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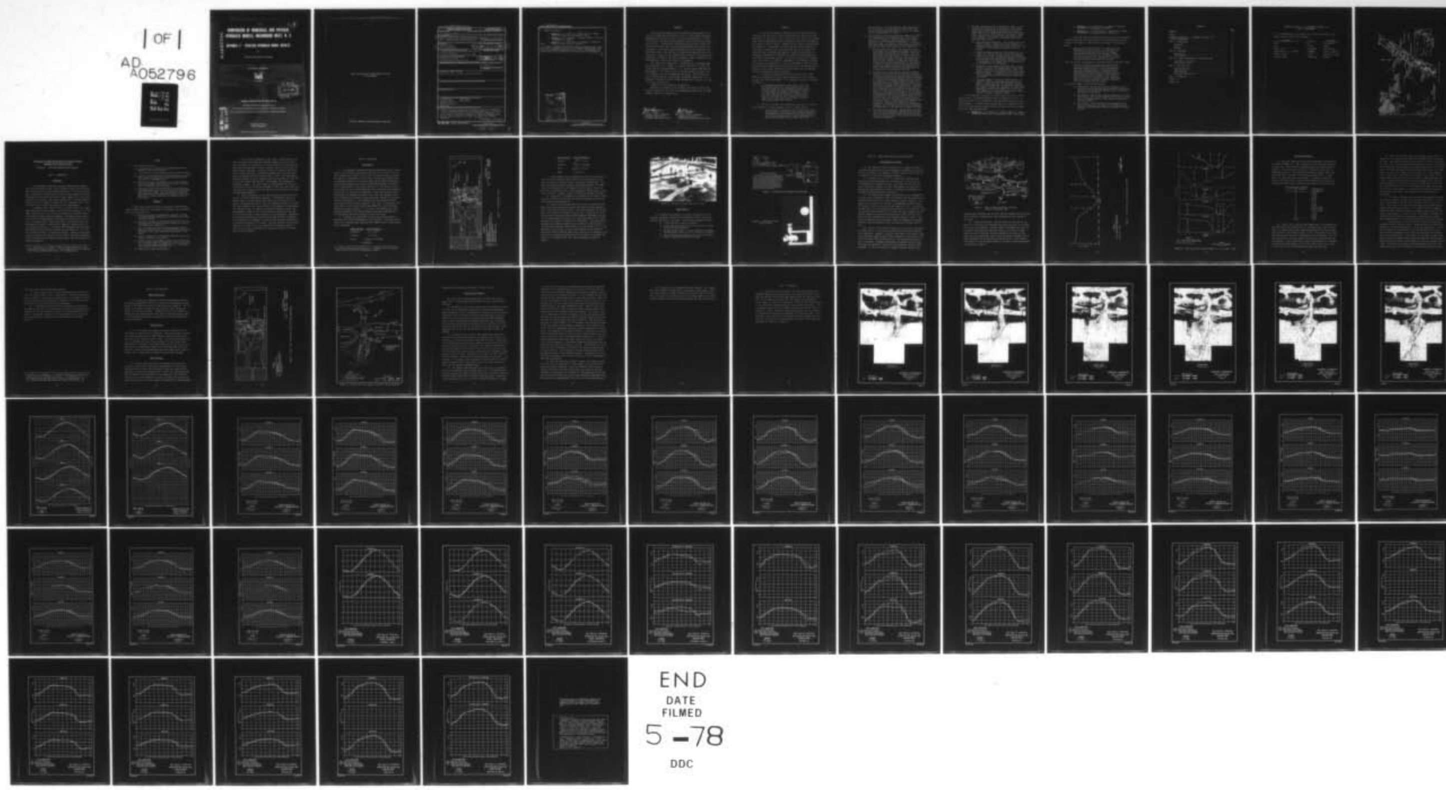

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COMPARISON OF NUMERICAL AND PHYSICAL HYDRAULIC MODELS, MASONBORO INLET, N. C.

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APPENDIX 1: FIXED-BED HYDRAULIC MODEL RESULTS

by

Richard A. Sager, William C. Seabergh

GITI REPORT 6-APPENDIX 1

June 1977

GENERAL INVESTIGATION OF TIDAL INLETS

A Program of Research Conducted Jointly by

U. S. Army Coastal Engineering Research Center, Fort Belvoir, Virginia

U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

Department of the Army
Corps of Engineers

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This appendix discusses the verification, base tests, and predictive test of a fixed-bed hydraulic model of Masonboro Inlet, N. C., as part of the evaluation of the state-of-the-art inlet modeling techniques. It presents the data necessary for a comparison of results of the physical and numerical models discussed in the basic report and in the following appendixes:

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20. ABSTRACT (Continued).

a. Appendix 2. F. D. Masch, R. J. Brandes, and J. U. Reagan, "Numerical Simulation of Hydrodynamics (WRE)."

b. Appendix 3. R. M. Chen and L. A. Hembree, "Numerical Simulation of Hydrodynamics (TRACOR)."

c. Appendix 4. C. J. Huval and G. L. Wintergerst, "Simplified Numerical (Lumped Parameter) Simulation."

cont.

Further information concerning the physical fixed-bed model of which this report is a summary can be found in the reports "Physical Model Simulation of the Hydraulics of Masonboro Inlet, N. C." (in preparation), and "Supplementary Tests of Masonboro Inlet Fixed-Bed Model" (in preparation).

FOREWORD

This report was prepared by the Estuaries and Wave Dynamics Divisions of the Hydraulics Laboratory at the U. S. Army Engineer Waterways Experiment Station (WES) as part of the General Investigation of Tidal Inlets (GITI). The GITI research program is under the technical surveillance of the U. S. Army Coastal Engineering Research Center (CERC) and is conducted by CERC, WES, and other Government agencies and private organizations. This report contains detailed results of a physical model developed as part of an evaluation of physical and numerical models of a tidal inlet. Details of the evaluation are contained in the basic report "Comparison of Numerical and Physical Hydraulic Models, Masonboro Inlet, North Carolina" to which this report is an appendix.

This report was prepared by R. A. Sager and W. C. Seabergh, under the supervision of R. A. Sager, E. C. McNair, and CPT F. C. Perry, CE (former WES GITI Program Managers), C. L. Vincent (present WES GITI Program Manager), R. W. Whalin, Chief of the Wave Dynamics Division, and H. B. Simmons, Chief of the Hydraulics Laboratory. CERC technical direction was provided by C. Mason under the general supervision of R. M. Sorensen. Technical Directors of CERC and WES were T. Saville, Jr., and F. R. Brown, respectively.

Comments on this publication are invited.

Approved for publication in accordance with Public Law 166, 79th Congress, approved 31 July 1945, as supplemented by Public Law 172, 88th Congress, approved 7 November 1963.

JOHN L. CANNON
Colonel, Corps of Engineers
Commander and Director
Waterways Experiment Station

JOHN H. COUSINS
Colonel, Corps of Engineers
Commander and Director
Coastal Engineering Research Center

PREFACE

1. The Corps of Engineers, through its Civil Works program, has sponsored, over the past 23 years, research into the behavior and characteristics of tidal inlets. The Corps' interest in tidal inlet research stems from its responsibilities for navigation, beach erosion prevention and control, and flood control. Tasked with the creation and maintenance of navigable U. S. waterways, the Corps routinely dredges millions of cubic yards of material each year from tidal inlets that connect the ocean with bays, estuaries, and lagoons. Design and construction of navigation improvements to existing tidal inlets are an important part of the work of many Corps offices. In some cases, design and construction of new inlets are required. Development of information concerning the hydraulic characteristics of inlets is important not only for navigation and inlet stability, but also because inlets, by allowing for the ingress of storm surges and egress of flood waters, play an important role in the flushing of bays and lagoons.

2. A research program, General Investigation of Tidal Inlets (GITI), was developed to provide quantitative data for use in design of inlets and inlet improvements. It is designed to meet the following objectives:

> To determine the effects of wave action, tidal flow, and related phenomena on inlet stability and on the hydraulic, geometric, and sedimentary characteristics of tidal inlets; to develop the knowledge necessary to design effective navigation improvements, new inlets, and sand transfer systems at existing tidal inlets; to evaluate the water transfer and flushing capability of tidal inlets; and to define the processes controlling inlet stability.

3. The GITI is divided into three major study areas: (a) inlet classification, (b) inlet hydraulics, and (c) inlet dynamics.

- a. The objectives of the inlet classification study are to classify inlets according to their geometry, hydraulics, and stability, and to determine the relationships that exist among the geometric and dynamic characteristics and the environmental factors that control these characteristics. The classification study keeps the general investigation closely related to real inlets and produces an important inlet data base useful in documenting the characteristics of inlets.

b. The objectives of the inlet hydraulics study are to define the tide-generated flow regime and water-level fluctuations in the vicinity of coastal inlets and to develop techniques for predicting these phenomena. The inlet hydraulics study is divided into three areas: idealized inlet model study, evaluation of state-of-the-art physical and numerical models, and prototype inlet hydraulics.

(1) The idealized inlet model. The objectives of this model study are to determine the effect of inlet configurations and structures on discharge, head loss, and velocity distribution for a number of realistic inlet shapes and tide conditions. An initial set of tests in a trapezoidal inlet was conducted between 1967 and 1970. However, in order that subsequent inlet models are more representative of real inlets, a number of "idealized" models representing various inlet morphological classes are being developed and tested. The effects of jetties and wave action on the hydraulics are included in the study.

(2) Evaluation of state-of-the-art modeling techniques. The objectives of this part of the inlet hydraulics study are to determine the usefulness and reliability of existing physical and numerical modeling techniques in predicting the hydraulic characteristics of inlet/bay systems, and to determine whether simple tests, performed rapidly and economically, are useful in the evaluation of proposed inlet improvements. Masonboro Inlet, North Carolina, was selected as the prototype inlet which would be used along with hydraulic and numerical models in the evaluation of existing techniques. In September 1969 a complete set of hydraulic and bathymetric data was collected at Masonboro Inlet. Construction of the fixed-bed physical model was initiated in 1969, and extensive tests have been performed since then. In addition, three existing numerical models were applied to predict the inlet's hydraulics. Extensive field data were collected at Masonboro Inlet in August 1974 for use in evaluating the capabilities of the physical and numerical models.

(3) Prototype inlet hydraulics. Field studies at a number of inlets are providing information on prototype inlet/bay tidal hydraulic relationships and the effects of friction, waves, tides, and inlet morphology on these relationships.

c. The basic objective of the inlet dynamics study is to investigate the interactions of tidal flow, inlet configuration, and wave action at tidal inlets as a guide to improvement of inlet channels and nearby shore protection works. The study is subdivided into four specific areas: model materials evaluation, movable-bed modeling evaluation, reanalysis of a previous inlet model study, and prototype inlet studies.

(1) Model materials evaluation. This evaluation was initiated in 1969 to provide data on the response of movable-bed model materials to waves and flow to allow selection of the optimum bed materials for inlet models.

(2) Movable-bed model evaluation. The objective of this study is to evaluate the state-of-the-art modeling techniques, in this case movable-bed inlet modeling. Since, in many cases, movable-bed modeling is the only tool available for predicting the response of an inlet to improvements, the capabilities and limitations of these models must be established.

(3) Reanalysis of an earlier inlet model study. In 1957, a report entitled, "Preliminary Report: Laboratory Study of the Effect of an Uncontrolled Inlet on the Adjacent Beaches," was published by the Beach Erosion Board (now CERC). A reanalysis of the original data is being performed to aid in planning of additional GITI efforts.

(4) Prototype dynamics. Field and office studies of a number of inlets are providing information on the effects of physical forces and artificial improvements on inlet morphology. Of particular importance are studies to define the mechanisms of natural sand bypassing at inlets, the response of inlet navigation channels to dredging and natural forces, and the effects of inlets on adjacent beaches.

4. This appendix discusses the verification, base tests, and predictive test of a fixed-bed hydraulic model of Masonboro Inlet, N. C., conducted as part of the evaluation of the state-of-the-art inlet modeling techniques. It presents the data necessary for a comparison of results of the physical and numerical models discussed in the basic report and in the following appendixes:

a. Appendix 2. F. D. Masch, R. J. Brandes, and J. U. Reagan, "Numerical Simulation of Hydrodynamics (WRE)" (In 2 Vols).

b. Appendix 3. R. M. Chen and L. A. Hembree, "Numerical Simulation of Hydrodynamics (TRACOR)."

c. Appendix 4. C. J. Huval and G. L. Wintergerst, "Simplified Numerical (Lumped Parameter) Simulation."

5. Important modeling terms--"verification" and "postconstruction verification"--have different meanings in this appendix than in other volumes of GITI Report 6. When used in this report, "verification" means:

> The process by which hydraulic (or numerical) model adjustments are made to assure that the model accurately reproduces prototype data (for perhaps many different combinations of prototype driving forces) to such an extent that evaluations of various proposed projects and alternatives can be confidently predicted from results of the model.

Also, when used in this appendix, "postconstruction verification" means:

> The process by which prototype data acquired subsequent to project completion are used to verify that model predictions do or do not satisfactorily represent prototype behavior. Hopefully, model predictions performed during the planning and design phase can be used; however, if the constructed project differs from that tested in the original model study (which is usually the case), additional model tests may be required to perform a satisfactory post construction verification.

In the basic report, related definitions are:

a. Calibration. The process by which a hydraulic model is checked with prototype data and systematically adjusted to reproduce desired prototype phenomena from corresponding prototype driving forces.

b. Verification. The process by which independent prototype data (data not used in the calibration) are used to verify that a calibrated hydraulic model produces satisfactory prototype results.

c. Confirmation. The process by which prototype data are used to confirm that the results of a calibrated, verified model satisfactorily predicted subsequent prototype behavior.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
feet	0.3048	metres
square feet	0.09290304	square metres
square miles (U. S. statute)	2.589988	square kilometres
feet per second	0.3048	metres per second
degrees (angle)	0.01745329	radians

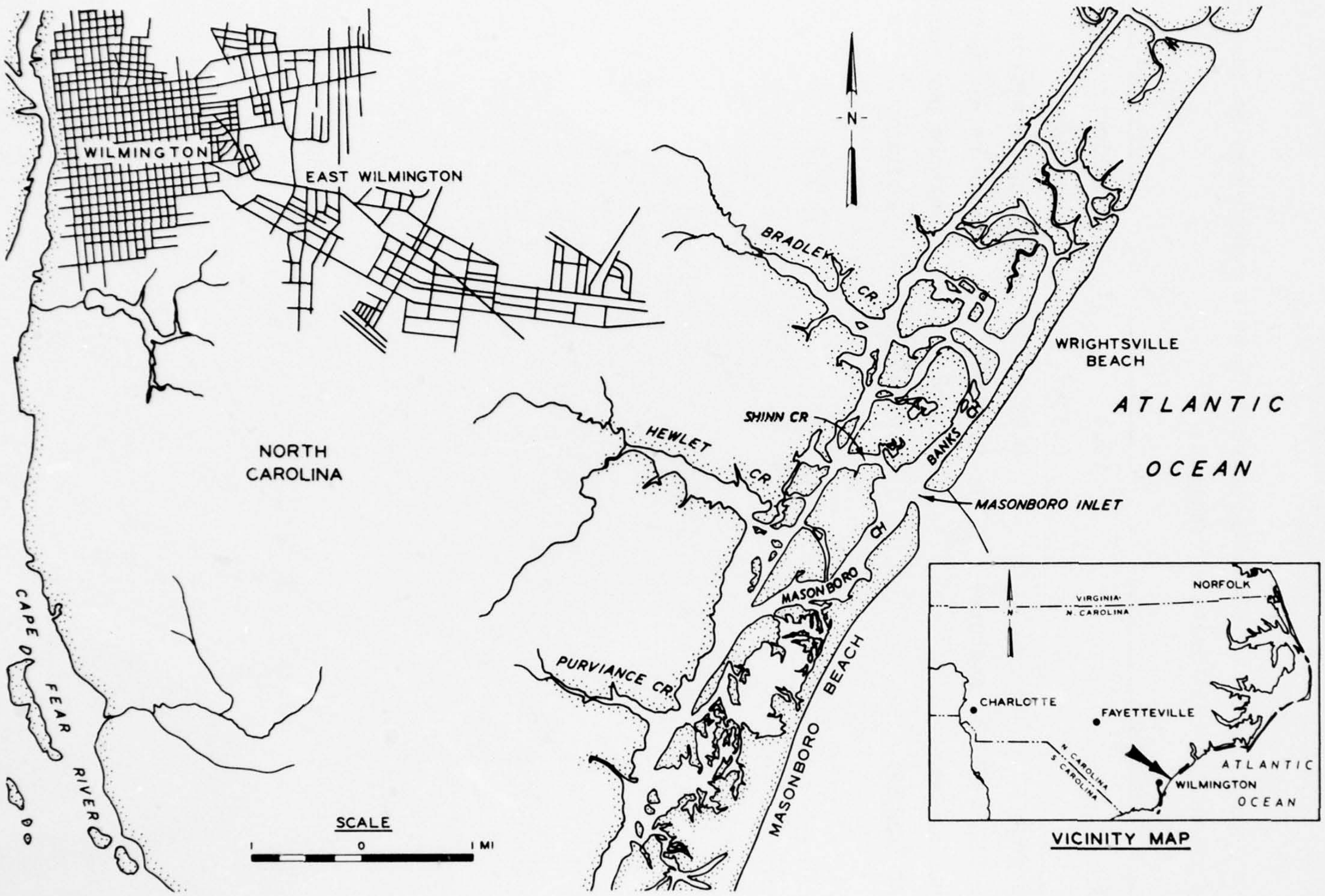

Figure 1. Location map

COMPARISON OF NUMERICAL AND PHYSICAL HYDRAULIC MODELS
MASONBORO INLET, NORTH CAROLINA

APPENDIX 1: FIXED-BED HYDRAULIC MODEL RESULTS

PART I: INTRODUCTION

Background

1. This appendix summarizes selected fixed-bed model hydraulic data collected during a model study of Masonboro Inlet, North Carolina, which was designed to meet two primary objectives. The first objective was to evaluate the effectiveness of state-of-the-art physical modeling techniques in predicting the effects of major changes to an inlet on the hydraulics of the inlet. The second objective was to determine whether simple model tests, performed quickly and for a reasonable cost, could be relied upon to evaluate the design of inlet improvements.

2. Masonboro Inlet (Figure 1) was in a natural state until August 1965, when major man-made changes to the inlet were initiated. By July 1966, construction of a weir jetty and dredging of a deposition basin and navigation channel had been completed. The physical model was initially verified using bathymetric and hydraulic data collected at the inlet in September 1969. Selected portions of the verified model were subsequently remolded for prediction of hydraulic characteristics for the following conditions: (a) November 1964 bathymetry and (b) November 1964 bathymetry plus simulated postconstruction conditions, i.e., with jetty, deposition basin, and navigation channel. Results of these model tests are presented and discussed in this report, and detailed analyses of data from these and additional fixed-bed model tests are presented by Sager and Seabergh.*

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* R. A. Sager and W. C. Seabergh, "Physical Model Simulation of the Hydraulics of Masonboro Inlet, N. C." (in preparation), U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Scope

3. This report consists of:

- a. A description of the physical distorted-scale model of Masonboro Inlet, North Carolina.
- b. A description of the verification procedure for the model.
- c. Results of the verification of the model based on a prototype current and tidal height survey obtained from the prototype on 12 September 1969.
- d. Prediction of tides and currents for the 1964 prototype (base) hydrographic conditions before a plan of improvement was installed in the prototype.
- e. Prediction of the tides and currents for the 1964 prototype hydrographic conditions with the plan of improvement installed in the model. This test would have been the model prediction of the hydraulic effects of the improvement plan if a model study had been conducted prior to construction.

