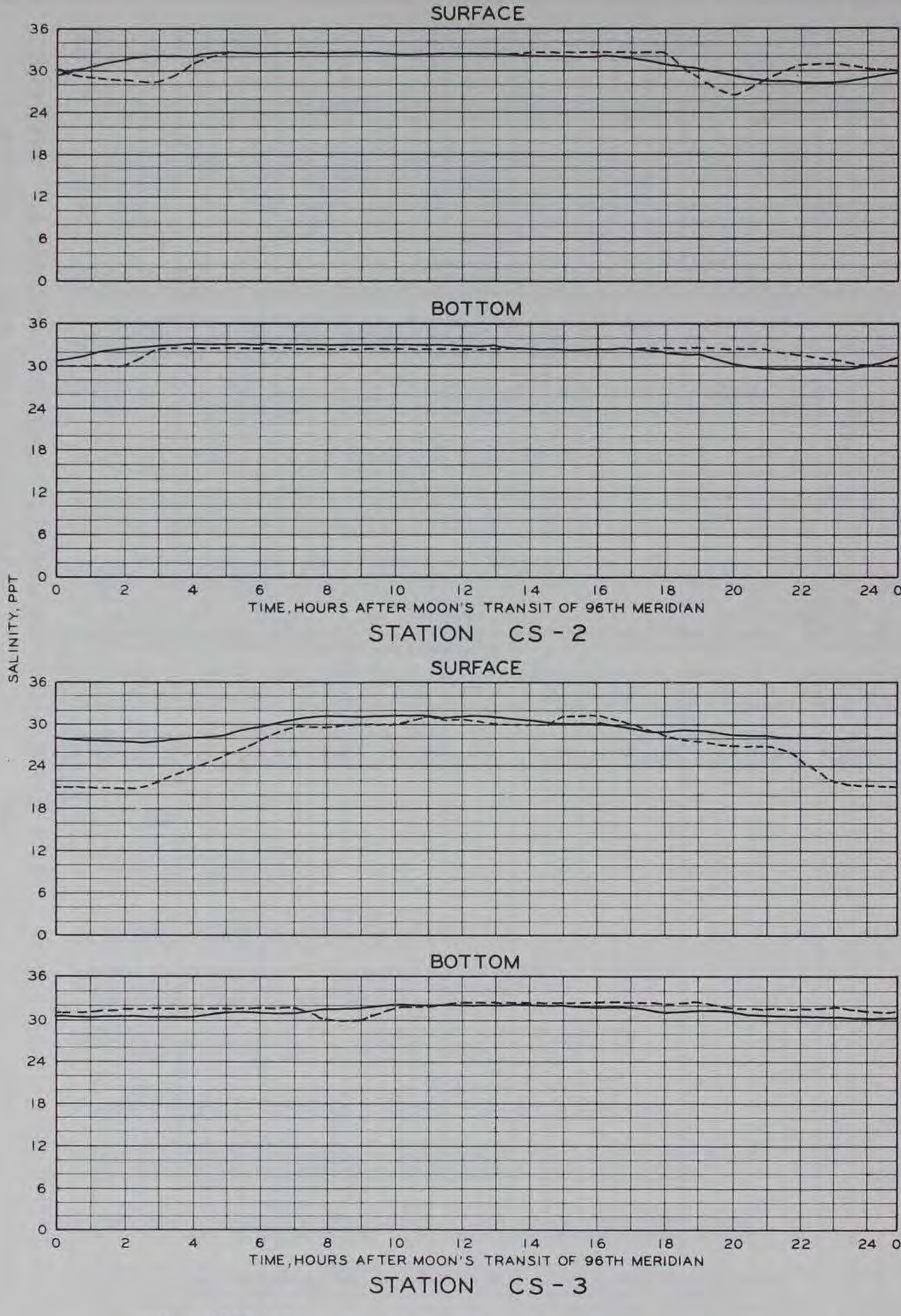


VERIFICATION OF VELOCITY OBSERVATIONS

STATION F-4



VERIFICATION OF VERTICAL MIXING
OF SALT AND FRESH WATER



MODEL TEST DATA

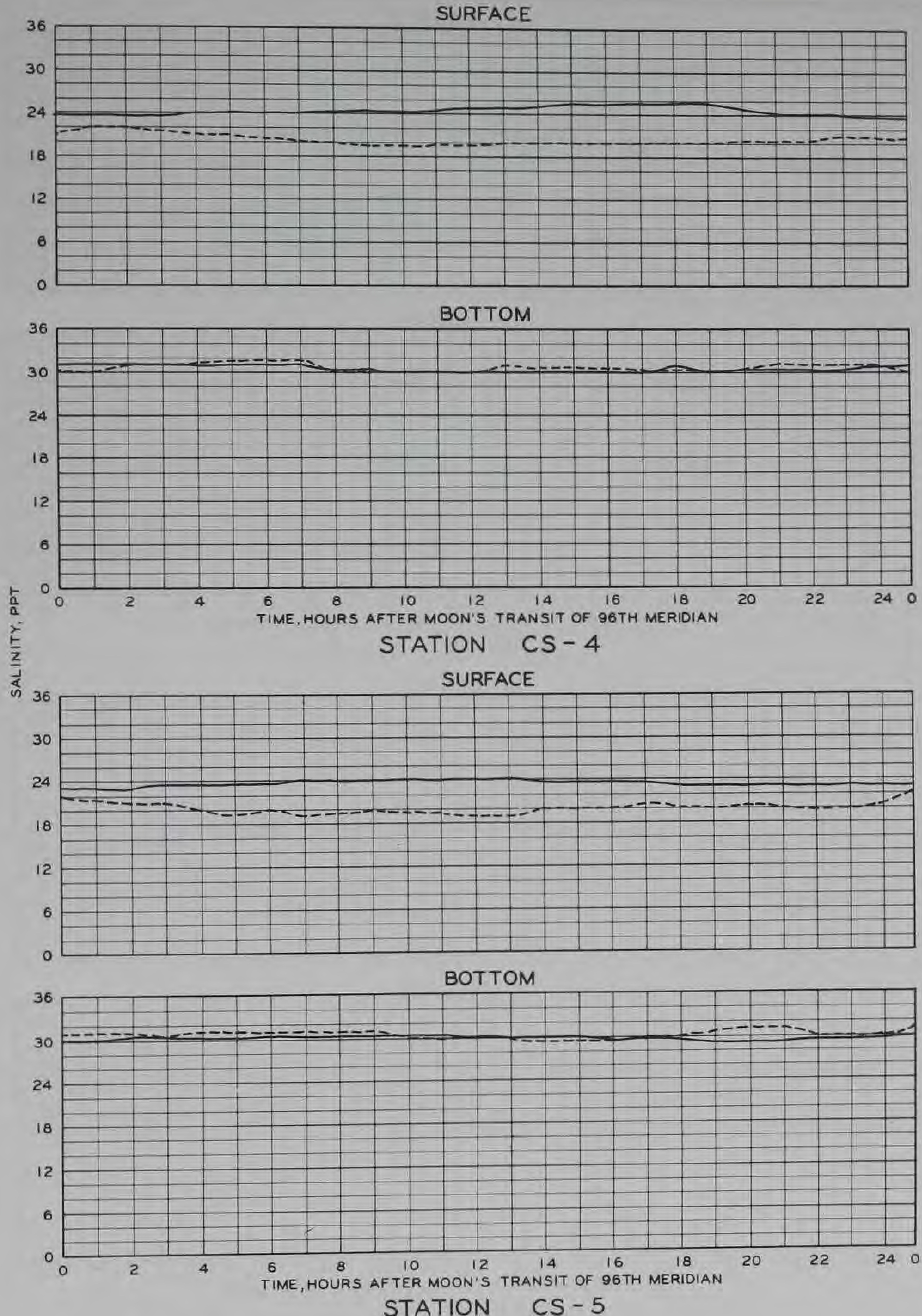
TIDE . . . . 26-28 FEB. 1964
FRESH-WATER DISCHARGE . . . . . 8368 CFS
SOURCE SALINITY . . . . 32.5 PPT

LEGEND

——— PROTOTYPE
– – – – – MODEL

VERIFICATION OF SALINITY OBSERVATIONS

STATIONS CS - 2 AND CS - 3



MODEL TEST DATA

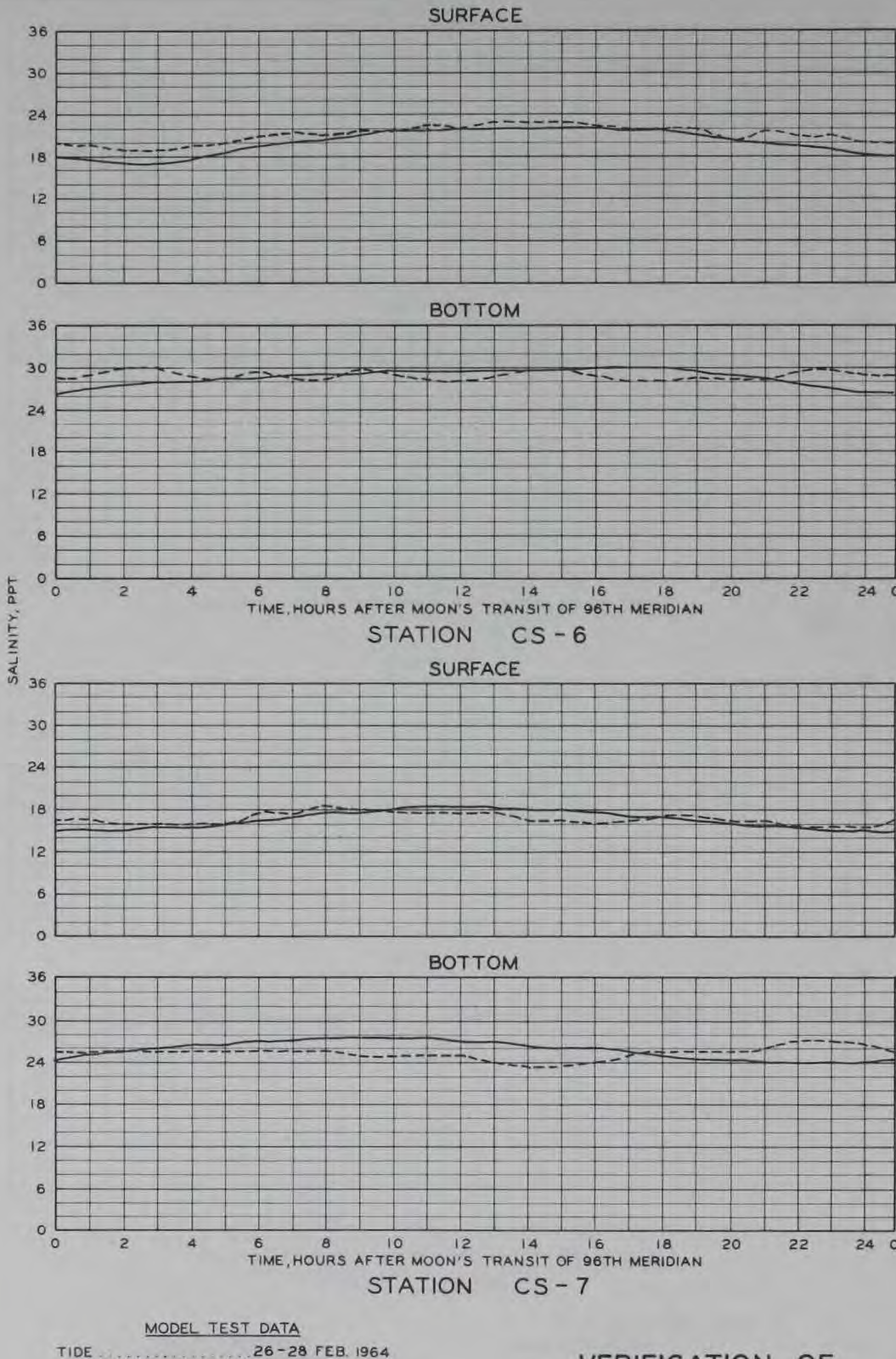
TIDE . . . . 26 - 28 FEB. 1964
FRESH-WATER DISCHARGE . . . . . 8368 CFS
SOURCE SALINITY . . . . 32.5 PPT