Approach

4. The normal sequence of events in a physical fixed-bed model study conducted simply for the purpose of developing a plan of improvement for a tidal inlet is:

- a. Obtain the necessary prototype data required to verify the model (includes bathymetries, velocities, wave data, and tidal heights).
- b. Construct the model to the bathymetric condition that existed when all prototype data were obtained for the pre-improvement inlet conditions.
- c. Adjust (verify) the model to obtain agreement between model and prototype data, which ensures that the physical parameters of the inlet are properly reproduced in the model.
- d. Obtain a complete set of base data consisting of all conditions of interest in the model.
- e. Install a plan of improvement, obtain a set of data similar to the base data, and predict the effects of the plan on the important physical parameters, i.e., velocities, tidal heights, material movement, etc.
- f. Repeat e for other proposed plans.

5. For the inlet considered in this study, a modification in the order of events listed above was necessary because of the fact that a major improvement had been made to the inlet previous to this study and sufficient prototype data to verify the model had not been obtained for preimprovement conditions. Briefly outlining the history of the prototype, a single weir jetty, a navigation channel, and a sand deposition basin were constructed at the natural inlet in 1965. The inlet channel migrated northward into the deposition basin and alongside the outer end of the jetty between 1966 and 1969. These changes are documented by bathymetric surveys. The only records of tidal heights and velocities in the inlet for this period were obtained in 1969, four years after construction of the project; thus, the model had to be verified to the 1969 postimprovement condition.

6. After verification to the 1969 condition, the model was modified to the 1964 preimprovement condition. A bathymetric survey of a limited region in and around the inlet throat was available for this period. The modeled bay area of the inlet remained the same as the original 1969 condition since there was very little change in the bay during the 1964-1969 period. No hydraulic data were available to verify this preimprovement condition, but the area that was changed from the 1969 to the 1964 condition is small relative to the entire model. Experience with the 1969 verification should have provided sufficient information in the adjustment of roughness to allow the 1964 hydraulic conditions to be simulated accurately in the model. Data were collected from the 1964 condition to provide a basis for comparison with numerical models. A similar set of data was obtained with the plan installed in the model with the 1964 bathymetry.

PART II: THE MODEL

Description

7. The Masonboro Inlet model reproduced approximately 14.5 square miles* of the prototype including the bay area to the limits of the inlet's influence and offshore to the -45 ft mlw (mean low water) contour. The model was constructed in a 50-ft-wide by 150-ft-long facility which is completely enclosed to protect the model and necessary appurtenances from inclement weather and to allow uninterrupted operation. However, due to the limitation of the lateral extension of the facility, artificial bending of the bay areas north and south of the inlet was necessary. Distant areas of the bay were schematized. Since the principal area of interest was the immediate vicinity of the inlet, this primarily schematic reproduction of the bay allowed significant savings to be achieved in model construction. In the prototype, the bay extended north and south from the inlet entrance parallel to the coast. In the model, both outer limits of the bay were folded back toward the rear of the model facility, as shown in Figure 2. As a result, the wetland areas of the bay were maintained in the correct model-to-prototype proportion and thus should have provided the proper tidal prism storage.

8. The model was constructed to linear scale ratios, model to prototype, of 1:300 horizontally and 1:60 vertically. From these linear ratios, the following scale relations were computed based on the Froudian law of similitude:

Characteristic	Scale Relations
Horizontal	$L_H = 1:300$
Vertical	$L_V = 1:60$
Volume	$L_H L_H L_V = 1:5,400,000$

(Continued)

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 7.

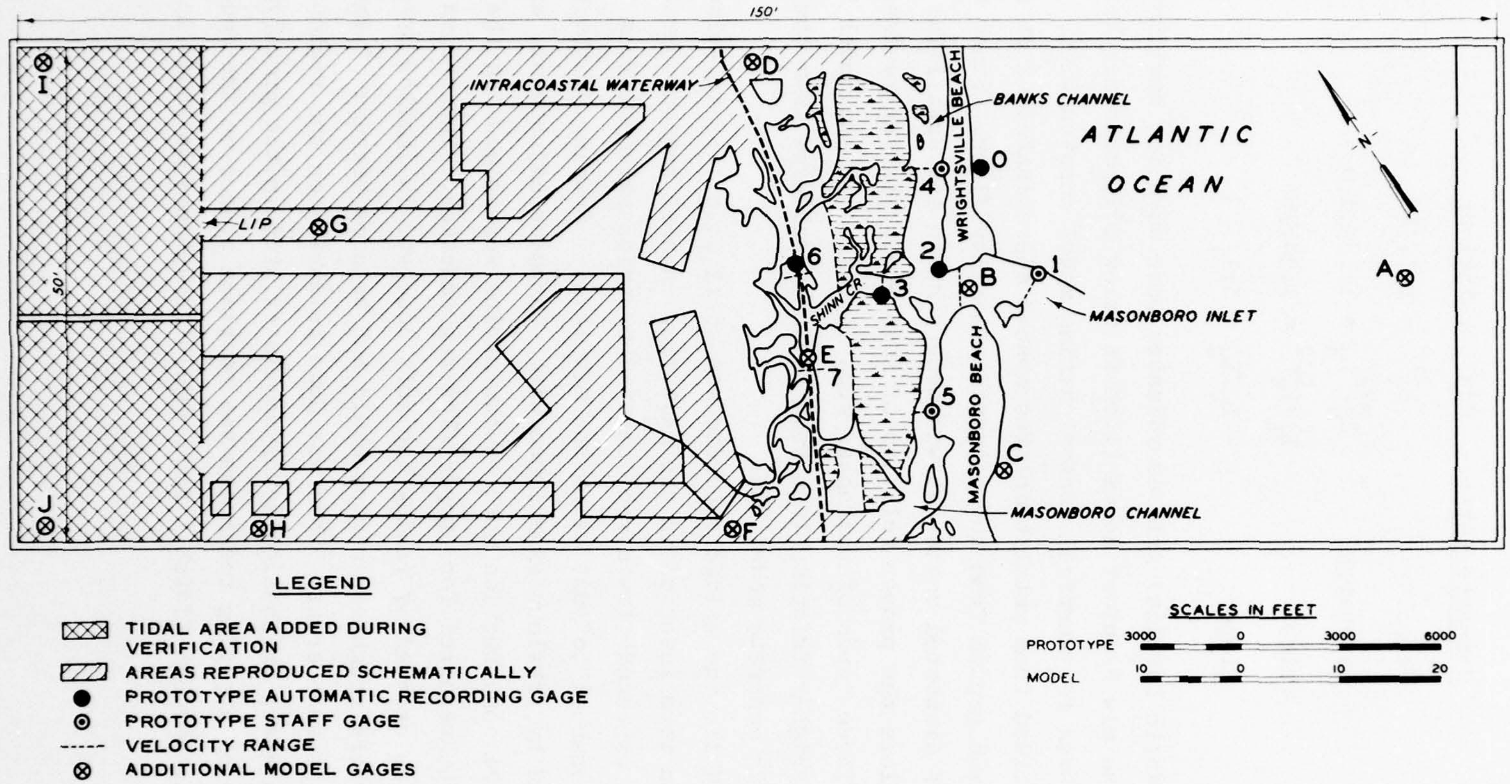


Figure 2. General model layout

Characteristic	Scale Relations
Velocity	$L_V^{1/2} = 1{:}7.746$
Discharge	$L_V^{3/2} L_H = 1{:}139{,}320$
Time	$L_H / L_V^{1/2} = 1{:}38.76$
Slope	$L_V / L_H = 5{:}1$

9. North Carolina grid coordinates were used for horizontal control, and the mlw Beaufort datum (1.88 ft below 1929 mean sea level (msl)) was used for vertical control during model construction. The model was molded from metal templates spaced approximately 2 ft apart, secured to and graded from the permanent facility floor. Since the model was of distorted scale, it was necessary to add artificial roughness to achieve the proper relation of model-to-prototype resistance.

10. Three types of roughness were installed in the model in order to obtain a higher friction loss than could be achieved from the relatively smooth concrete model bed.

11. While the molded concrete was still soft, 1/2-in.-wide flat metal strips were inserted in the main flow channel regions perpendicular to the expected flow directions. The strips extended from the bottom of the channel to just below the mlw level. Spacing of the strips was governed by previous experience with roughness adjustment, and during the model construction more of the strips were placed in the model than would be required for proper flow reproduction. The second type of roughness was created by raking the soft concrete in shallow areas of the model where roughness strips could not be used because of their low efficiency in such areas. This was done primarily on the regions in which marsh grass or shallow sandy shoals existed in the prototype. The third means of applying roughness was to place stucco on the model and trowel it to a rough finish. Each type of roughness is shown in Figure 3.

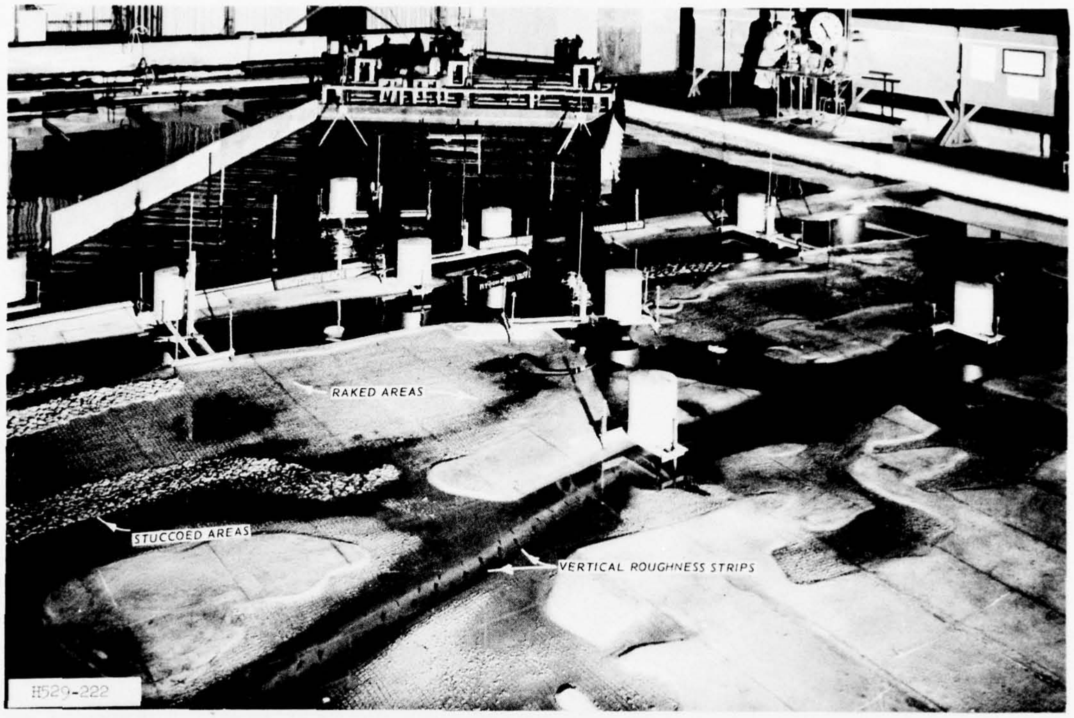


Figure 3. The model, looking from bay to ocean

Appurtenances

12. The model was equipped to reproduce and measure all the pertinent phenomena including tidal elevations, current velocities, velocity distribution, and waves. The necessary equipment included:

- a. A tide generator as shown in Figure 4.
- b. A tide data acquisition system that consisted of transmitters and drum recorders.
- c. Velocity meters (Figure 5) with a capability of measuring velocities as low as 0.05 fps (0.40 fps prototype).
- d. Two 20-ft-wide wave generators that could be adjusted to obtain a desired wave height and period.

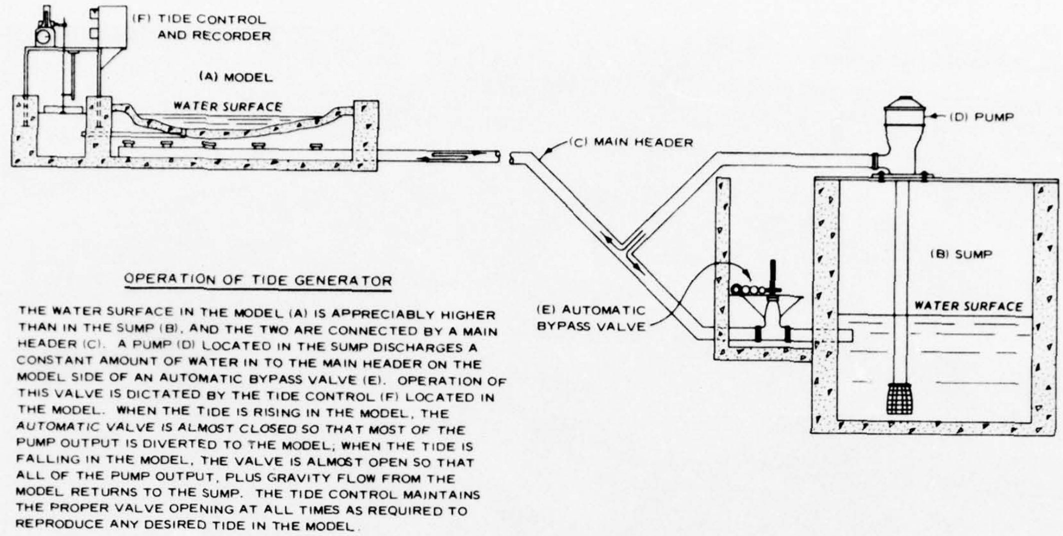
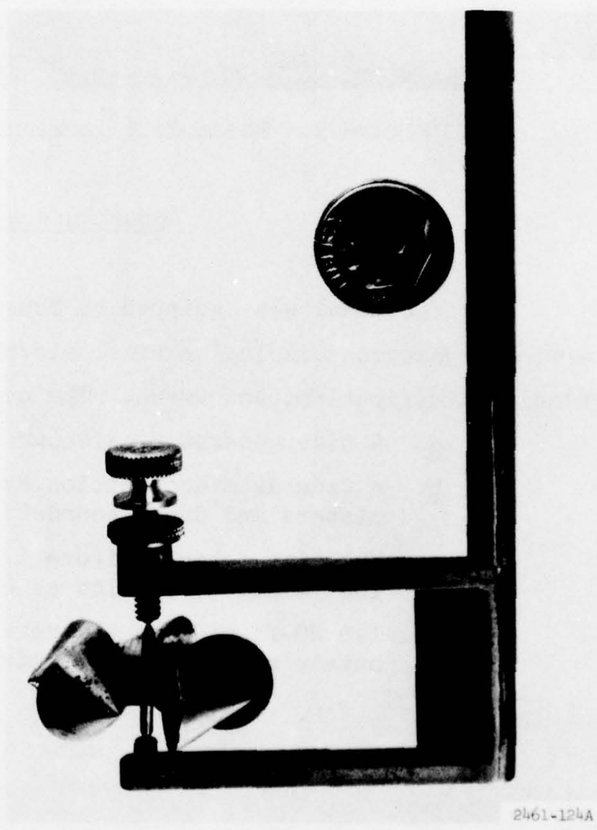


Figure 4. Tide generator features and operation

Figure 5. Miniature current velocity meter



PART III: MODEL VERIFICATION TO 1969 CONDITIONS

Adjustment of the Model

13. The purpose of model verification is to adjust the model to accurately reproduce known prototype hydraulic characteristics prior to its use in predicting the changes in hydraulic characteristics that can be expected to occur under subsequent conditions.

14. Prototype velocities at five ranges and prototype tidal elevation data at seven gages were collected over a 15-hr period on 12 September 1969 at Masonboro Inlet. These data were the basis for model verification, wherein the model bed roughness and tidal prism storage area were adjusted to achieve a satisfactory reproduction of prototype velocities and tidal elevations.

15. The initial step of model verification was the adjustment of the tide control mechanism so that the prototype tide was accurately reproduced in the ocean at the control gage 0 as shown in Figure 1. The range of this tide was 4.15 ft which is intermediate between the mean tide range of 3.8 ft and the spring tide range of 4.5 ft. In addition, the mean level of the verification tide was about 0.6 ft above msl. With the prototype tide reproduced in the ocean, the model roughness was adjusted to obtain the desired tidal elevations at each station of the model for which prototype data were available (Figures 1 and 6). Once the tidal elevations were reasonably close, the roughness was adjusted further to improve agreement between the model and prototype velocity data.

16. Figures 7 and 8 show the channel cross sections of the velocity ranges and identify the points where velocity data were collected in the prototype. Normally, velocities were taken in the model at three depths (surface, middepth, and bottom); however, at some locations only one or two depths were instrumented due to the shallow depth and the size of the meter. Roughness immediately surrounding the model velocity ranges was removed to prevent any local turbulent effects on measurements. It was not necessary to reproduce density currents since

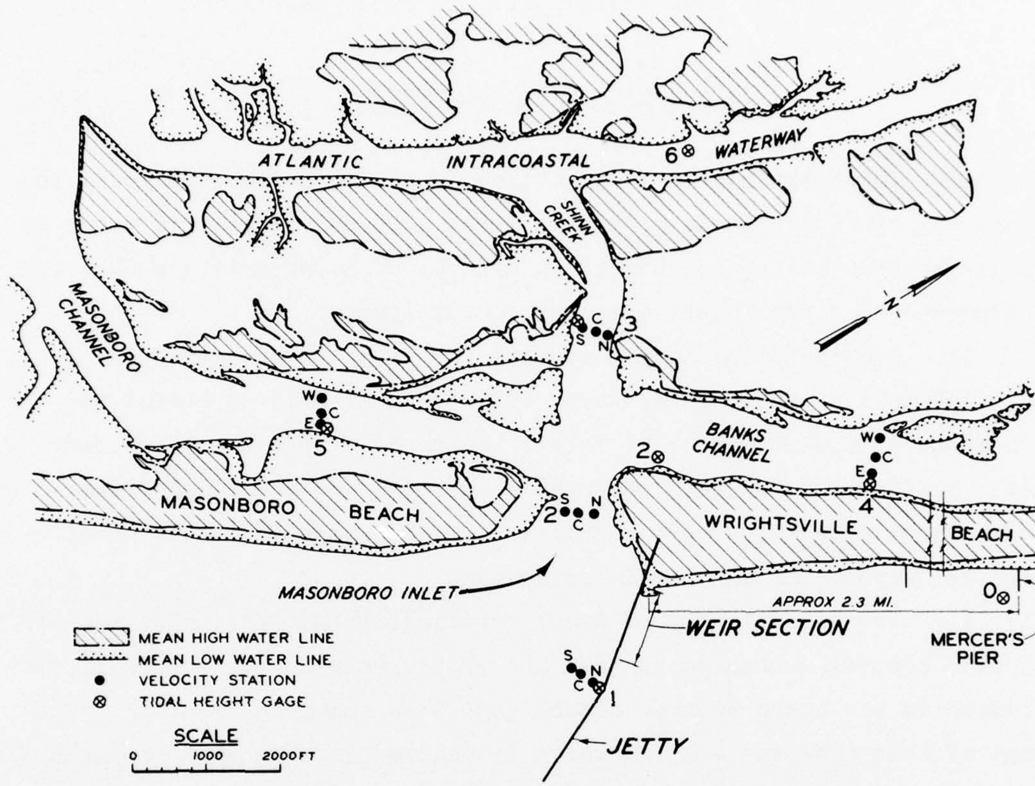


Figure 6. Range and gage locations, prototype survey, 12 September 1969

prototype data indicated that the inlet and bay contained well-mixed seawater; therefore, freshwater was used throughout the test program in the model.

17. During verification, a general trend for velocities in the model to be lower than the comparable prototype velocities was observed. To resolve this difference, a second method of adjustment was used that consisted of enlarging the model bay (Figure 1) to develop a larger tidal prism and to increase velocities throughout the inlet and bay. After this was accomplished, model velocities and tidal heights were in close agreement with the appropriate prototype data. A more detailed discussion of the verification appears in a report by Sager and Seabergh (see footnote on page 9).

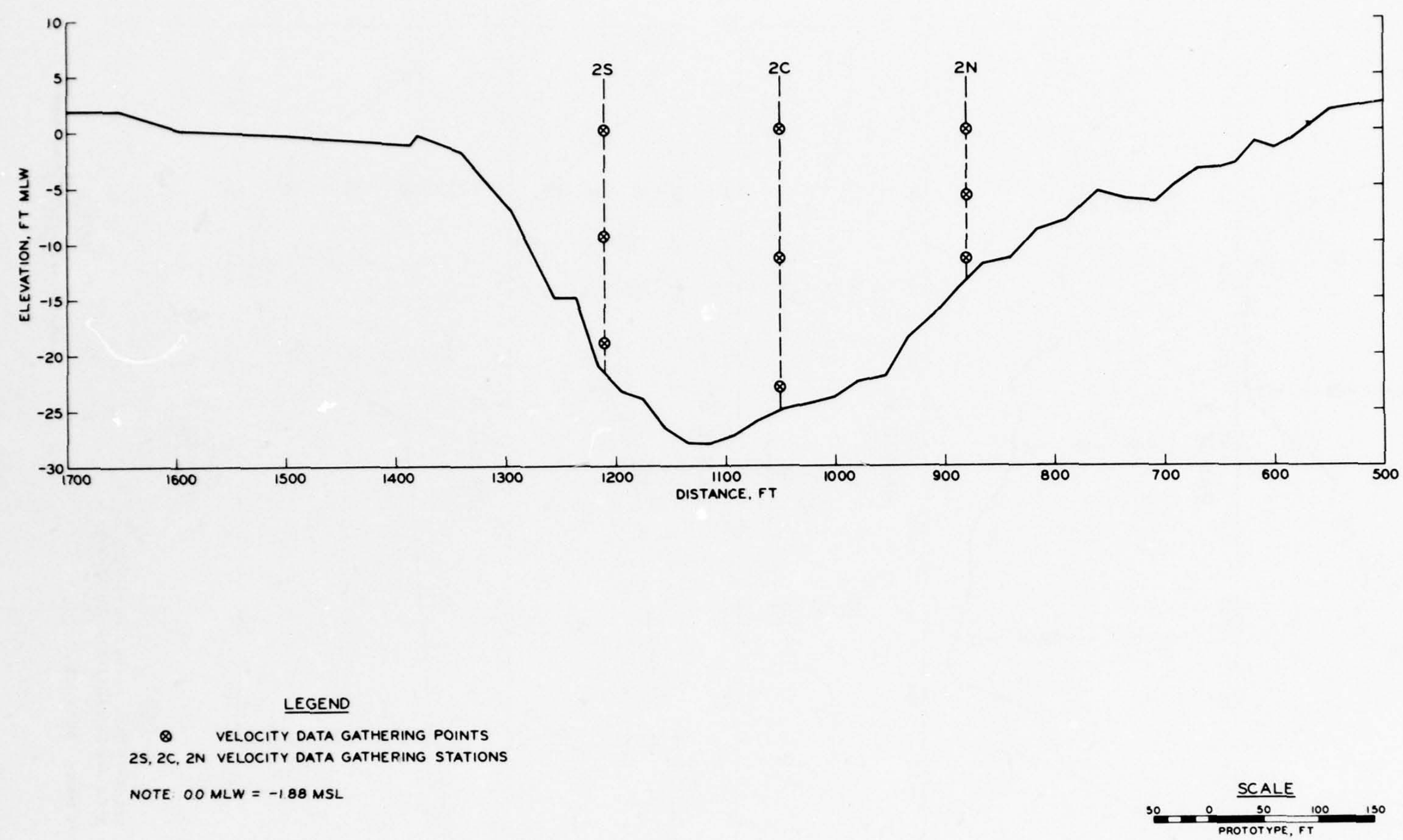


Figure 7. Cross section at velocity range 2, 1969

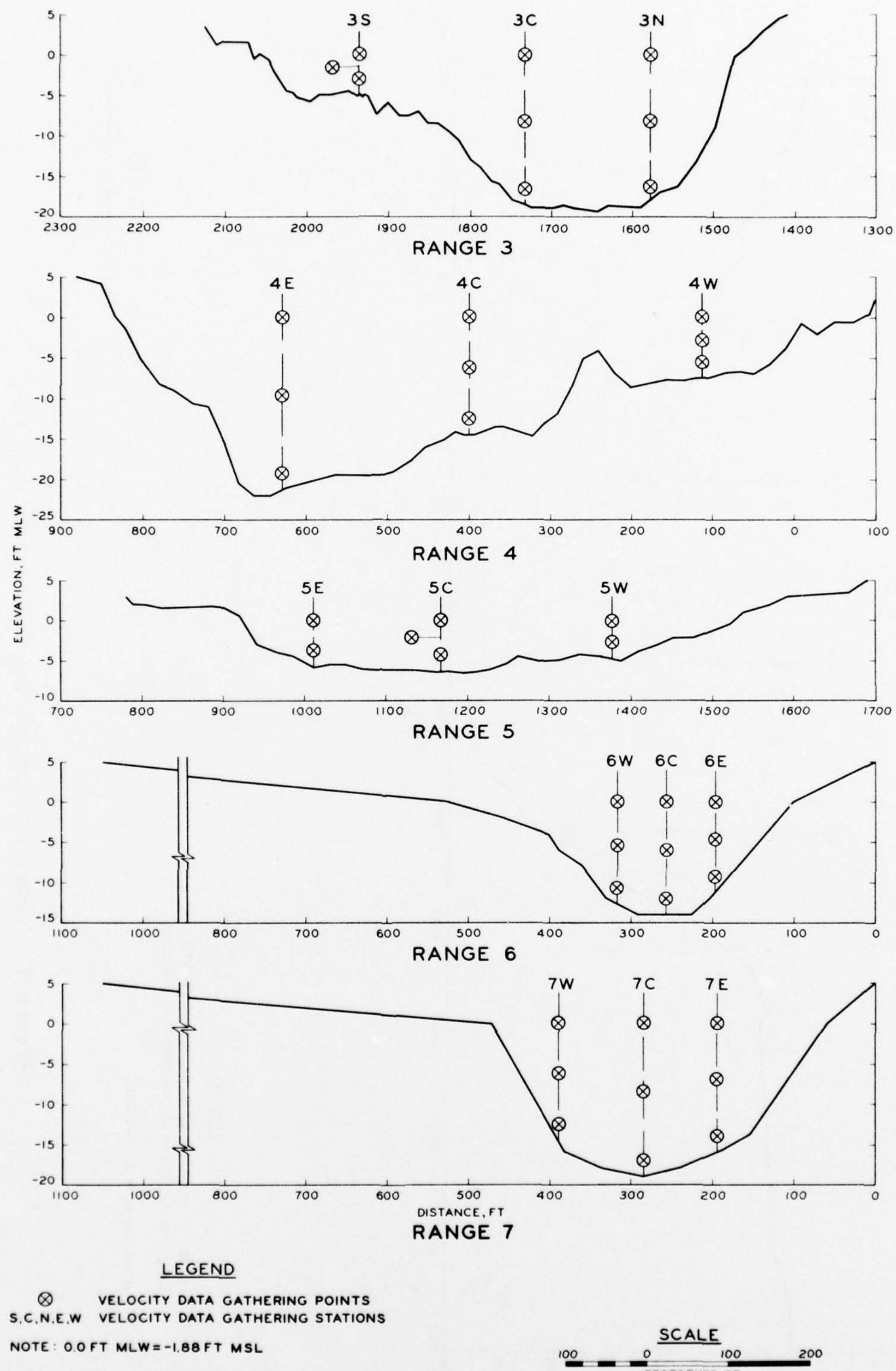


Figure 8. Cross section at velocity ranges 3, 4, 5, 6, and 7, 1969

Verification Results

18. The model verification data and corresponding prototype data are shown in Plates 1-17. The prototype time scale has been converted to lunar time. This is based on calculating the time that the moon is directly over the meridian of the point of interest and this time is identified as hour 0. The following tabulation correlates lunar time and actual time on the day of the prototype survey; hour 0 occurred about 5 hr after data collection started. In order to assign time values to all data points, a mean 12.42-hr tidal period is assumed and one works back from hour 0, assigning time values to the earlier data.

Time After Moon's Transit of the 77°49' Meridian hr	Prototype Time hr, EST
0	12:34
1	13:34
2	14:34
3	15:34
4	16:34
5	17:34
6	18:34
7	19:34 (7:09)
8	20:34 (8:09)
9	21:34 (9:09)
10	10:09
11	11:09
12	12:09
12:25	12:34

19. Plates 1 and 2 show the tidal height data. The agreement between the model and prototype curves is generally good, with the exception of the lower water-surface elevation measured in the model between hours 8 and 10, particularly at gages 4 and 6. Short-period ocean waves and wind were not reproduced in the model during verification. As a result, any setup of the water surface from the wave and wind action was not simulated. Since penetration of wave effects would be at a maximum at high water (approximately hour 8 of the tidal cycle), this is probably the cause of the difference between model and prototype.

20. Plates 3-17 show the model and prototype velocity data for ranges 1-5. The prototype data shown were obtained during one continuous tidal cycle starting shortly after strength of flood and continuing for 15 hr. Since the model time was established just prior to low water, the prototype data were plotted for the appropriate portion of the tidal cycle. The model data agree with the prototype data, except for differences of up to 2 fps at ranges 1 and 2 (Plates 3-8). At the middepth level of the south (S) and center (C) stations of each range, data obtained during flood flow from the model remained constant between hours 4 and 7. This difference from the prototype appeared to be caused by an eddy generated as flood flow came over the shoal south of the inlet. The relatively large size of the meter required for model observations did not permit good response to or definition of these local velocity fluctuations in the model. All attempts to obtain agreement were unsuccessful.

21. At range 1, the model ebb velocities were generally slightly lower than velocities observed in the prototype (Plates 3-5). The reason for this appears to be the effect of waves on this region of the inlet. Wave action on the day of the prototype survey affected the prototype velocities taken at range 1. Wave effects were not simulated until after model verification and the results of these tests are discussed in more detail in a report by Sager and Seabergh. However, the following brief discussion of wave effects is presented to provide a better understanding of the verification results for tidal motions only.

22. Waves breaking on the south shoal of the model caused mass transport of water toward the inlet. During ebb flow, this water interacted with and reduced the magnitude of the ebb currents over the south shoal, causing an increased flow in the deep channel near the jetty. This effect was observed when only waves were reproduced in the model, without tidal reproduction. This increase of flow plus the water level setup from waves increased the prototype ebb velocities through range 1. Model velocities at range 1 during flood flow were also affected by wave action. The peaks in the model velocities between hours 3 and 4 were eliminated, and the phase differences occurring near slack water after

both flood and ebb were significantly improved.

23. Surface currents in the model for maximum flood and ebb currents are shown in Photos 1 and 2, respectively. Similar prototype data were not obtained. Velocities are proportioned to the length of the confetti streaks and may be determined by comparison of the length of each streak with the scale provided with each photograph.

24. A confirmation of the model verification was not able to be performed as there were no other prototype velocity or tidal height data available for the inlet during the period of testing described in this report. In July 1974, another set of prototype data was collected and model tests with this condition will be described in a later GITI report.*

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* C. Mason, J. E. McTamany, W. C. Seabergh, "Evaluation of Physical and Numerical Models of Masonboro Inlet, N. C." (in preparation), U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss., and U. S. Army Coastal Engineering Research Center, Fort Belvoir, Va.

PART IV: THE 1964 DATA

Model Modification

25. The model was converted to the 1964 hydrographic conditions by removing approximately 400 sq ft of concrete and remolding the inlet region to the extent covered by the 1964 survey map (Figure 9). The remainder of the model was kept the same except for short transitions between the new and old regions. Roughness strips in the interior remained the same; roughness strips were added to the newly molded region in the same general locations and quantities as had been required for the 1969 condition.

1964 Base Data

26. Once the model was prepared, tests were conducted for the 1964 unjettied (base) mean tide condition. The same tide gage locations as had been monitored for the 1969 condition study were monitored for this test and are shown in Figures 1 and 6. The same velocity range and station locations were also monitored (Figure 6), except range 4 was shifted 600 ft southward to avoid eddy effects on the ebb flow due to a small channel entering Banks Channel at the prototype data collection location. Surface current photographs were also taken and are shown in Photos 3 and 4. These data are identified as the 1964 base data.

1964 Plan Data

27. After the 1964 base data for the natural inlet were collected, the 14-ft-deep by 400-ft-wide design channel, the 16-ft-deep deposition basin, and the 3650-ft-long weir jetty were constructed in the model, as shown by the dashed lines in Figure 10. Tidal height and velocity data were then obtained for this plan test at the same locations as those for the 1964 base test data. The data for the plan compared with the base test data are shown in Plates 18-33. Surface current

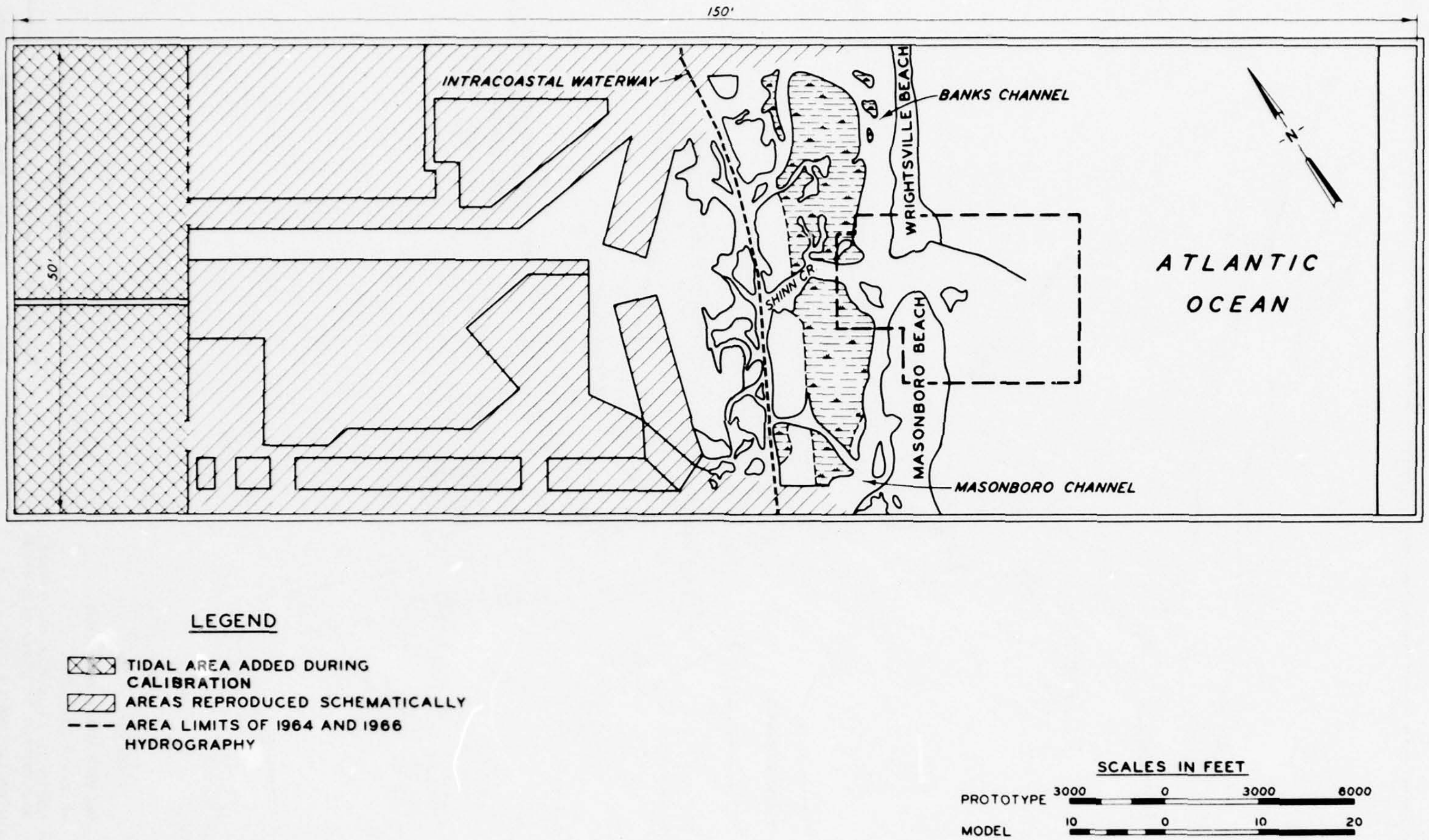


Figure 9. Model areas reproduced to 1964 and 1966 hydrography

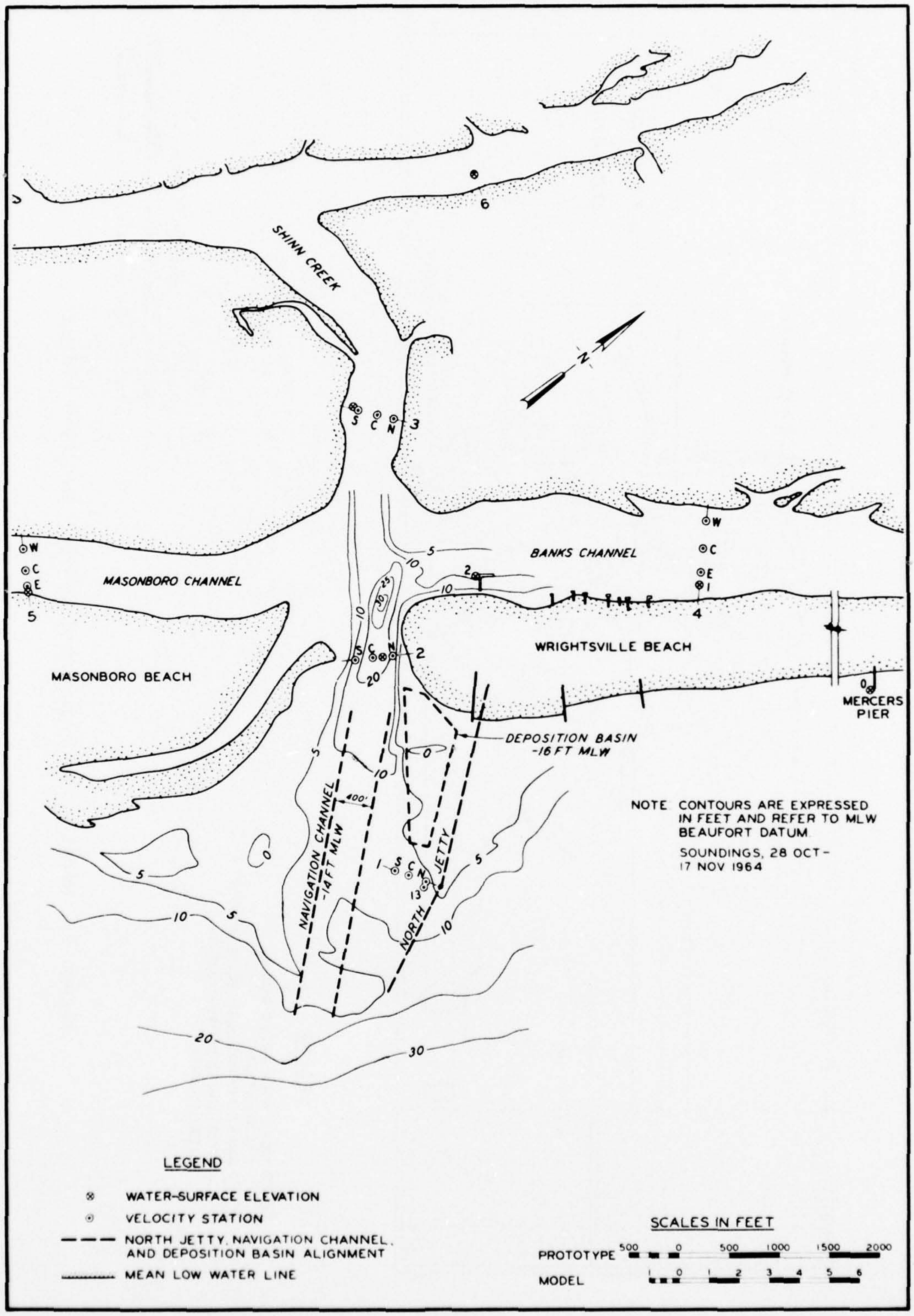


Figure 10. Velocity and tide station locations, 1964 hydrography

photographs for the plan are presented in Photos 5 and 6.