LEGEND

——— PROTOTYPE
- - - - - - MODEL

VERIFICATION OF SALINITY OBSERVATIONS

STATIONS CS - 4 AND CS - 5



MODEL TEST DATA

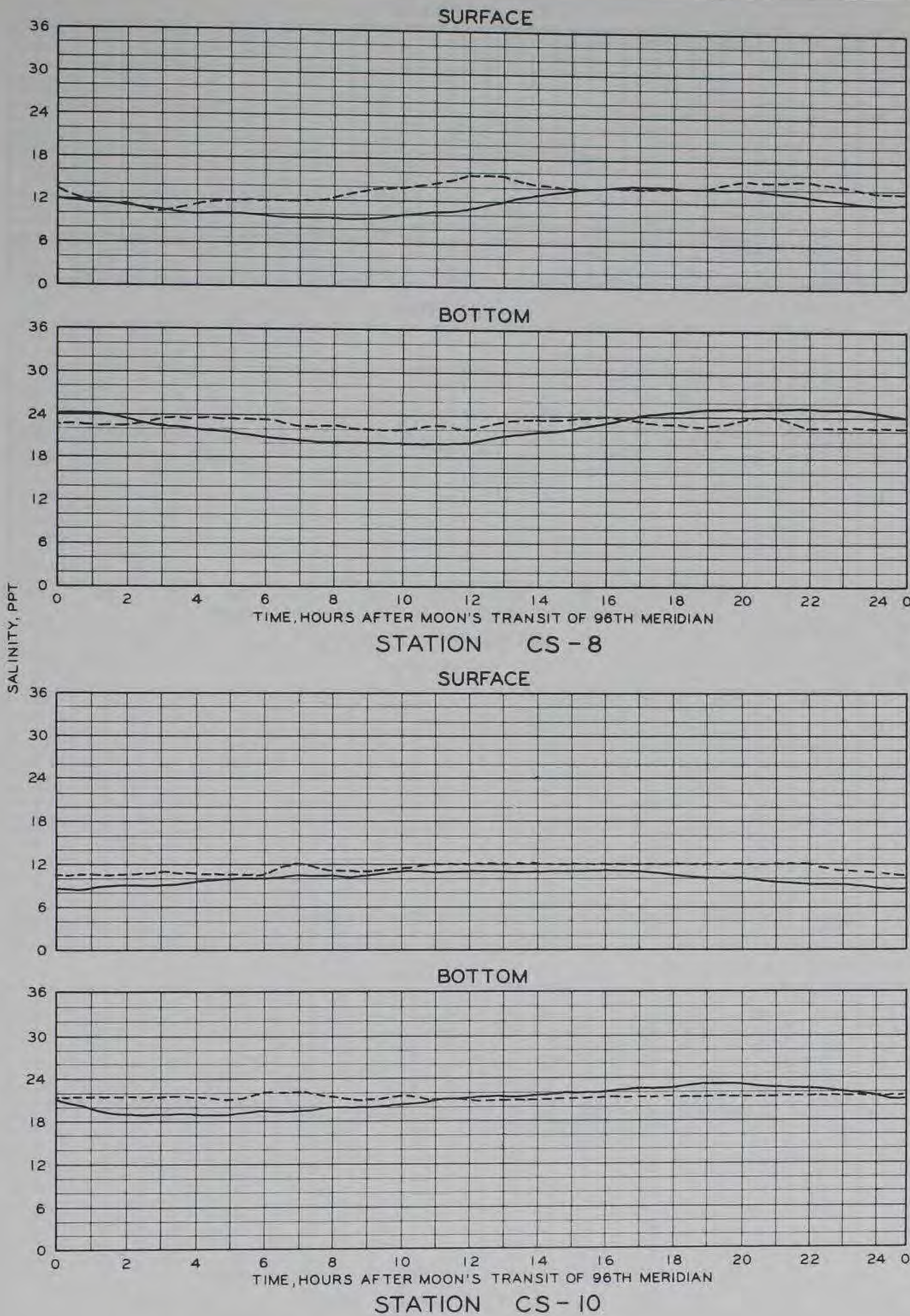
TIDE .... 26-28 FEB. 1964
FRESH-WATER DISCHARGE ...... 8368 CFS
SOURCE SALINITY .... 32.5 PPT

LEGEND

——— PROTOTYPE
------ MODEL

VERIFICATION OF SALINITY OBSERVATIONS

STATIONS CS-6 AND CS-7



MODEL TEST DATA

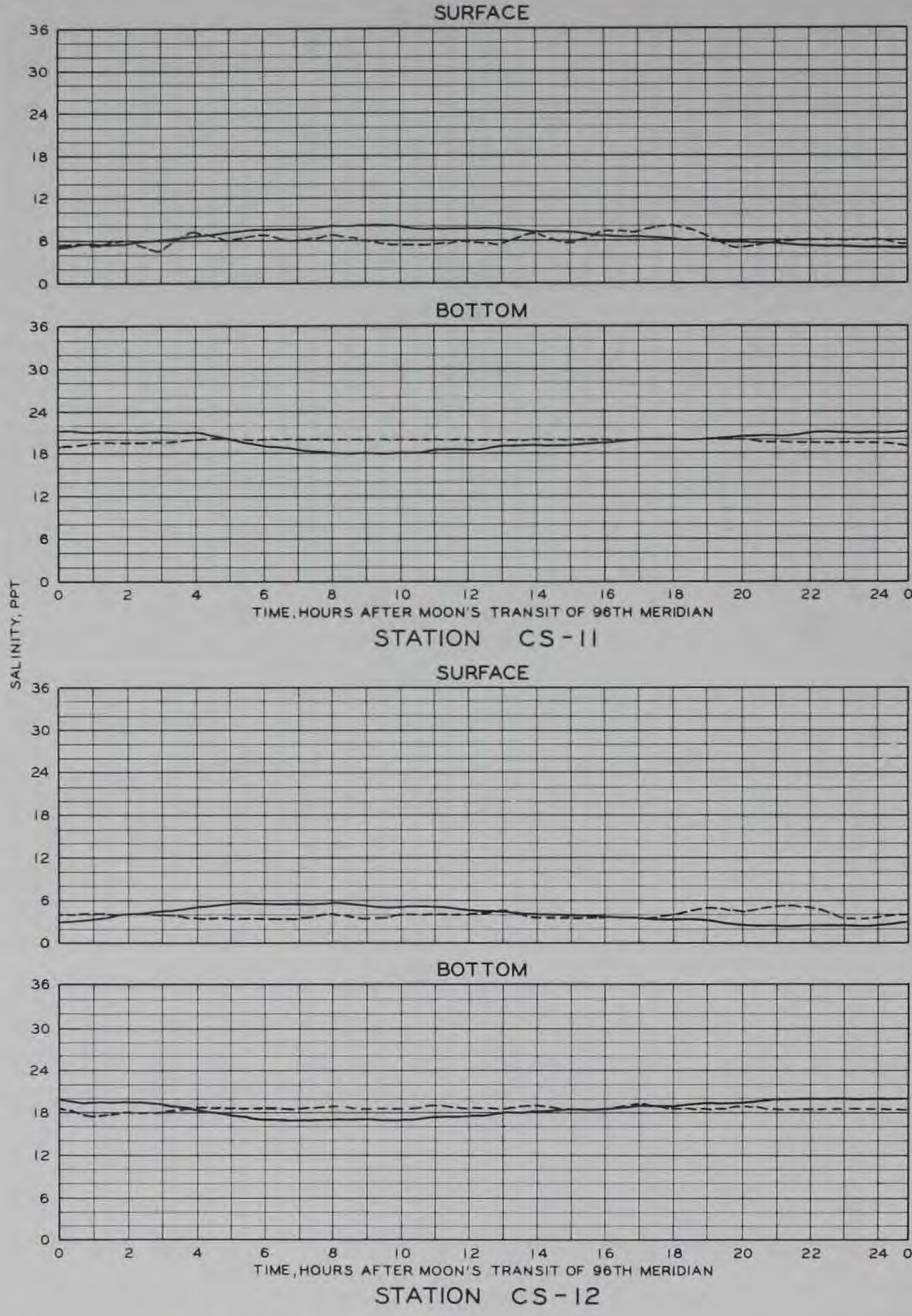
TIDE .... 26-28 FEB. 1964
FRESH-WATER DISCHARGE ...... 8368 CFS
SOURCE SALINITY .... 32.5 PPT

LEGEND

——— PROTOTYPE
- - - - - - MODEL

VERIFICATION OF SALINITY OBSERVATIONS

STATIONS CS-8 AND CS-10



MODEL TEST DATA

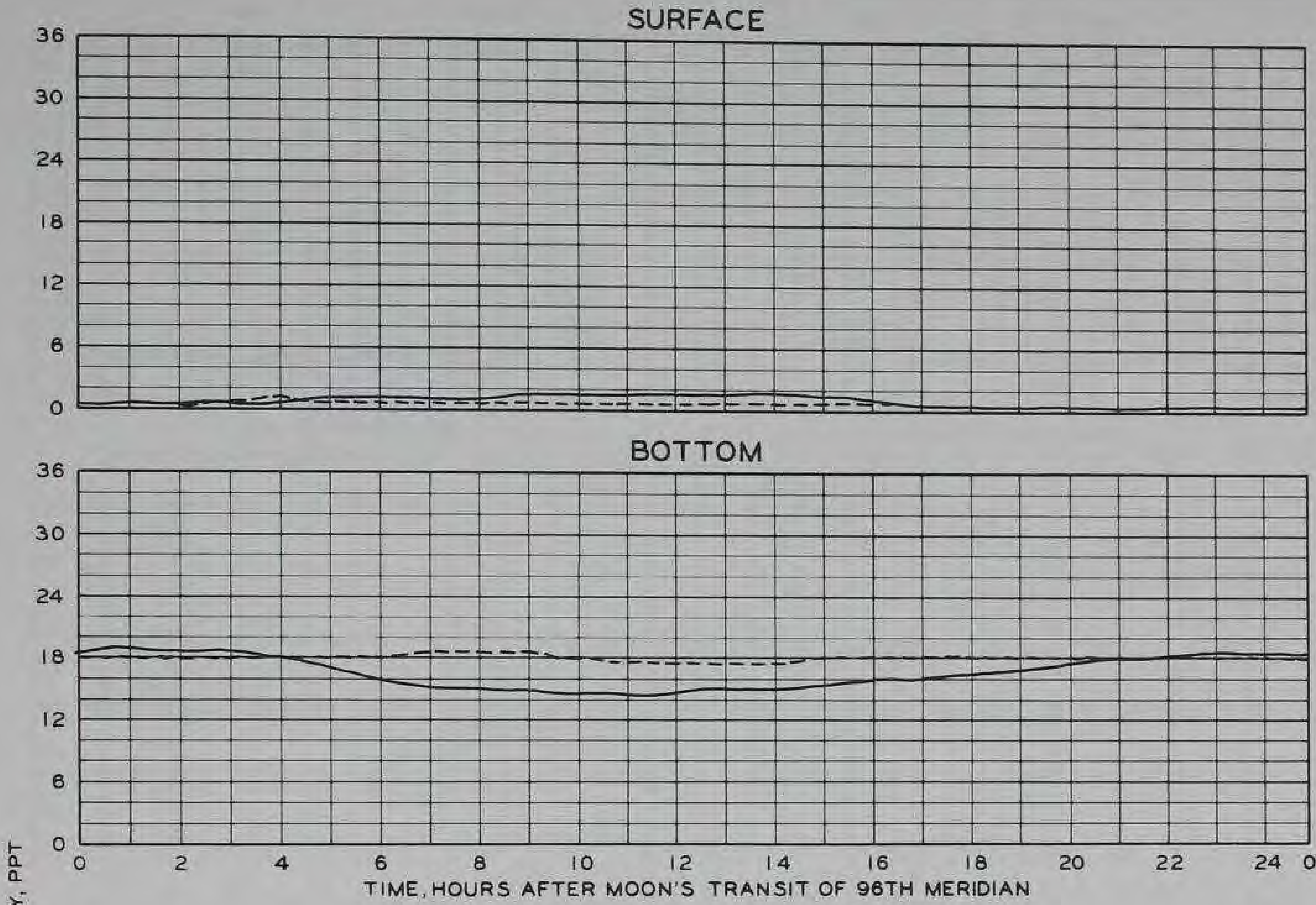
TIDE . . . . 26-28 FEB. 1964
FRESH-WATER DISCHARGE . . . . . 8368 CFS
SOURCE SALINITY . . . . 32.5 PPT