Discussion and Results

28. Tidal data for the base and plan conditions are shown in Plates 18-20. Limited changes occurred when the plan conditions were installed.

29. Inspection of the surface current data for strength of flood (Photos 3 and 5) shows that current directions have shifted approximately 90 degrees: prior to installation of the plan, flow was directed toward the throat of the inlet; with the plan installed, velocity directions at the outer end of the jetty are directed toward Masonboro Beach for some distance before swinging toward the inlet. Inspection of the surface current data for strength of ebb flow (Photos 4 and 6) shows the shift in ebb flow to the south with the plan in place. Minor changes in the direction of the ebb flow with the plan in place are observed.

30. Inspection of the velocity data obtained near the bend in the jetty (Plates 21 and 22) shows the continuing trend for flow to be shifted in a southerly direction and away from the jetty. During flood flow, reduced current velocities are observed near the jetty (sta 1C and 1N) with the plan installed in the model. The surface current photographs for strength of flood (Photos 3 and 5) show an increase in surface velocities some distance south of the jetty and a decrease in flood velocities near the jetty. The ebb velocities near the jetty (sta 1S, 1C, and 1N) show a reduction with the plan installed in the model. Inspection of the surface current patterns for ebb flow (Photos 4 and 6) shows the general shift of flow away from the jetty with the plan in place, and the eddy near Masonboro Beach.

31. The minimum cross-sectional area of the inlet is located at range 2 just oceanward from the gorge (Figure 10). The maximum velocities were observed at range 2, although velocities at range 3 (Figure 10) located in Shinn Creek were of nearly the same magnitude. Inspection of the velocity data for sta 2C (Plate 24) shows essentially no change

in velocity for the center of the channel when the plan was installed. Inspection of the velocity data for sta 2N (Plate 23) shows that ebb velocities were essentially unchanged with the plan installed; however, flood velocities were reduced by about 1.0 fps at middepth and near the surface and were increased by about 1.0 fps near the bottom. These differences are probably a result of the source of flow to this area. At middepth and near the surface, flow comes from the shallow area oceanward from range 2 and along Wrightsville Beach. When the plan is installed this source of flow is greatly reduced, causing a reduction of flood velocities at middepth and near the surface. The source of flow to the bottom depth at sta 2N is probably from the same general area; possibly with some increased contribution from the area directly oceanward from the station before the plan is installed. When the plan is installed as shown in Figure 10, the alignment of the navigation channel focuses flow toward sta 2N; however, inspection of the contours (Figure 10) shows the significant increase in depths toward sta 2C from the ocean. The alignment of the channel results in an increase in velocity at the bottom depth with less of an effect at higher depths, due to the trend of the flow to favor the deeper depths around sta 2C. If the navigation channel had been aligned more toward the south at the throat end, a greater reduction in velocities during flood would have been observed at the middepth and surface of sta 2N. Velocity data for sta 2S (Plate 25) show a reduction of velocities for both flood and ebb with the plan installed. These reductions are most probably caused by the alignment and depth of the navigation channel. Inspection of the surface current patterns shown in Photos 3-6 does not aid in development of additional information.

32. Data for velocities at range 3 (Figure 10) located in Shinn Creek are shown in Plates 26-28. Minor changes are observed for ebb flow with the plan installed. Flood flow velocities show a general trend to distribute flow more evenly across the range with the plan installed. Velocities at sta 3C (Plate 27) were generally reduced and those at 3N and 3S (Plates 26 and 28) were increased to generally bring the velocities to approximately 2.0-2.5 fps at all locations measured.

33. Velocities in the remaining interior channels, i.e., ranges 4 and 5 which appear in Plates 29-33, showed slight local changes, but on the whole there was a minimal variation from the base data to the plan data. There was some indication that the flow past range 4 was shifted slightly toward the east side of the channel by the plan (Plates 29-31).

PART V: CONCLUSION

34. Verification of the physical model was achieved with good agreement between model and prototype tidal elevations and velocities. When the 1964 plan was installed and compared with the 1964 base condition little change was noted in the tidal elevations and therefore little change in the inlet's tidal prism. Ebb velocities showed a shift to the south after passing through the inlet entrance at range 2. Thus, it appeared currents would not attack along the north jetty. This is contrary to results observed in the model when waves from the northeast or southeast were individually reproduced in the physical model. The addition of waves indicated a circulation effect which ebbed out along the north jetty where the channel finally relocated in 1967 (Sager and Seabergh) (see footnote on page 9).