LEGEND

——— PROTOTYPE
– – – – – – MODEL

VERIFICATION OF SALINITY OBSERVATIONS

STATIONS CS-11 AND CS-12



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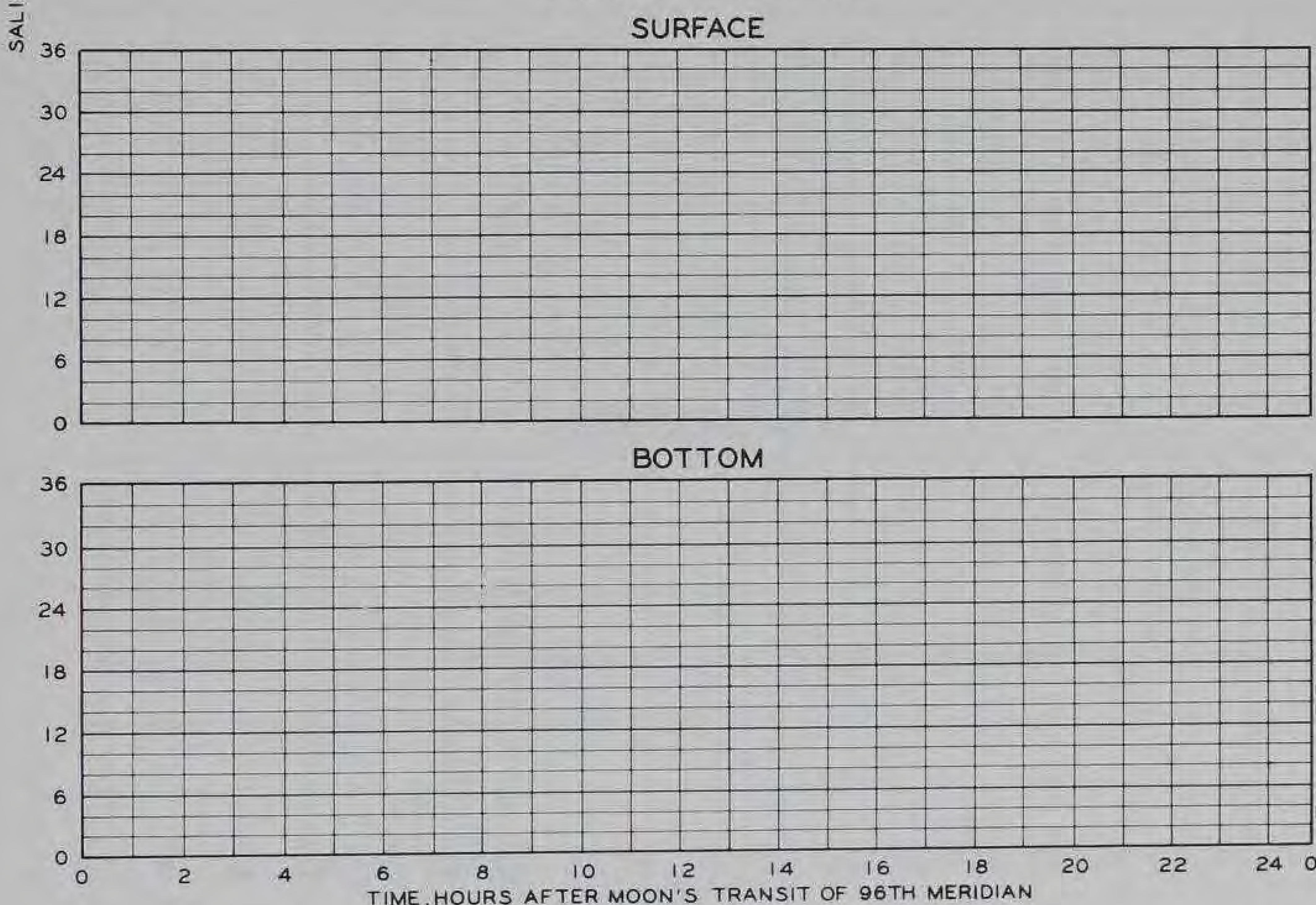


STATION

MODEL TEST DATA

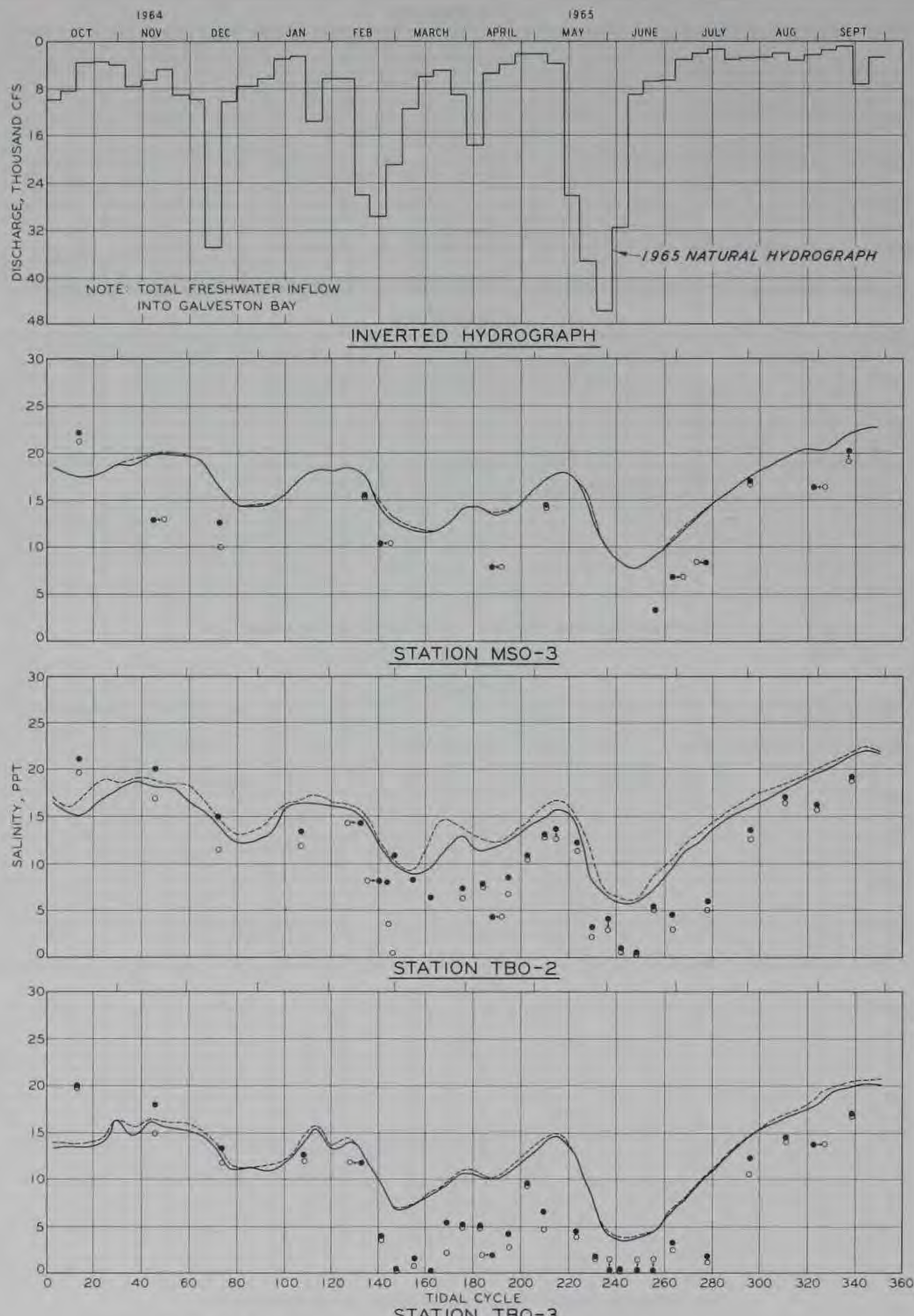
TIDE . . . . 26 - 28 FEB. 1964
FRESH-WATER DISCHARGE . . . . . . 8368 CFS
SOURCE SALINITY . . . . 32.5 PPT

LEGEND

——— PROTOTYPE
------ MODEL

VERIFICATION OF SALINITY OBSERVATIONS

STATION CS-13



MODEL TEST DATA

TIDE . . . MEAN (2.10' RANGE)
FRESHWATER DISCHARGE . . . 1965 NATURAL HYDROGRAPH
SOURCE SALINITY . . . 32.5 PPT

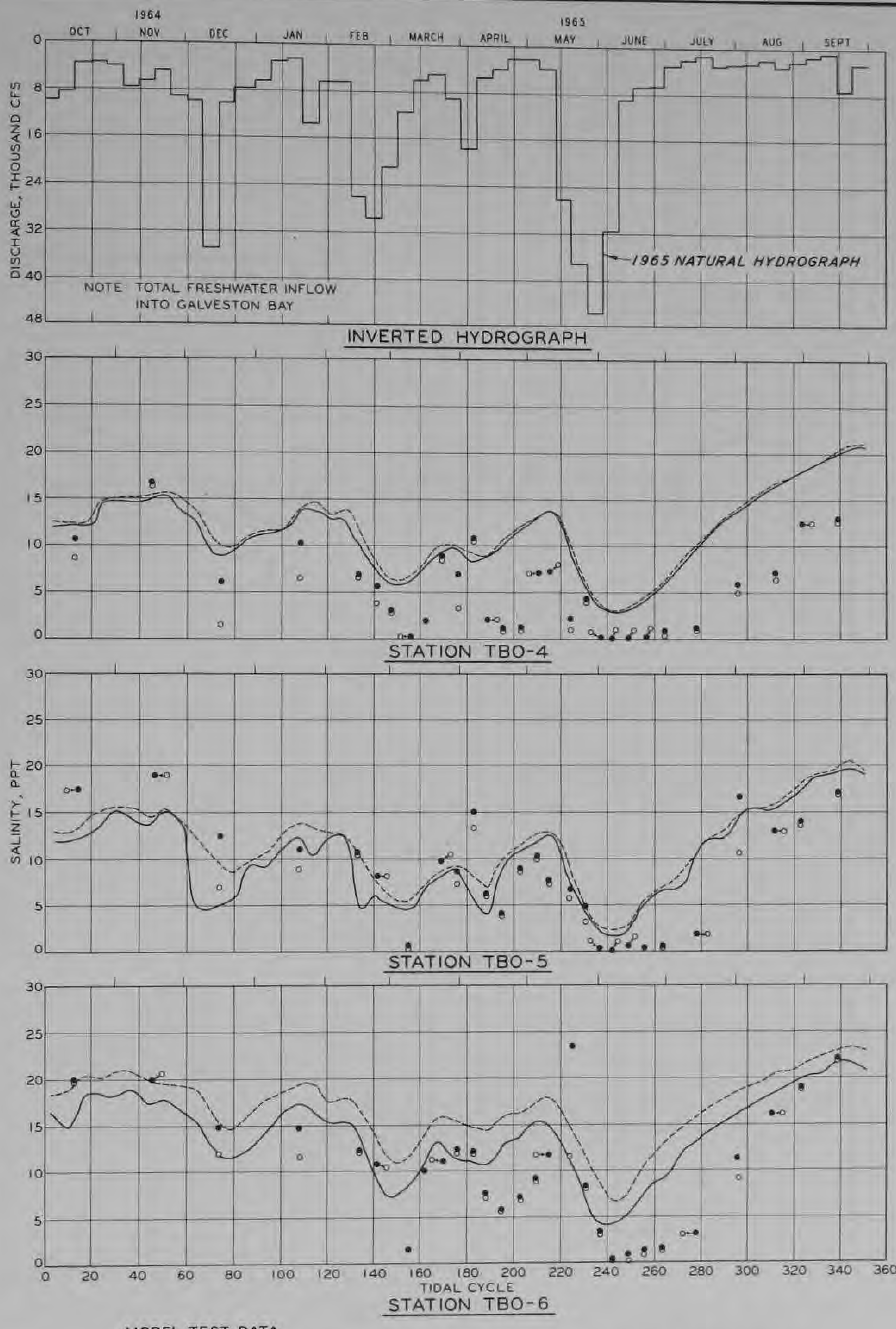
LEGEND

—— SURFACE, ------ BOTTOM } MODEL
○ SURFACE, ● BOTTOM } PROTOTYPE

LONG-TERM SALINITY VERIFICATION

HIGH-WATER SLACK SURFACE AND BOTTOM DEPTHS

STATIONS MSO-3, TBO-2, AND TBO-3



MODEL TEST DATA

TIDE .... MEAN (2.10' RANGE)
FRESHWATER DISCHARGE ... 1965 NATURAL HYDROGRAPH
SOURCE SALINITY .... 32.5 PPT

LEGEND

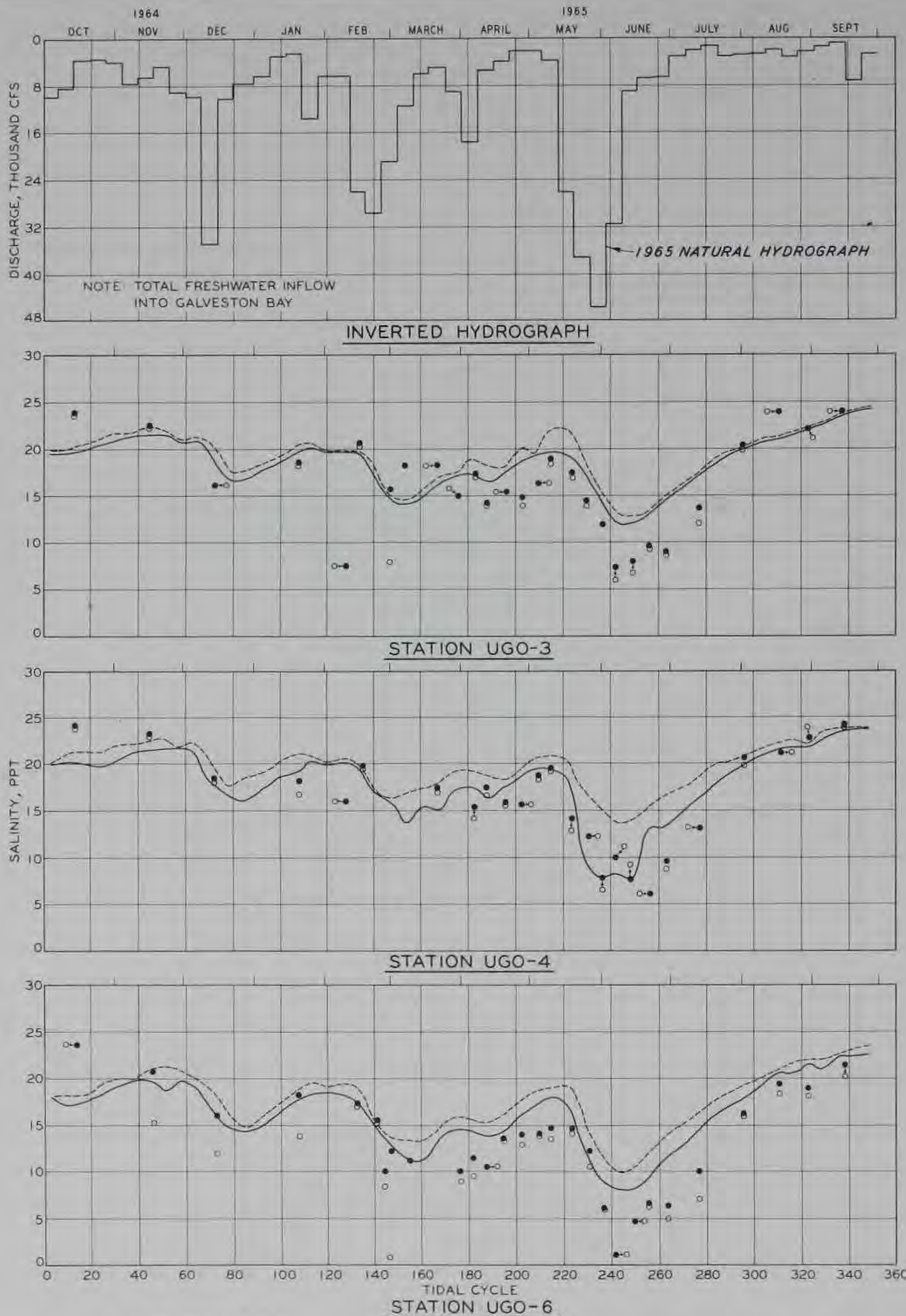
—— SURFACE } MODEL
------ BOTTOM }

○ SURFACE } PROTOTYPE
● BOTTOM }

LONG-TERM SALINITY VERIFICATION

HIGH-WATER SLACK SURFACE AND BOTTOM DEPTHS

STATIONS TBO-4, TBO-5, AND TBO-6



MODEL TEST DATA

TIDE	MEAN (2.10' RANGE)
FRESHWATER DISCHARGE	1965 NATURAL HYDROGRAPH
SOURCE SALINITY	32.5 PPT

LEGEND

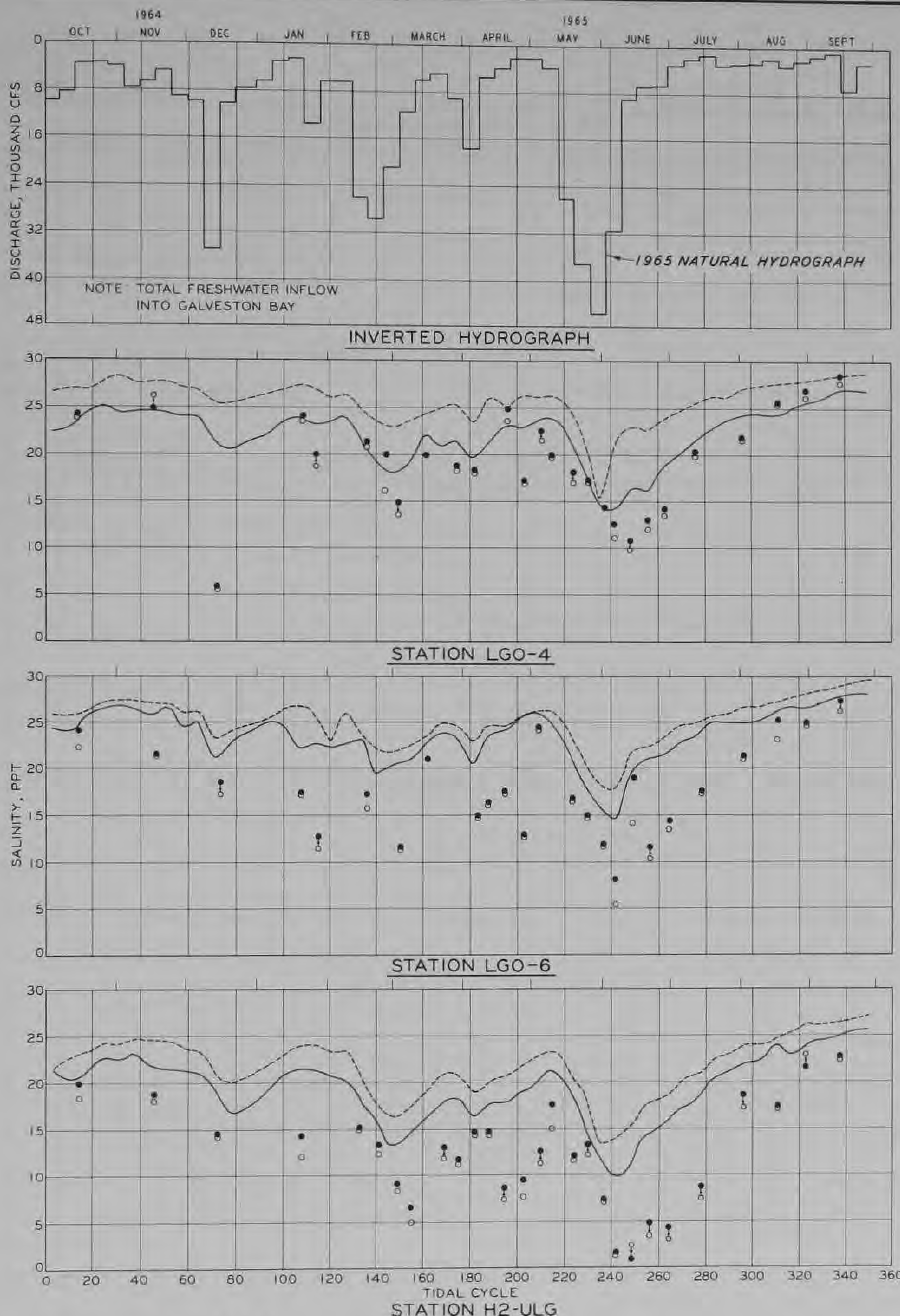
——— SURFACE } MODEL
- - - - BOTTOM }

○ SURFACE } PROTOTYPE
● BOTTOM }

LONG-TERM SALINITY VERIFICATION

HIGH-WATER SLACK SURFACE AND BOTTOM DEPTHS

STATIONS UGO-3, UGO-4, AND UGO-6



MODEL TEST DATA

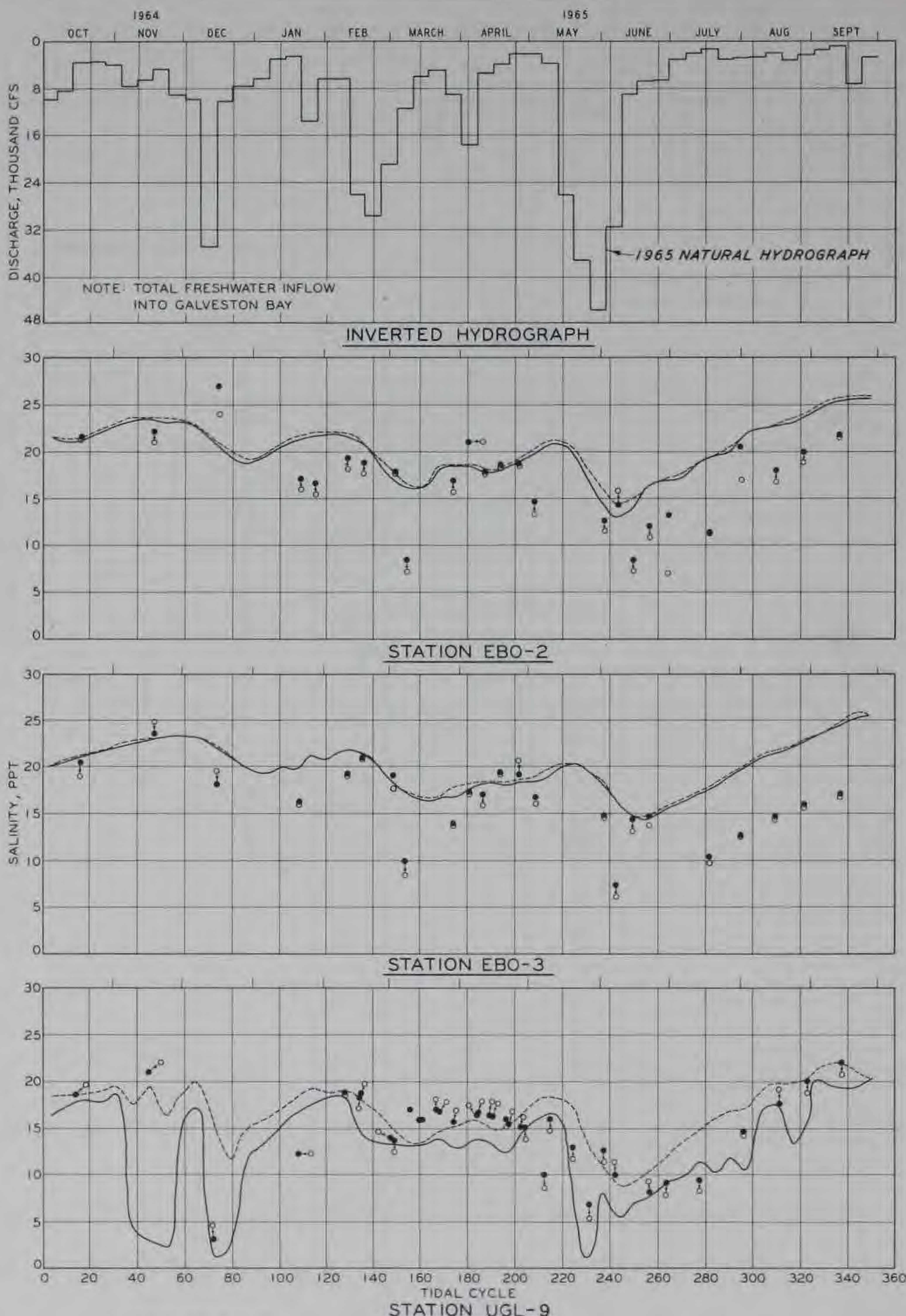
TIDE	MEAN (2.10' RANGE)
FRESHWATER DISCHARGE	1965 NATURAL HYDROGRAPH