VELOCITY SCALE

0 4 8 12 FPS

SURFACE CURRENTS
VERIFICATION TEST
TIDE: 12 SEPT 69
HOUR 5

SCALES IN FEET

PROTOTYPE 600 0 600 1200 1800

MODEL 2 0 2 4 6

VELOCITY SCALE

0 4 8 12 FPS

SURFACE CURRENTS

VERIFICATION TEST

TIDE: 12 SEPT 69

HOUR 11

SCALES IN FEET

PROTOTYPE 600 0 600 1200 1800

MODEL 2 0 2 4 6

PHOTO 2

VELOCITY SCALE

5 0 5 10

FPS, PROTOTYPE

SCALES IN FEET

PROTOTYPE 600 0 600 1200 1800

MODEL 2 0 2 4 6

SURFACE CURRENTS
1964 CONDITIONS
MEAN TIDE
HOUR 5

PHOTO 3

VELOCITY SCALE

5 0 5 10

FPS, PROTOTYPE

SURFACE CURRENTS

1964 CONDITIONS

MEAN TIDE

HOUR 11

SCALES IN FEET

PROTOTYPE 600 0 600 1200 1800

MODEL 2 0 2 4 6

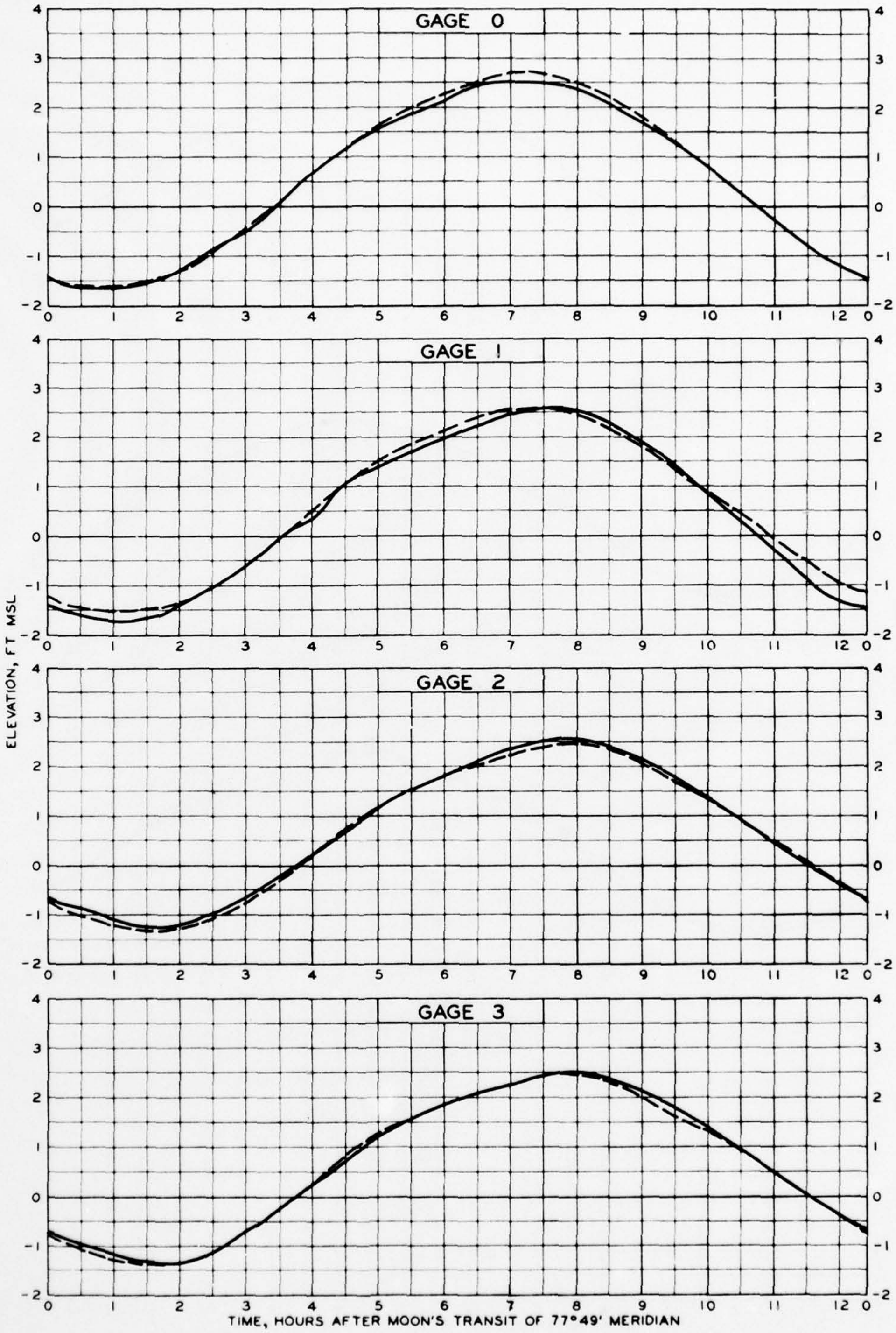
PHOTO 4

SURFACE CURRENTS
1964 CONDITIONS
WITH PLAN INSTALLED
MEAN TIDE
HOUR 5

SCALES IN FEET
PROTOTYPE 600 0 600 1200 1800
MODEL 2 0 2 4 6

SURFACE CURRENTS
1964 CONDITIONS
WITH PLAN INSTALLED
MEAN TIDE
HOUR 11

PHOTO 6



MODEL TEST DATA

TIDE ..... 12 SEPT 1969

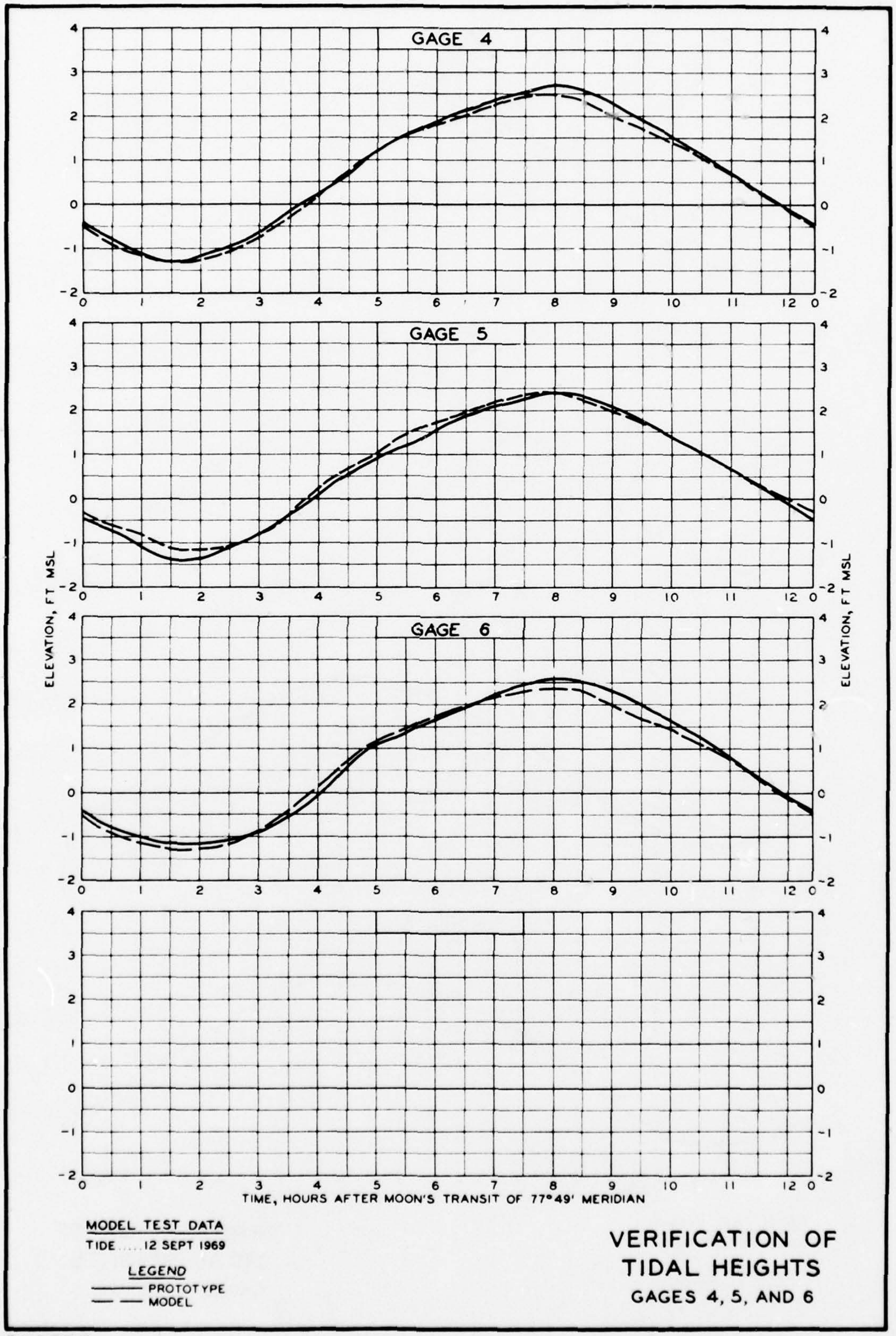
LEGEND

——— PROTOTYPE

— — MODEL

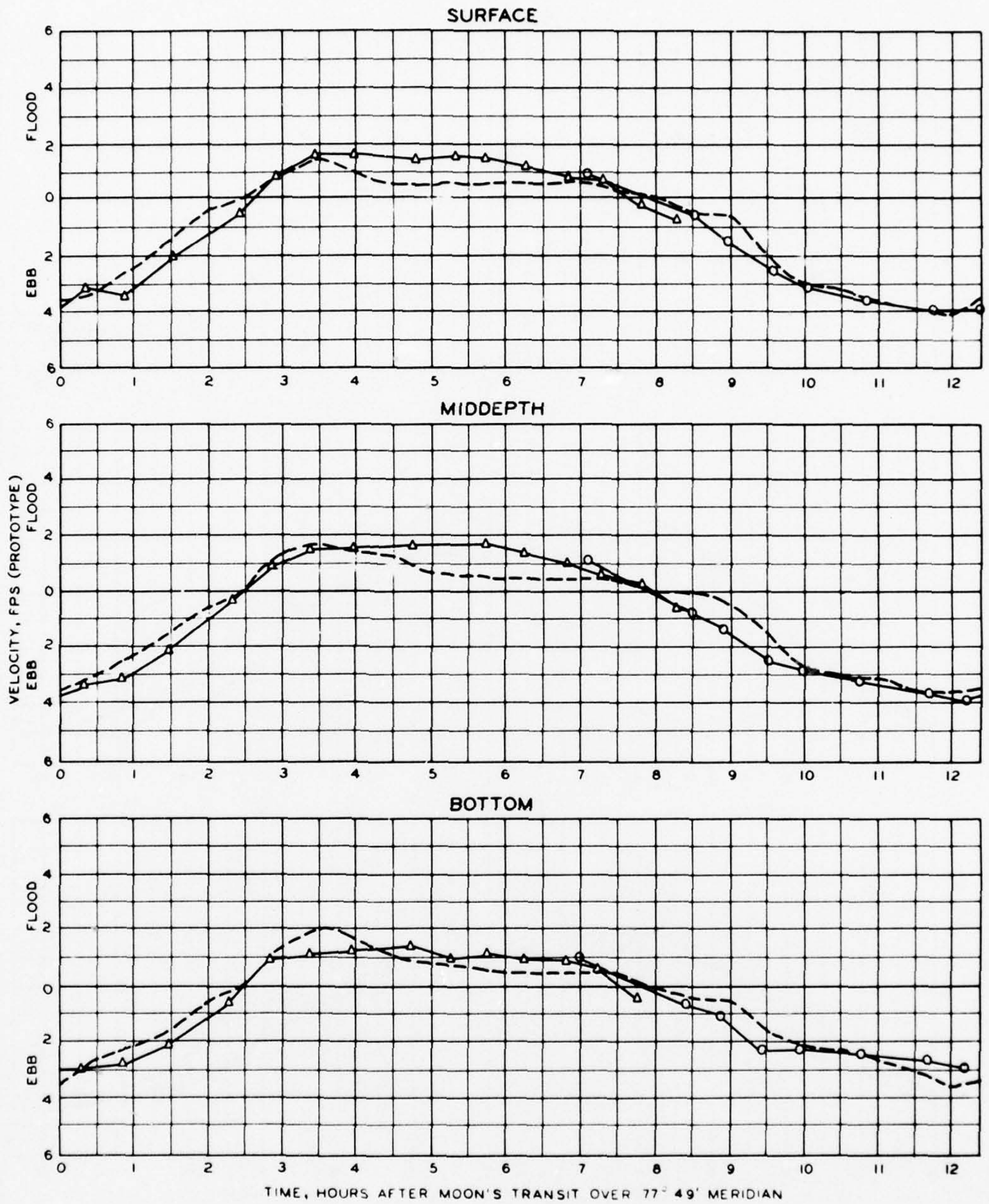
VERIFICATION OF TIDAL HEIGHTS

GAGES 0, 1, 2, AND 3



VERIFICATION OF TIDAL HEIGHTS
GAGES 4, 5, AND 6

PLATE 2



MODEL TEST DATA

TIDE 12 SEPT 1969

LEGEND

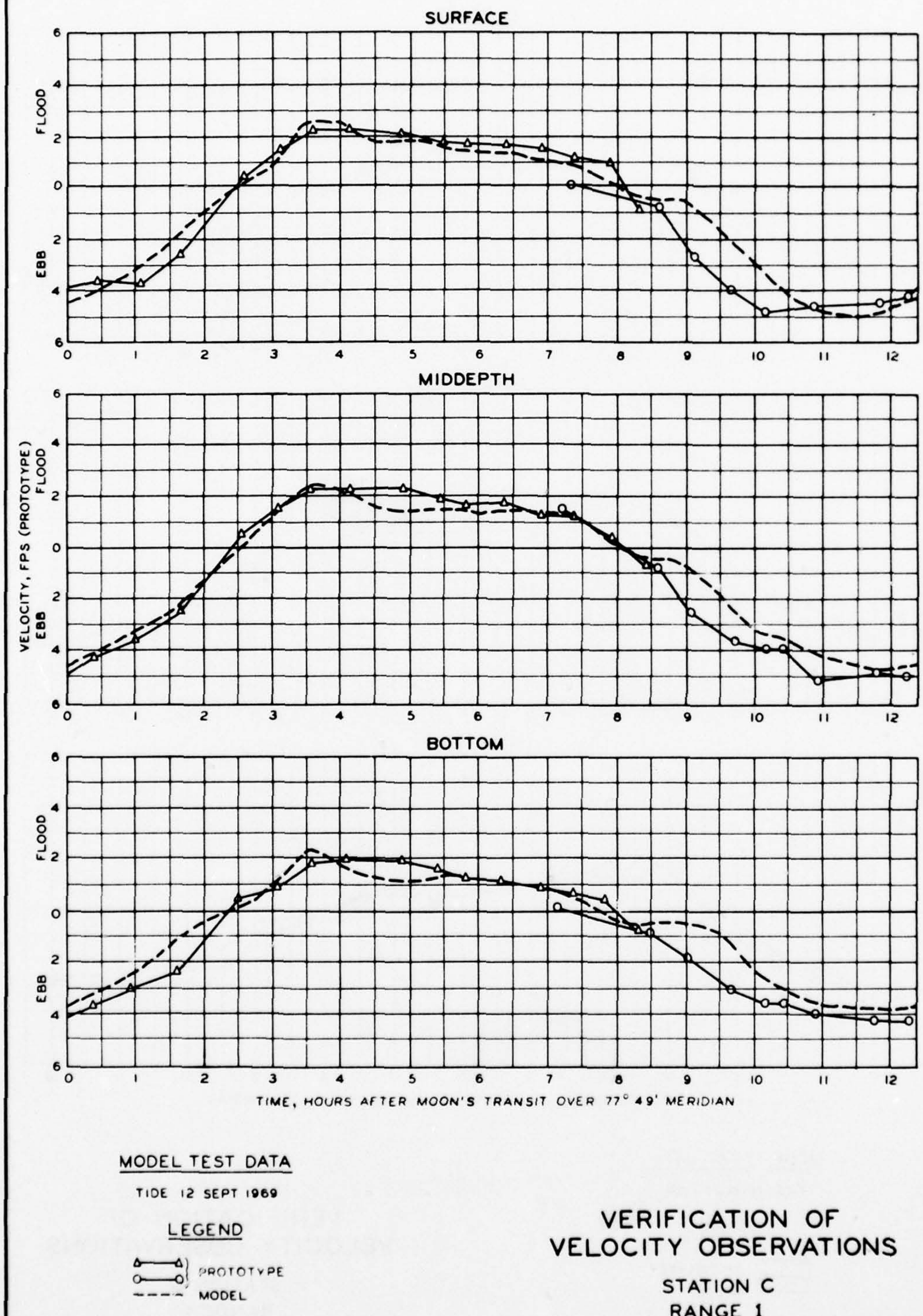
PROTOTYPE

MODEL