SOURCE SALINITY	32.5 PPT

LEGEND

- ——— SURFACE, - - - - BOTTOM: MODEL
- ○ SURFACE, ● BOTTOM: PROTOTYPE

LONG-TERM SALINITY VERIFICATION

HIGH-WATER SLACK
SURFACE AND BOTTOM DEPTHS
STATIONS LGO-4, LGO-6, AND H2-ULG



MODEL TEST DATA

TIDE . . . MEAN (2.10' RANGE)
FRESHWATER DISCHARGE . . 1965 NATURAL HYDROGRAPH
SOURCE SALINITY . . . 32.5 PPT

LEGEND

—— SURFACE } MODEL
- - - - BOTTOM }

○ SURFACE } PROTOTYPE
● BOTTOM }

LONG-TERM SALINITY VERIFICATION

HIGH-WATER SLACK SURFACE AND BOTTOM DEPTHS

STATIONS EBO-2, EBO-3, AND UGL-9

Unclassified
Security Classification

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4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Report 1 of a series

5. AUTHOR(S) *(First name, middle initial, last name)*
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Robert A. Boland, Jr.
Allen J. Banchetti

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	U. S. Army Engineer District Galveston, Texas

13. ABSTRACT

The Houston Ship Channel model, a fixed-bed model constructed to linear scale ratios of 1:600 horizontally and 1:60 vertically, reproduced a portion of the Gulf of Mexico adjacent to the Galveston Harbor Entrance, the Galveston Bay complex, including Trinity Bay in its entirety, East Bay, a portion of West Bay, the Houston Ship Channel to its upstream boundary in the City of Houston, Texas, and Buffalo Bayou from the Houston Ship Channel turning basin to the confluence of White Oak Bayou. The model was equipped with necessary appurtenances for the accurate reproduction and measurement of tides, tidal currents, salinity intrusion, freshwater inflow, density effects, shoaling, and other important prototype phenomena. The purpose of the model study was to determine if the present cost of maintenance dredging can be reduced by proposed plans involving channel realignments, partial or complete diking of connecting bays, sediment traps, dikes in Galveston Bay, local contractions, enlargements, and other remedial measures. Model verification tests were conducted to make certain that the model hydraulic and salinity regimens were in satisfactory agreement with those of the prototype. The agreements attained between similar model and prototype values were considered satisfactory.

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Unclassified
Security Classification

Unclassified

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Galveston Bay						
Houston Ship Channel						
Hydraulic models						
Hydraulic regimen						
Salinity						

Unclassified

Security Classification