VERIFICATION OF VELOCITY OBSERVATIONS

STATION N

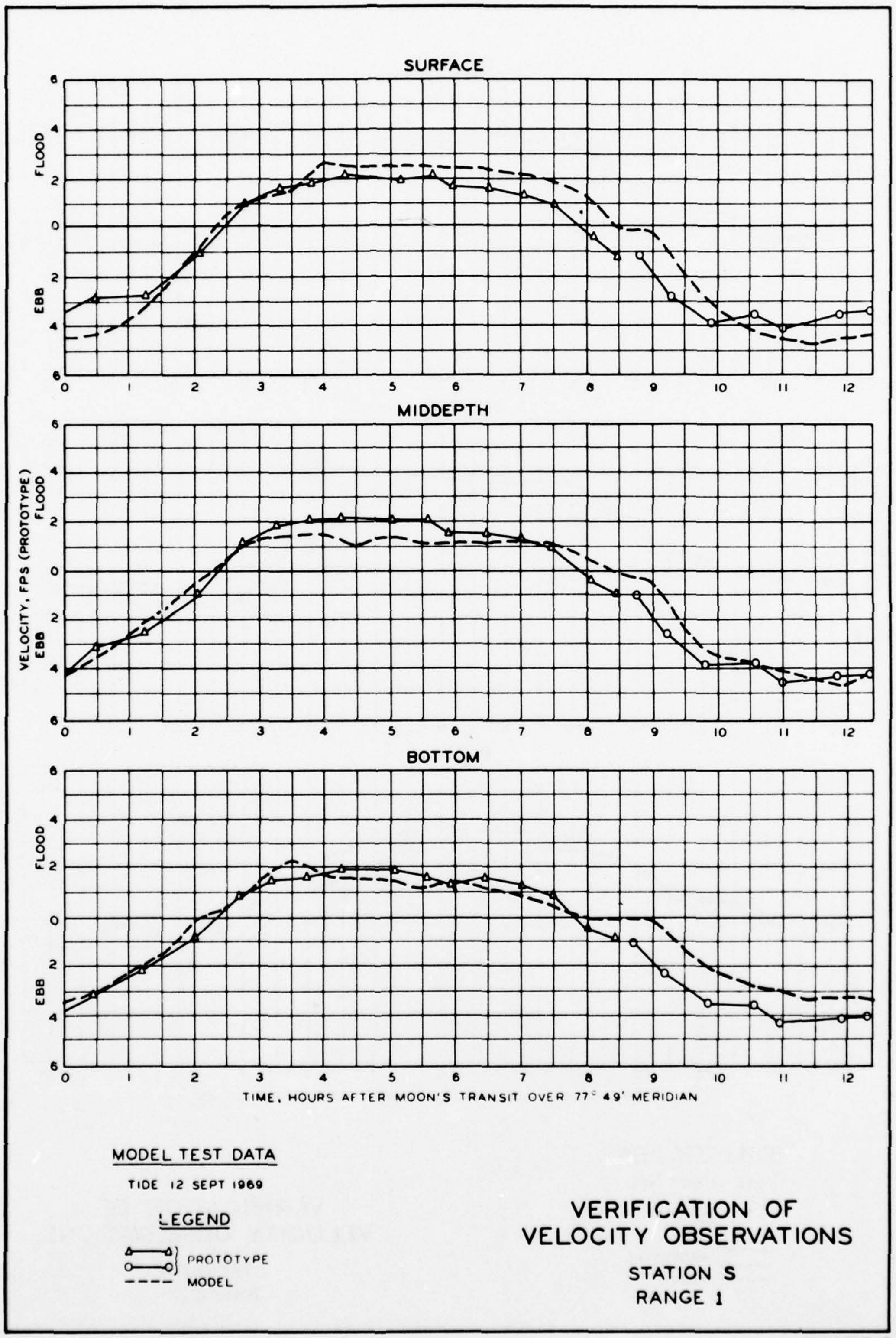
RANGE 1



VERIFICATION OF
VELOCITY OBSERVATIONS

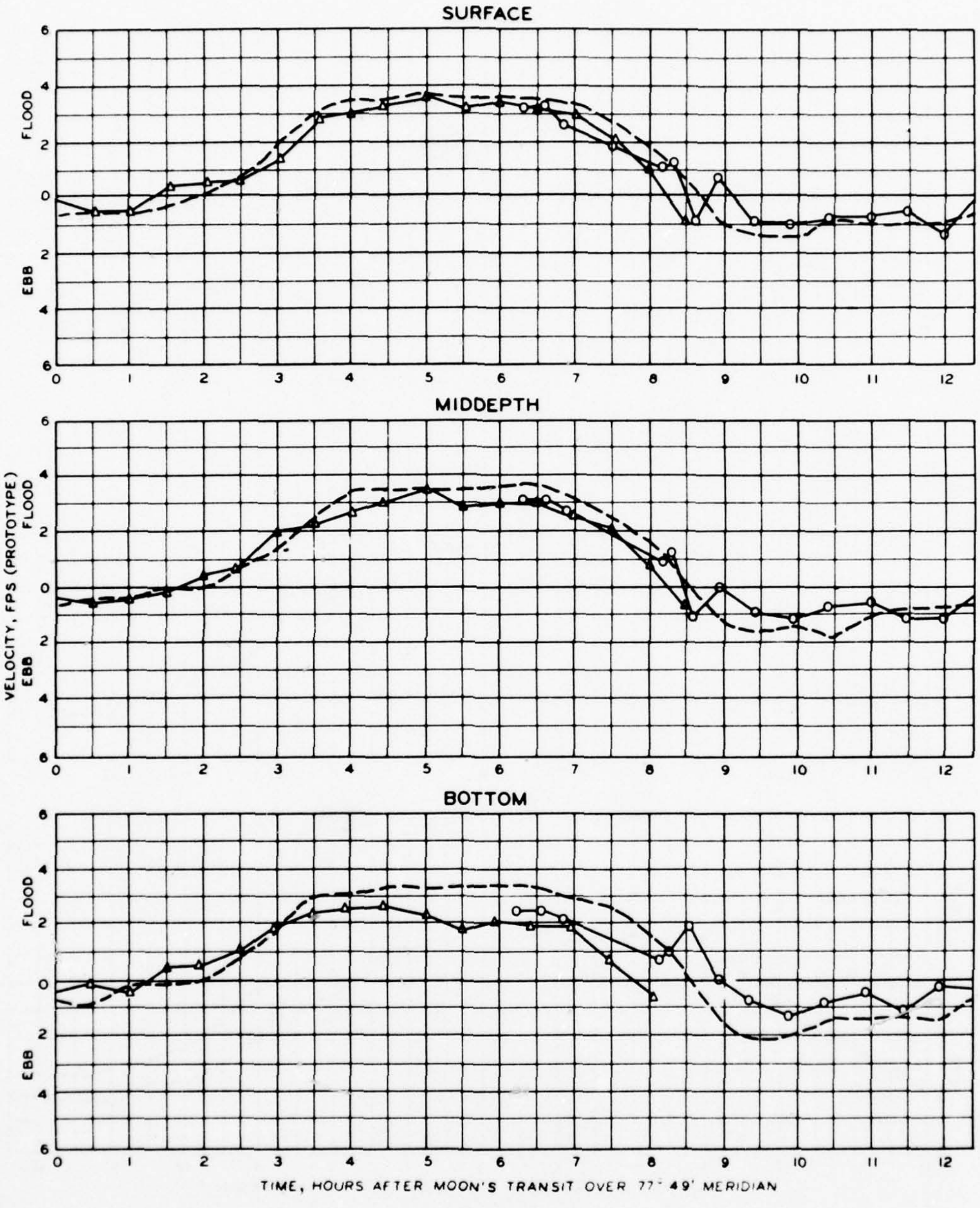
STATION C
RANGE 1

PLATE 4



VERIFICATION OF
VELOCITY OBSERVATIONS

STATION S
RANGE 1



MODEL TEST DATA

TIDE 12 SEPT 1969

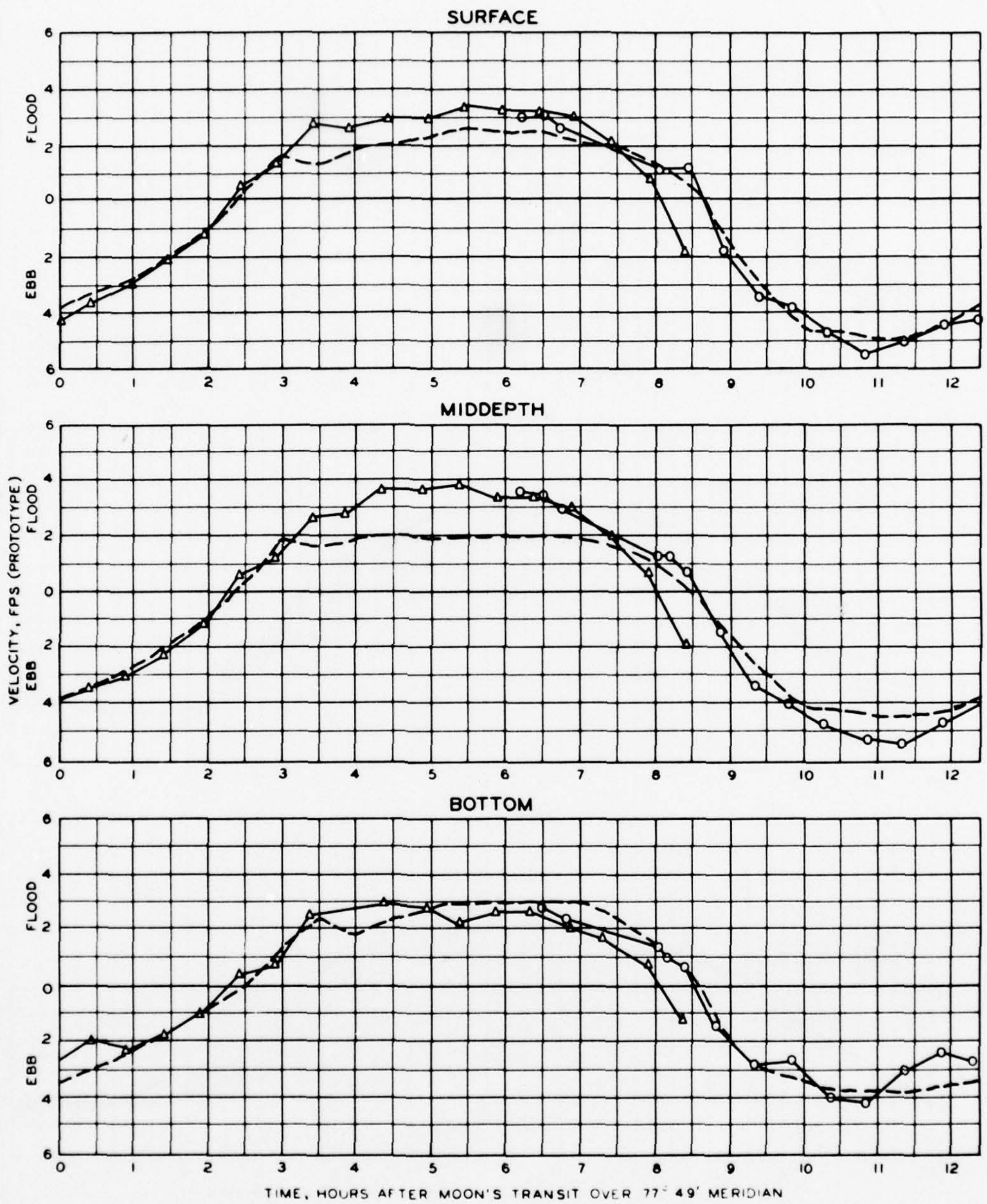
LEGEND

PROTOTYPE

MODEL

VERIFICATION OF VELOCITY OBSERVATIONS

STATION N
RANGE 2



MODEL TEST DATA

TIDE 12 SEPT 1969

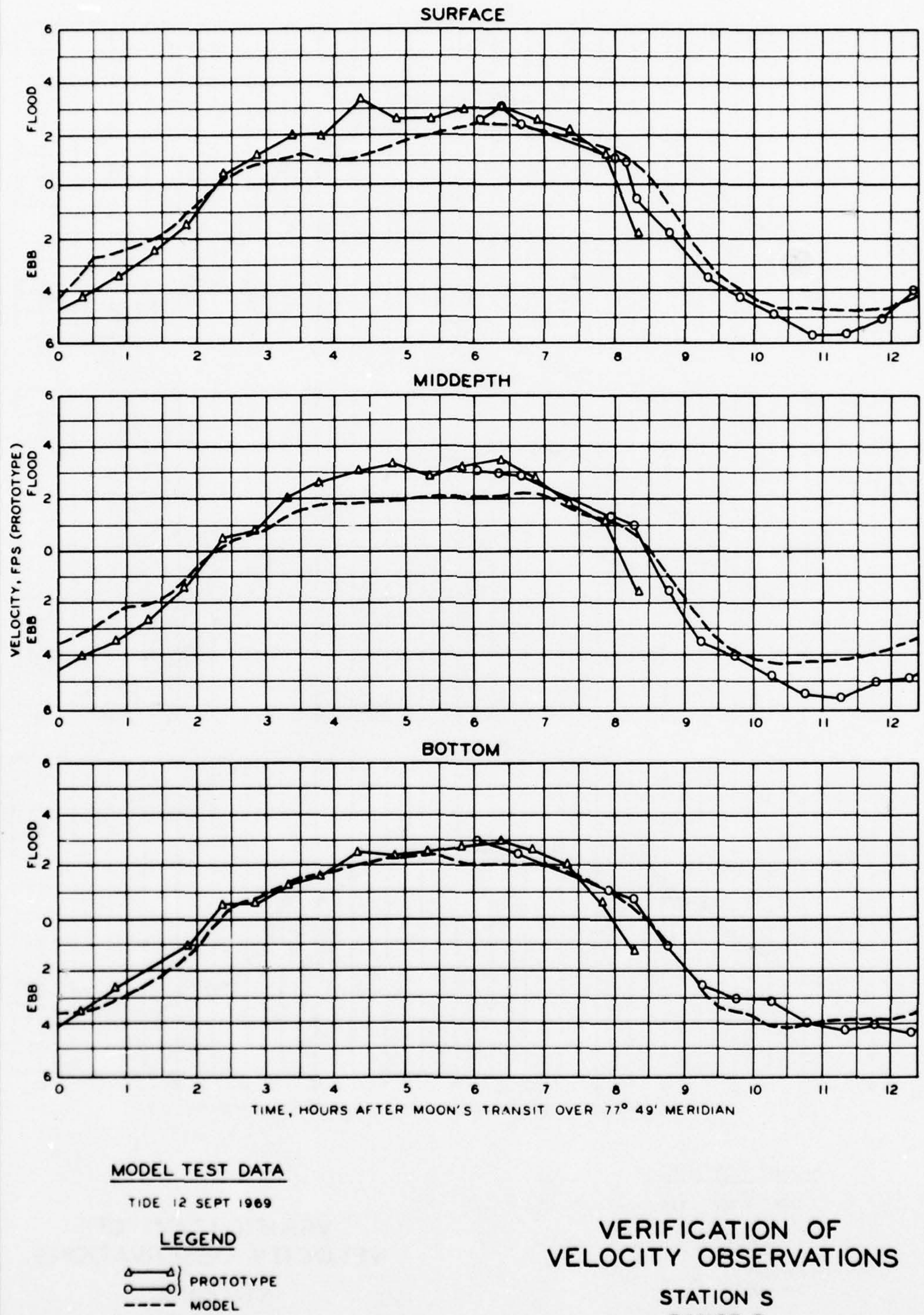
LEGEND

PROTOTYPE

MODEL

VERIFICATION OF
VELOCITY OBSERVATIONS

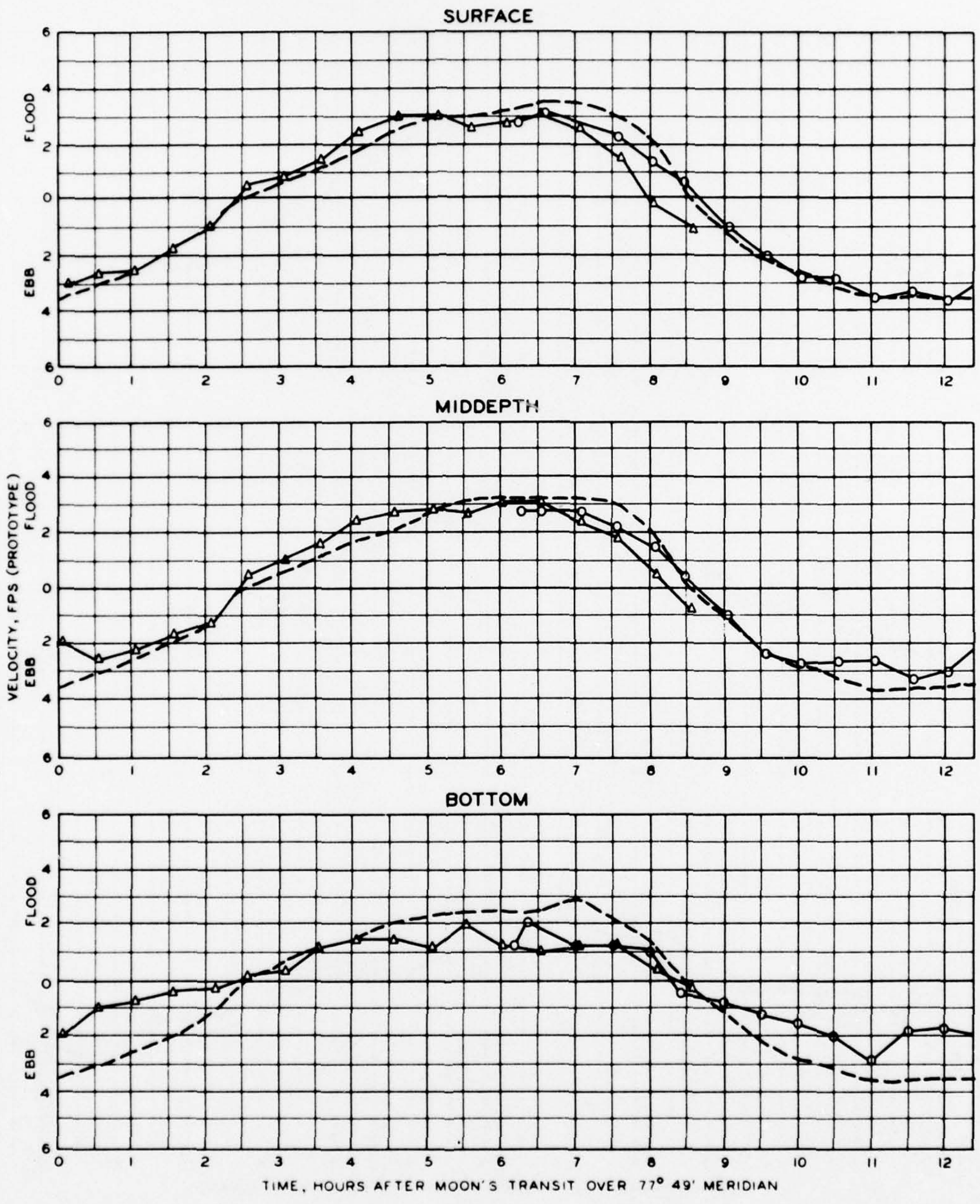
STATION C
RANGE 2



VERIFICATION OF
VELOCITY OBSERVATIONS

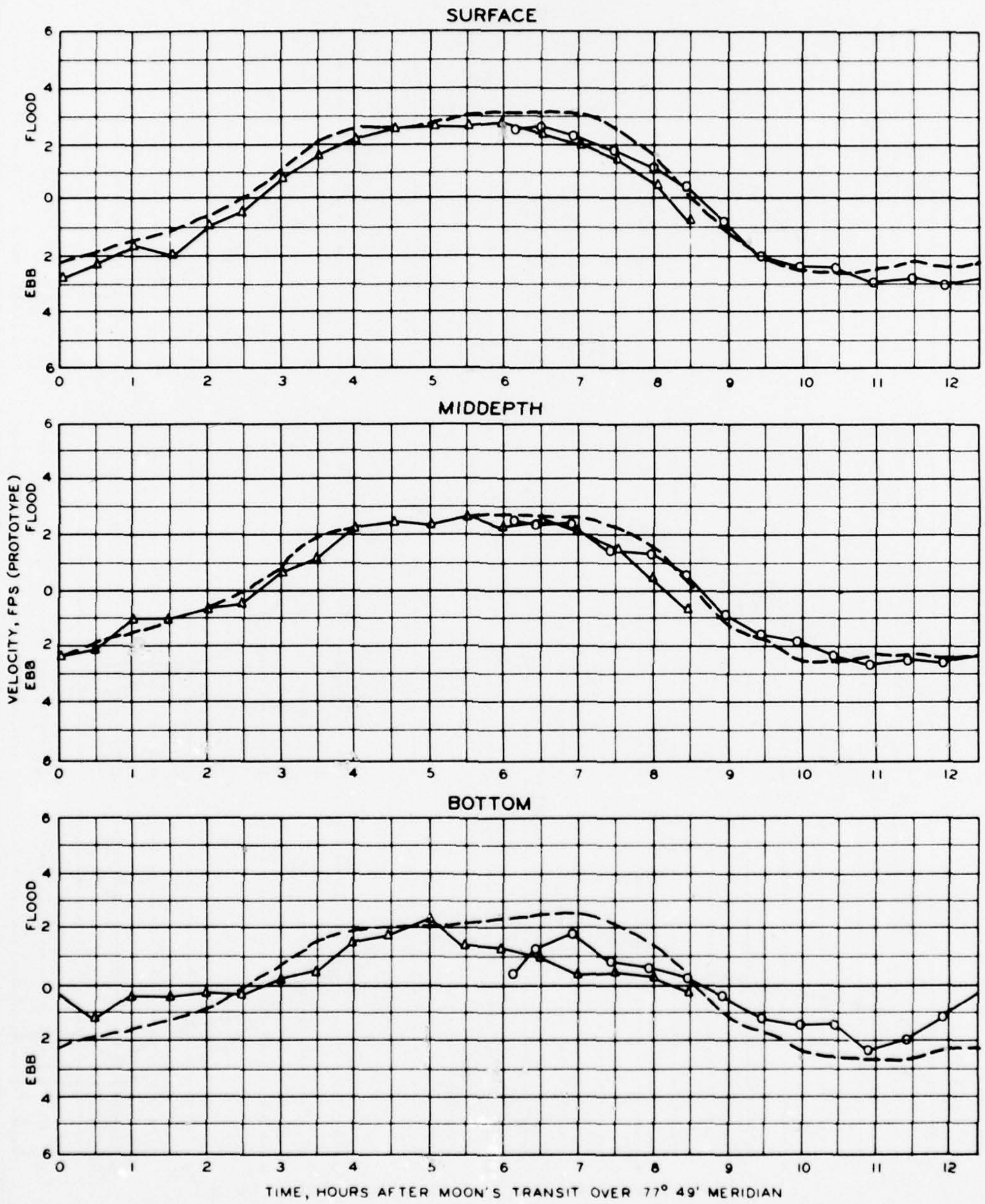
STATION S
RANGE 2

PLATE 8



VERIFICATION OF VELOCITY OBSERVATIONS

STATION N
RANGE 3



MODEL TEST DATA

TIDE 12 SEPT 1969

LEGEND

PROTOTYPE

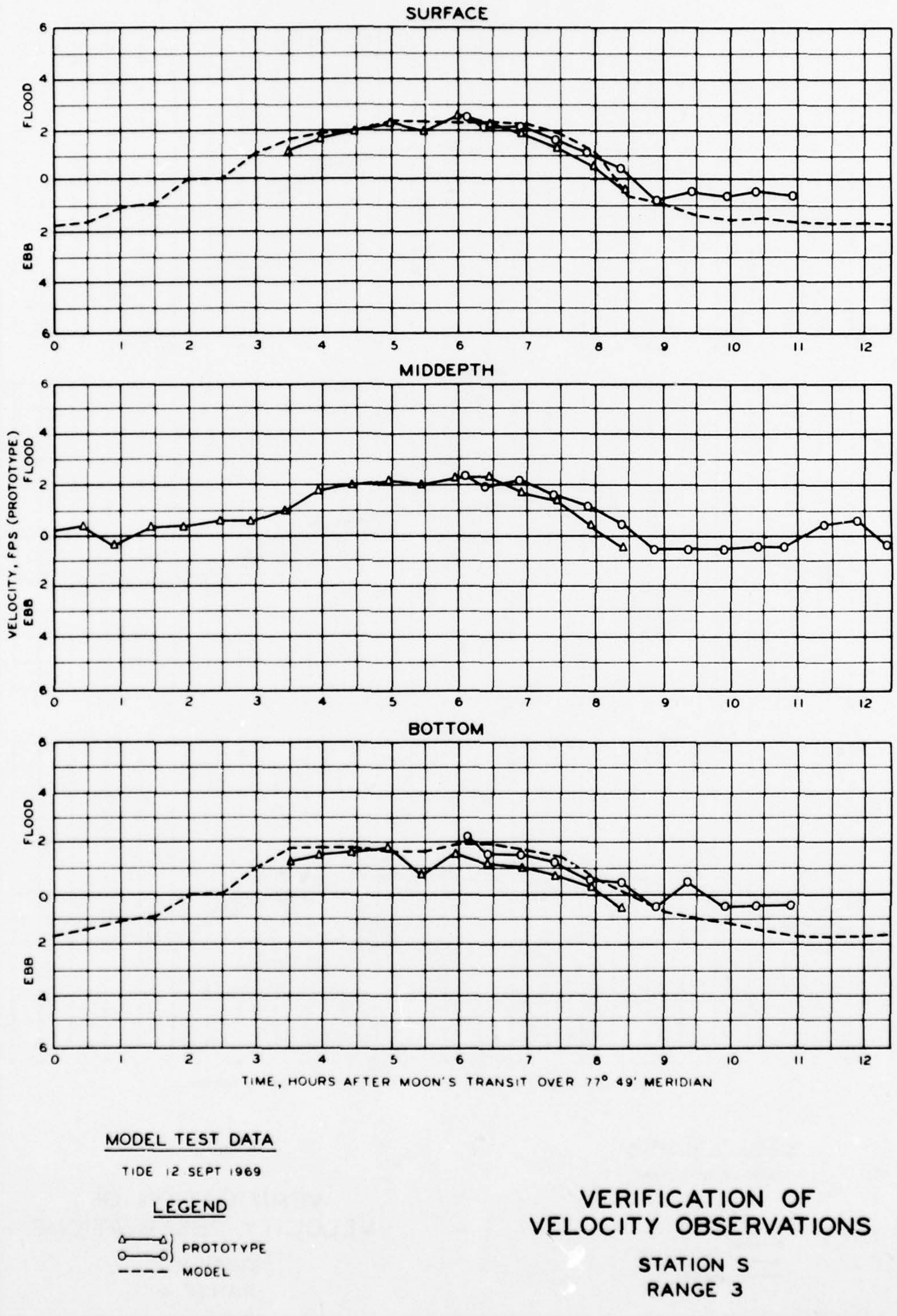
MODEL

VERIFICATION OF VELOCITY OBSERVATIONS

STATION C

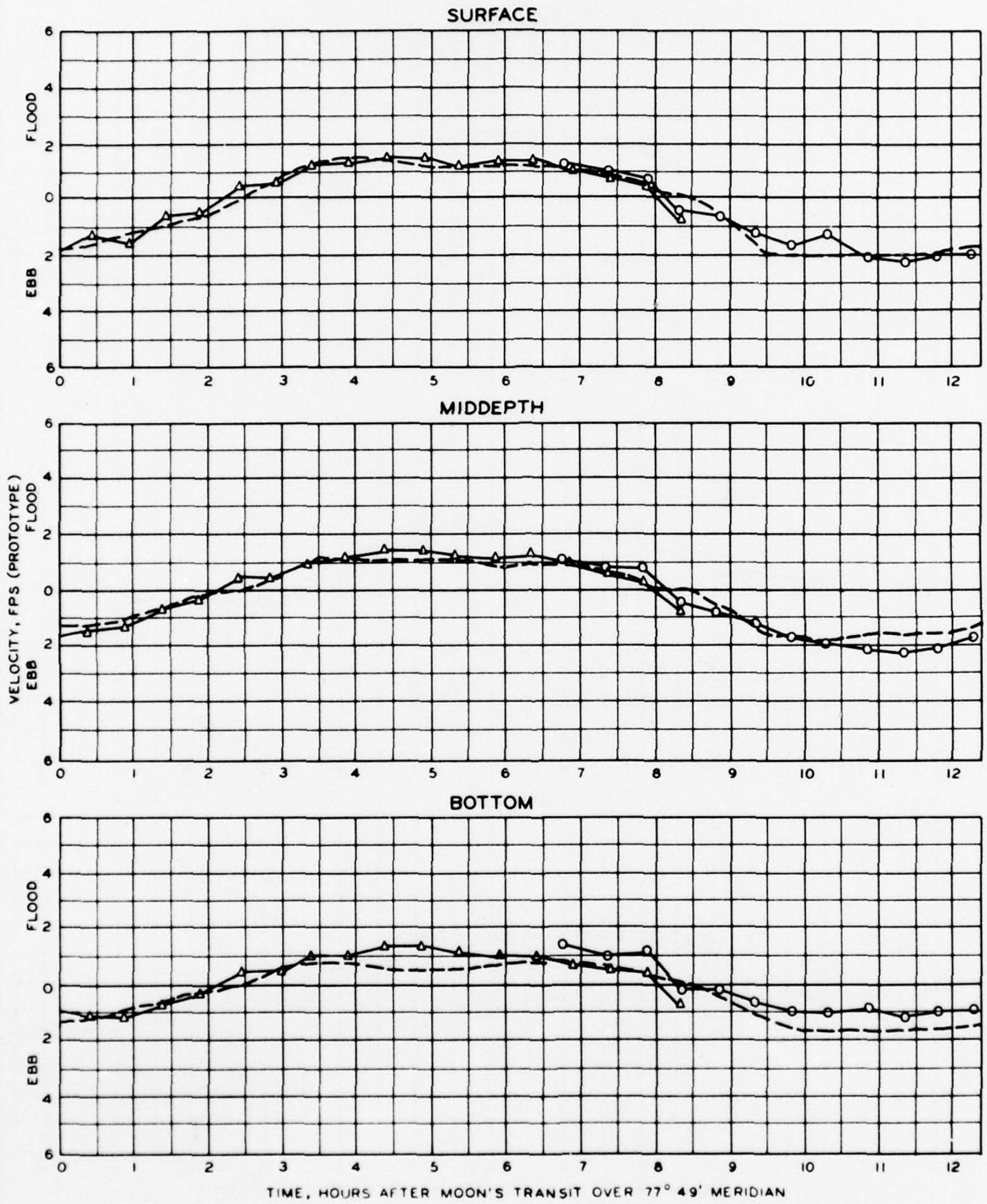
RANGE 3

PLATE 10



VERIFICATION OF
VELOCITY OBSERVATIONS

STATION S
RANGE 3



MODEL TEST DATA

TIDE 12 SEPT 1969

LEGEND

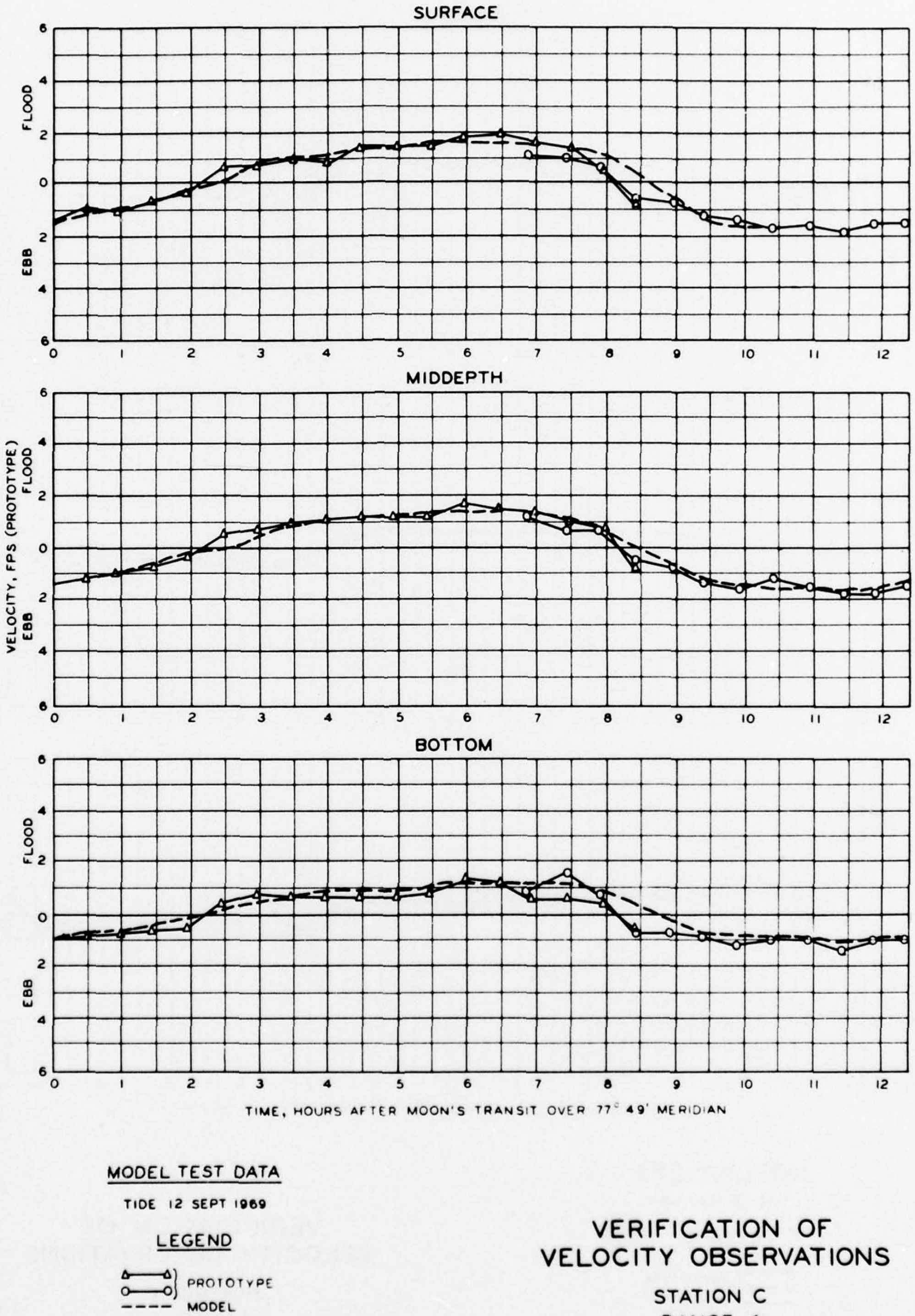
PROTOTYPE

MODEL

VERIFICATION OF VELOCITY OBSERVATIONS

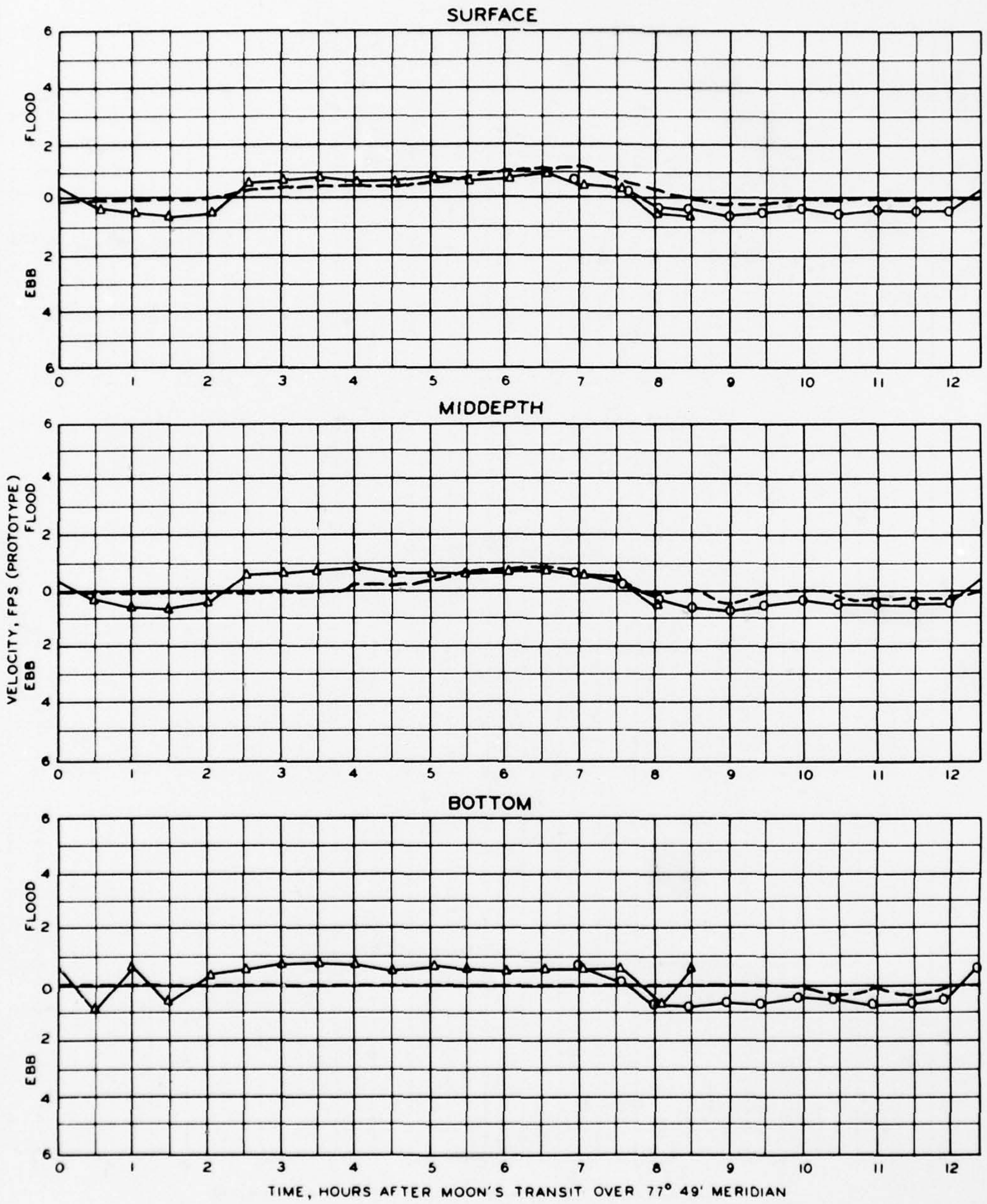
STATION E

RANGE 4



VERIFICATION OF
VELOCITY OBSERVATIONS

STATION C
RANGE 4



MODEL TEST DATA

TIDE 12 SEPT 1969

LEGEND

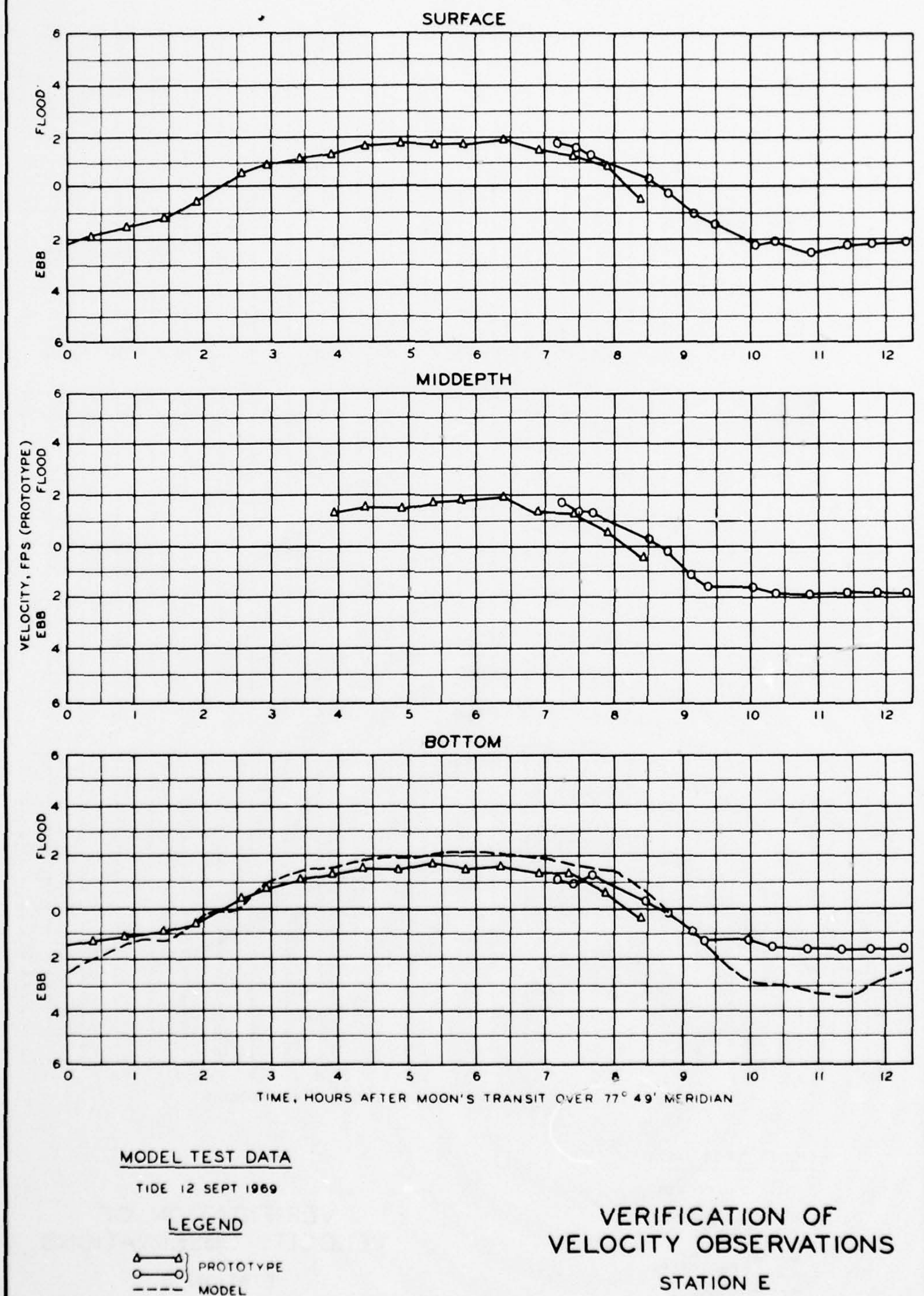
PROTOTYPE

MODEL

VERIFICATION OF
VELOCITY OBSERVATIONS

STATION W
RANGE 4

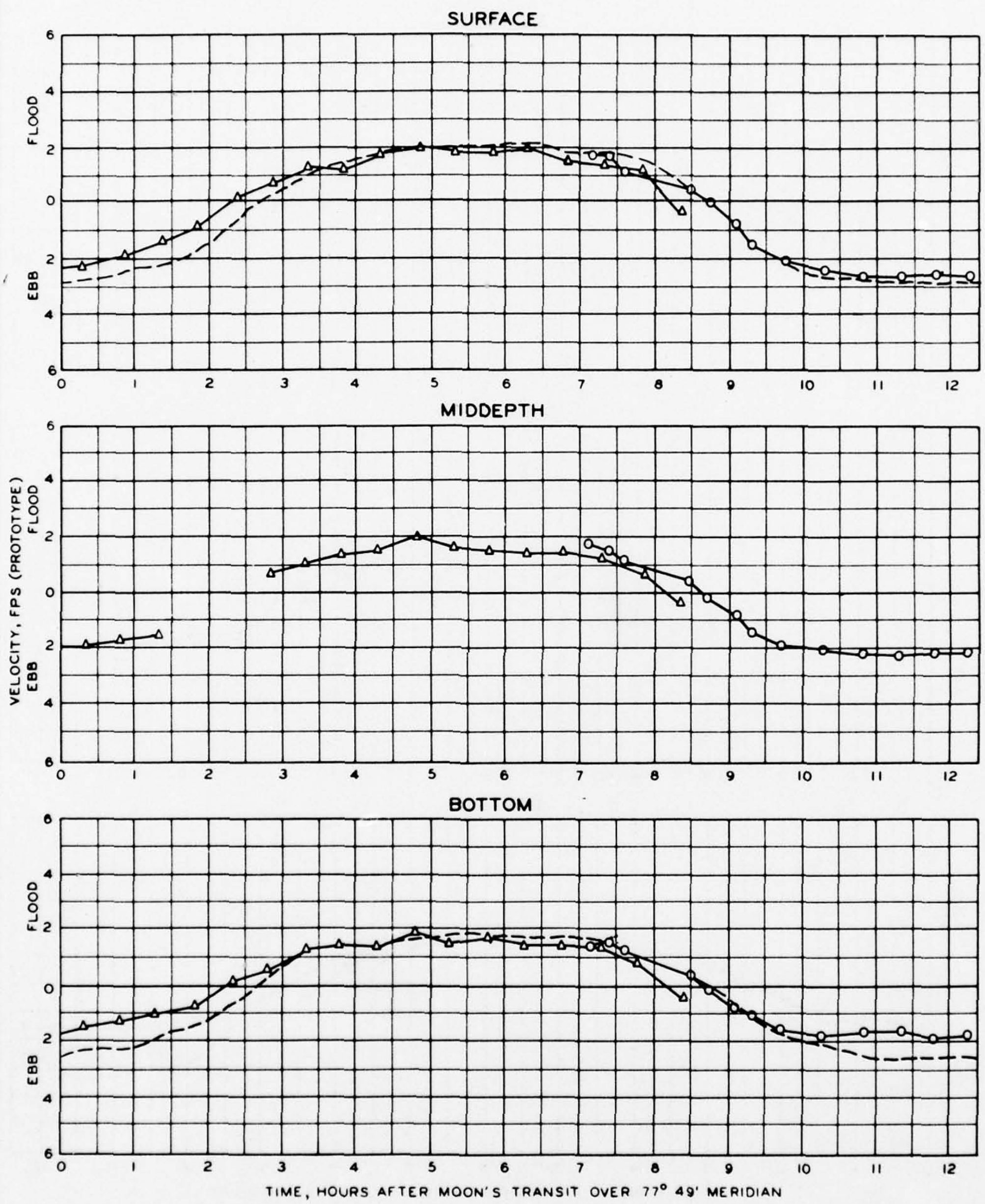
PLATE 14



VERIFICATION OF VELOCITY OBSERVATIONS

STATION E

RANGE 5



MODEL TEST DATA

TIDE 12 SEPT 1969

LEGEND

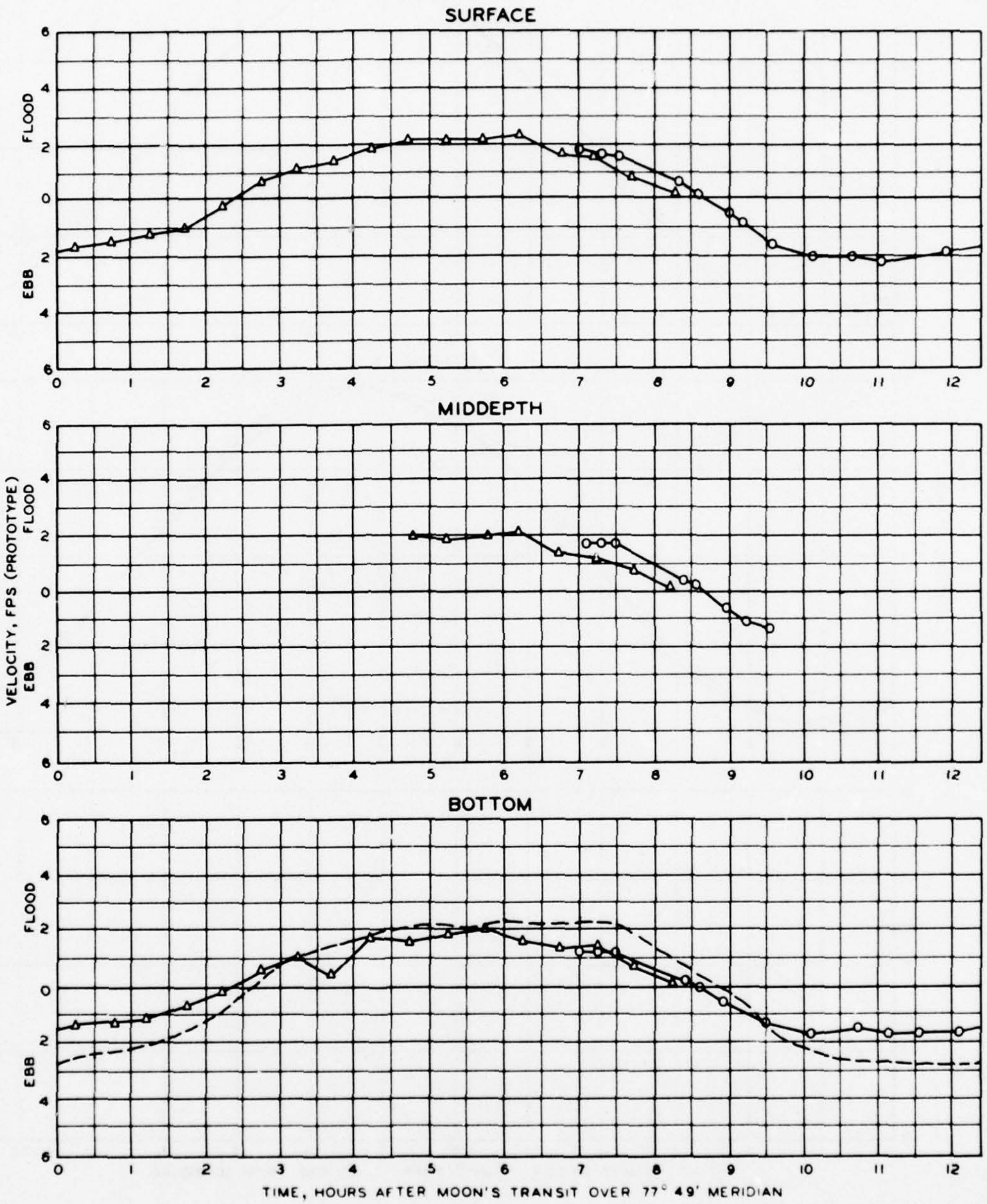
PROTOTYPE

MODEL

VERIFICATION OF
VELOCITY OBSERVATIONS

STATION C
RANGE 5

PLATE 16



MODEL TEST DATA

TIDE 12 SEPT 1969

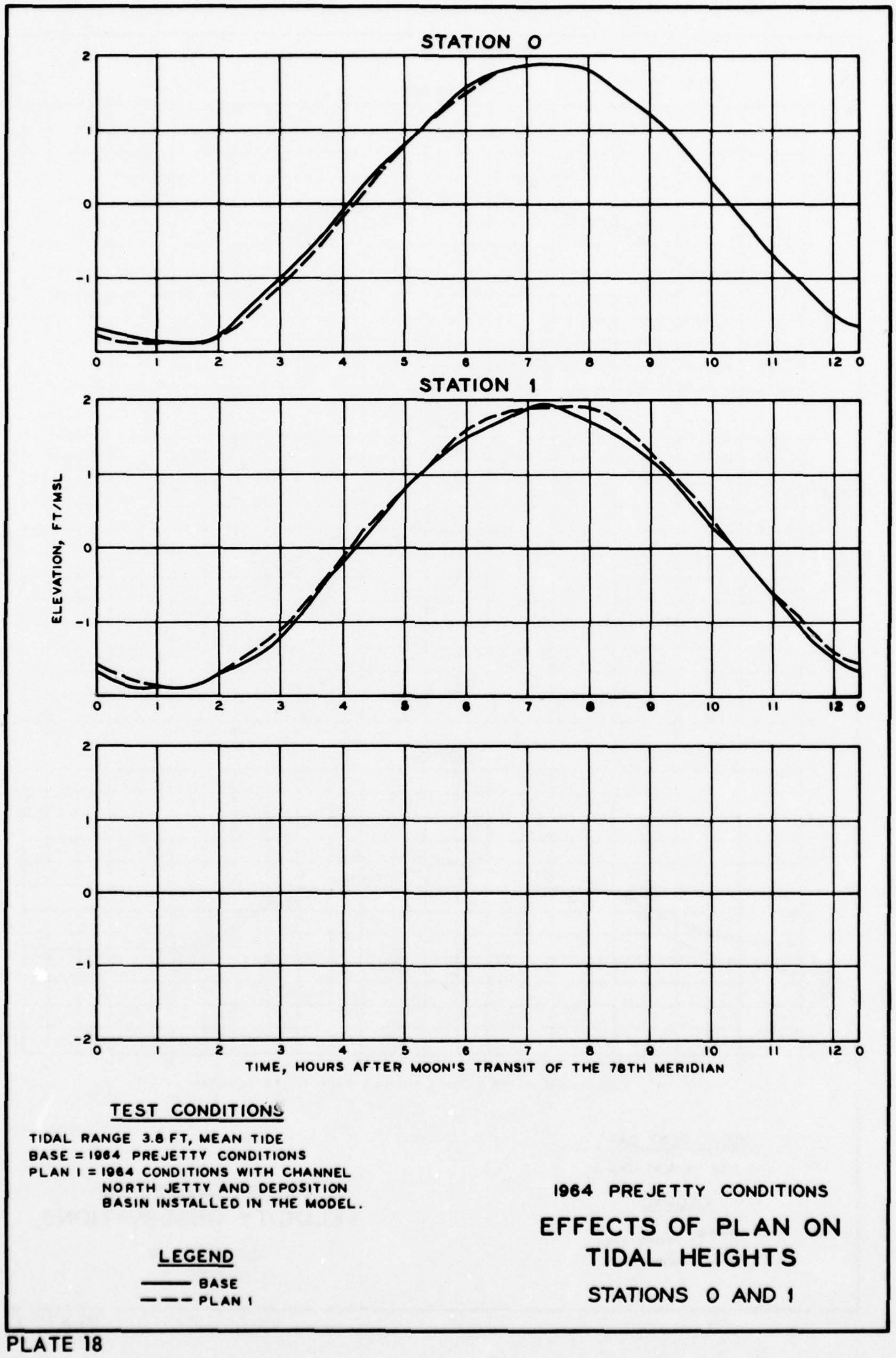
LEGEND

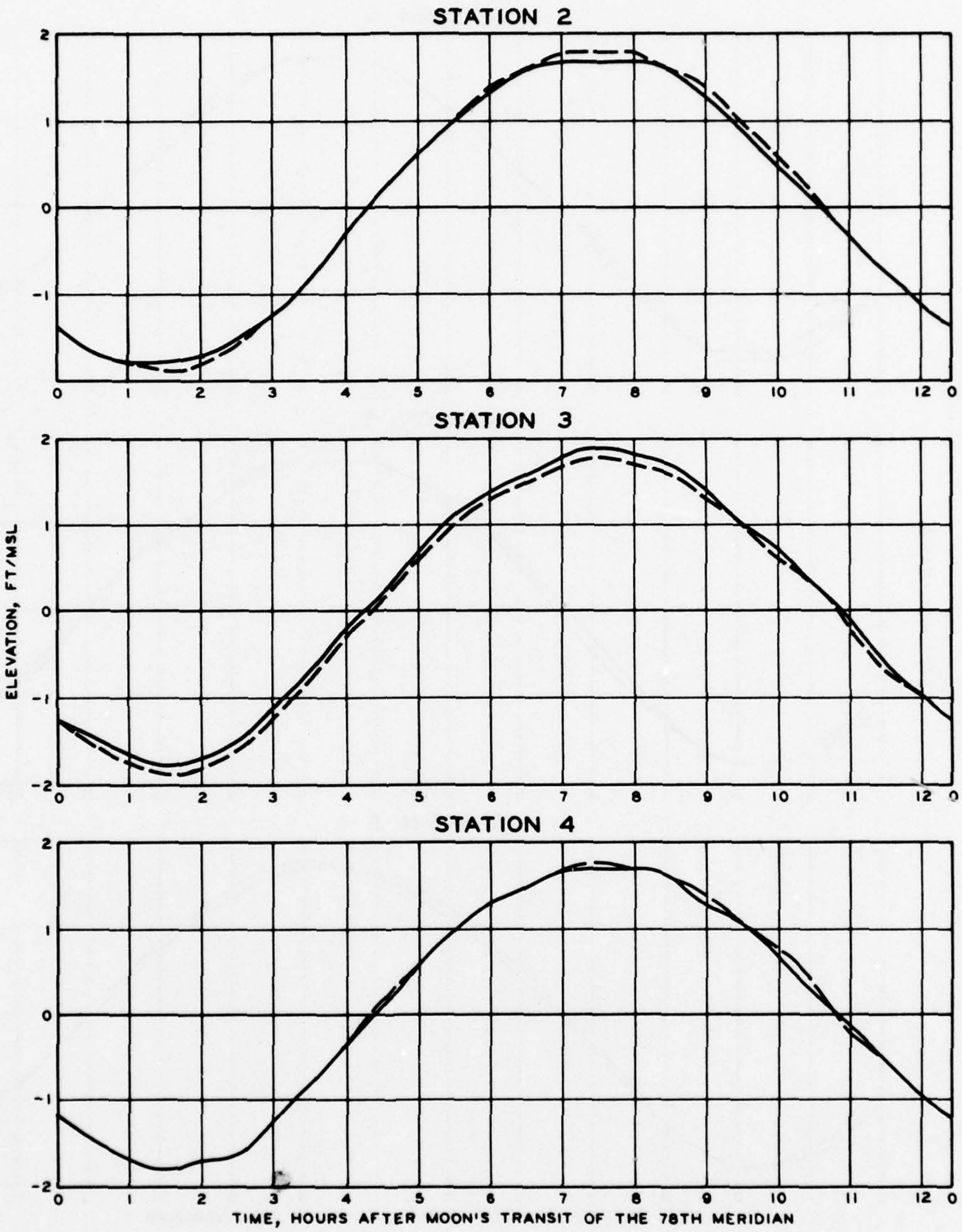
PROTOTYPE

MODEL

VERIFICATION OF
VELOCITY OBSERVATIONS

STATION W
RANGE 5


STATION 0
STATION 1
ELEVATION, FT/MSL
2
1
0
-1
-2
0 1 2 3 4 5 6 7 8 9 10 11 12 0
TIME, HOURS AFTER MOON'S TRANSIT OF THE 78TH MERIDIAN
TEST CONDITIONS
TIDAL RANGE 3.8 FT, MEAN TIDE
BASE = 1964 PREJETTY CONDITIONS
PLAN 1 = 1964 CONDITIONS WITH CHANNEL NORTH JETTY AND DEPOSITION BASIN INSTALLED IN THE MODEL.
LEGEND
BASE
PLAN 1
1964 PREJETTY CONDITIONS
EFFECTS OF PLAN ON TIDAL HEIGHTS
STATIONS 0 AND 1



TEST CONDITIONS

TIDAL RANGE 3.8 FT, MEAN TIDE
BASE = 1964 PREJETTY CONDITIONS
PLAN 1 = 1964 CONDITIONS WITH CHANNEL NORTH JETTY AND DEPOSITION BASIN INSTALLED IN THE MODEL.

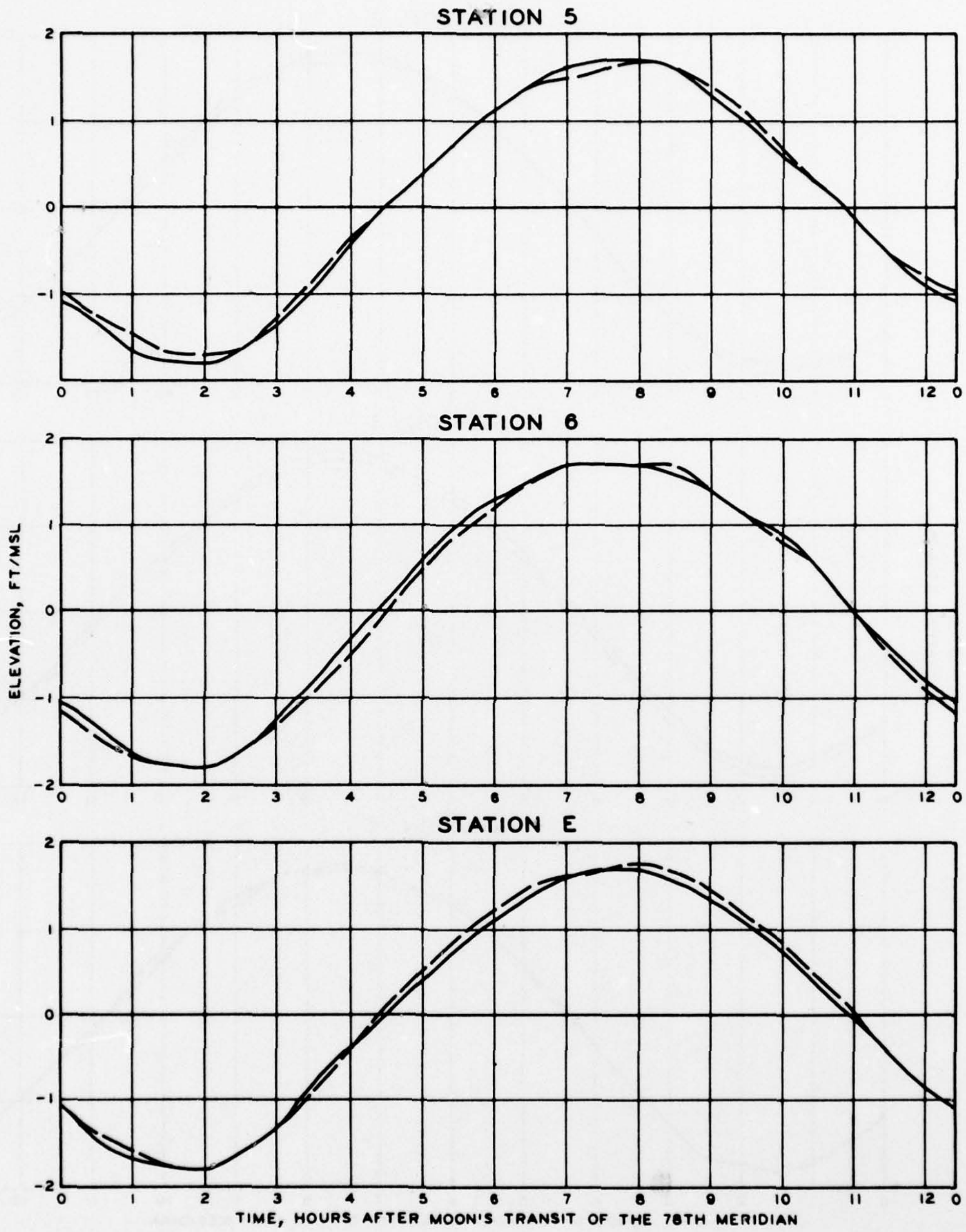
LEGEND

——— BASE
– – – PLAN 1

1964 PREJETTY CONDITIONS

EFFECTS OF PLAN ON TIDAL HEIGHTS

STATIONS 2, 3, AND 4



TEST CONDITIONS

TIDAL RANGE 3.8 FT, MEAN TIDE
BASE = 1964 PREJETTY CONDITIONS
PLAN 1 = 1964 CONDITIONS WITH CHANNEL NORTH JETTY AND DEPOSITION BASIN INSTALLED IN THE MODEL.

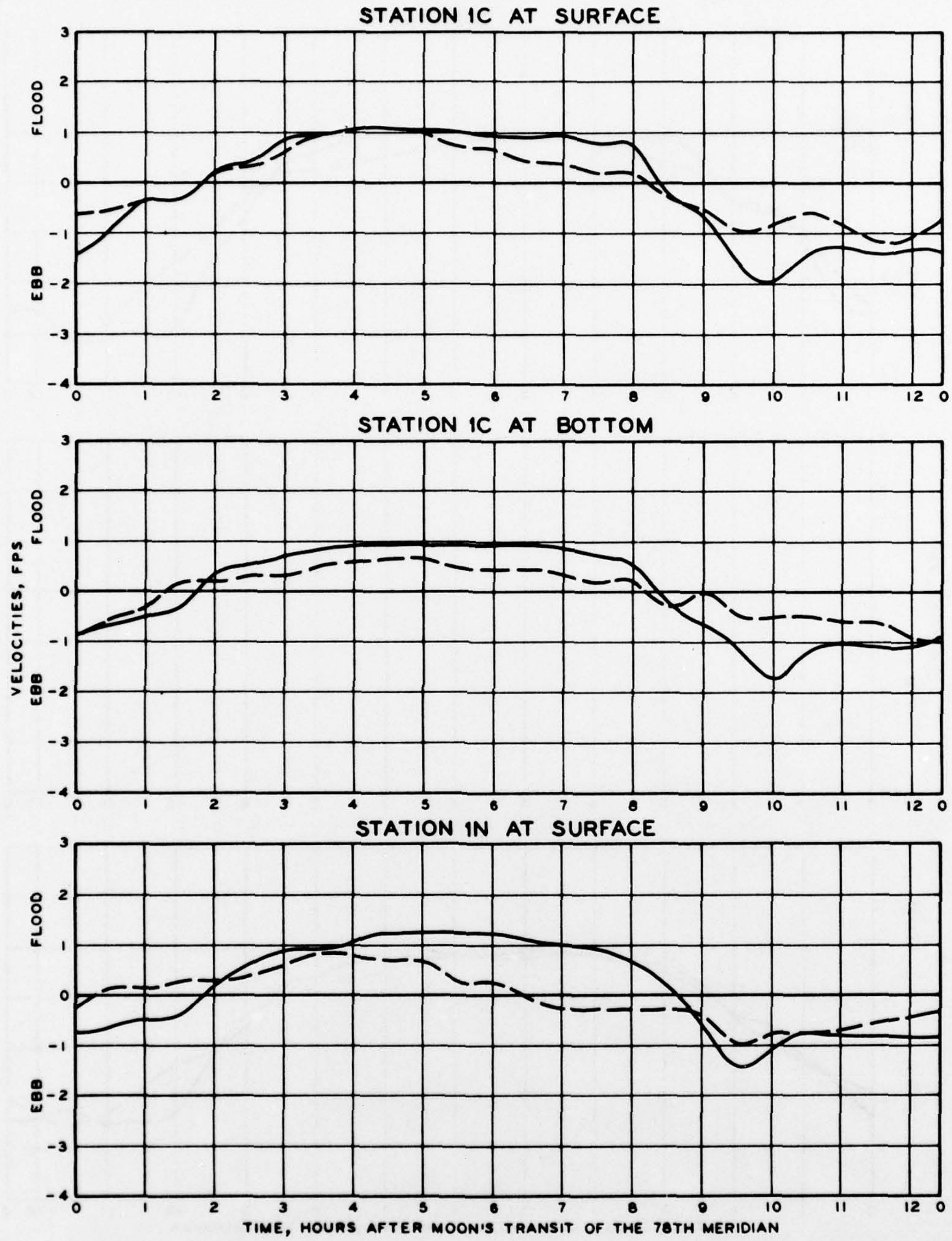
LEGEND

—— BASE
— — — PLAN 1

1964 PREJETTY CONDITIONS

EFFECTS OF PLAN ON TIDAL HEIGHTS

STATIONS 5, 6, AND E



TEST CONDITIONS

TIDAL RANGE 3.8 FT, MEAN TIDE
BASE = 1964 PREJETTY CONDITIONS
PLAN 1 = 1964 CONDITIONS WITH CHANNEL NORTH JETTY AND DEPOSITION BASIN INSTALLED IN THE MODEL.

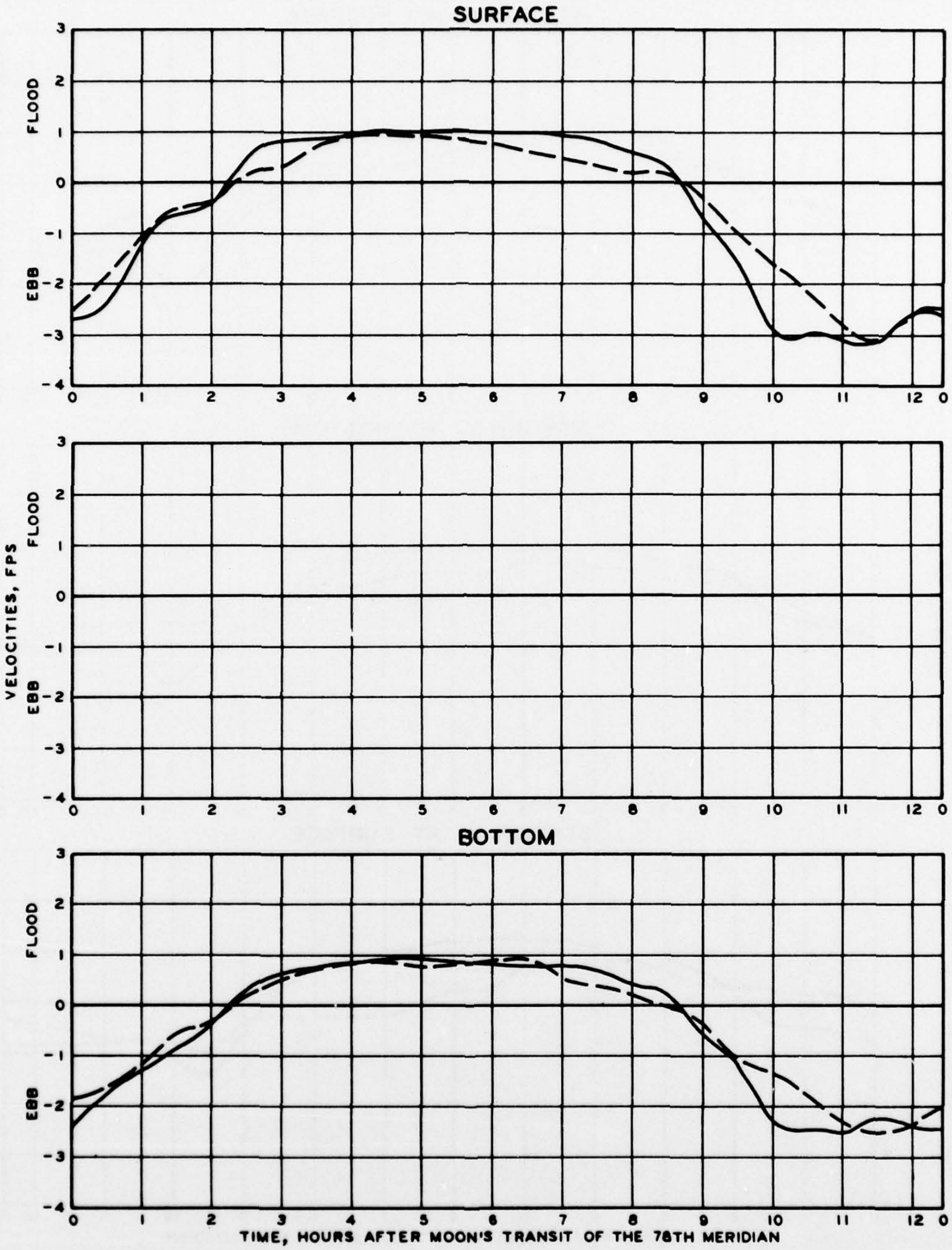
LEGEND

——— BASE
— — — PLAN 1

1964 PREJETTY CONDITIONS

EFFECTS OF PLAN ON VELOCITIES

STATIONS 1C AND 1N



TEST CONDITIONS

TIDAL RANGE 3.8 FT, MEAN TIDE
BASE = 1964 PREJETTY CONDITIONS
PLAN 1 = 1964 CONDITIONS WITH CHANNEL NORTH JETTY AND DEPOSITION BASIN INSTALLED IN THE MODEL.

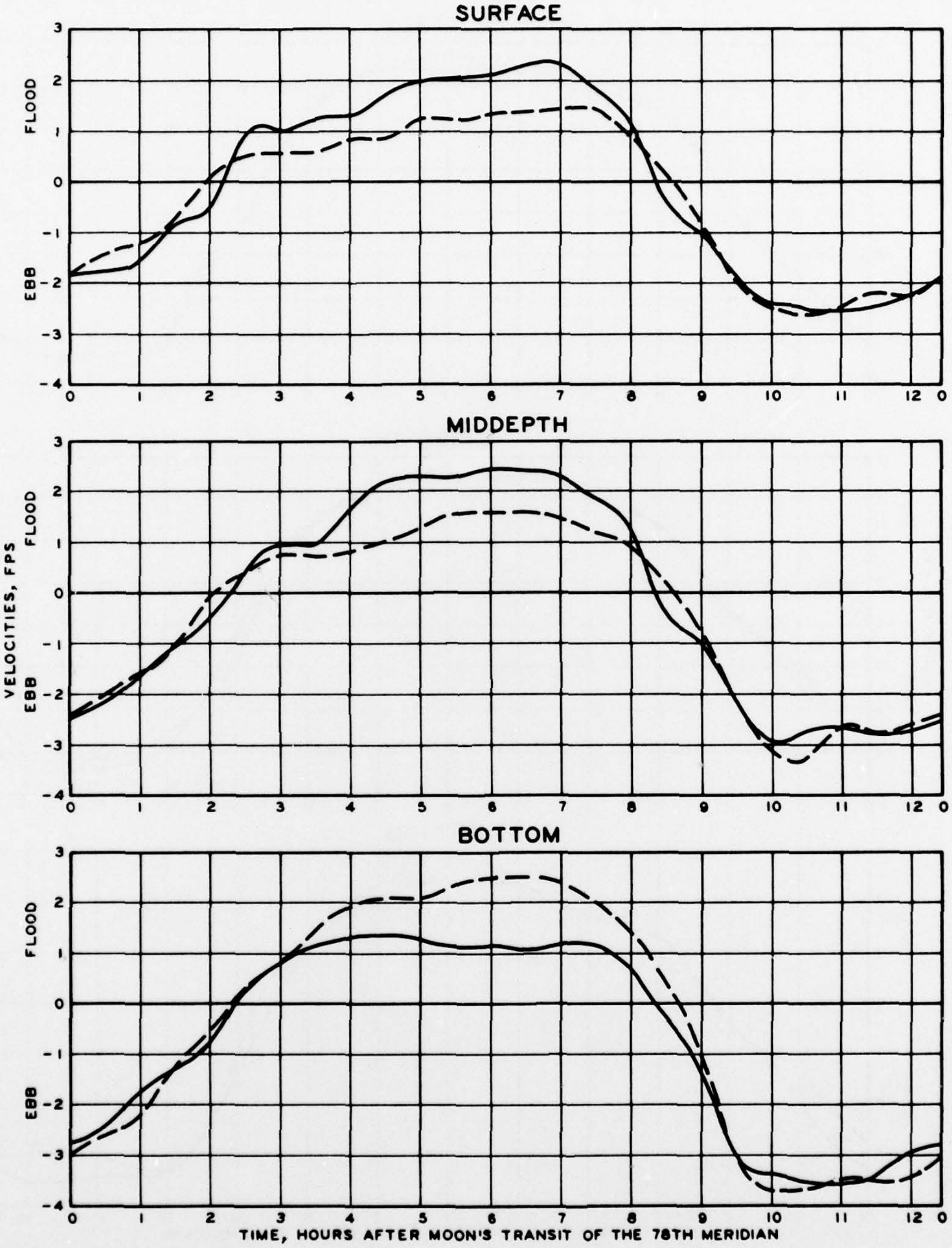
LEGEND

——— BASE
– – – PLAN 1

1964 PREJETTY CONDITIONS

EFFECTS OF PLAN ON VELOCITIES

STATION 1S



TEST CONDITIONS

TIDAL RANGE 3.8 FT, MEAN TIDE
BASE = 1964 PREJETTY CONDITIONS
PLAN 1 = 1964 CONDITIONS WITH CHANNEL NORTH JETTY AND DEPOSITION BASIN INSTALLED IN THE MODEL.

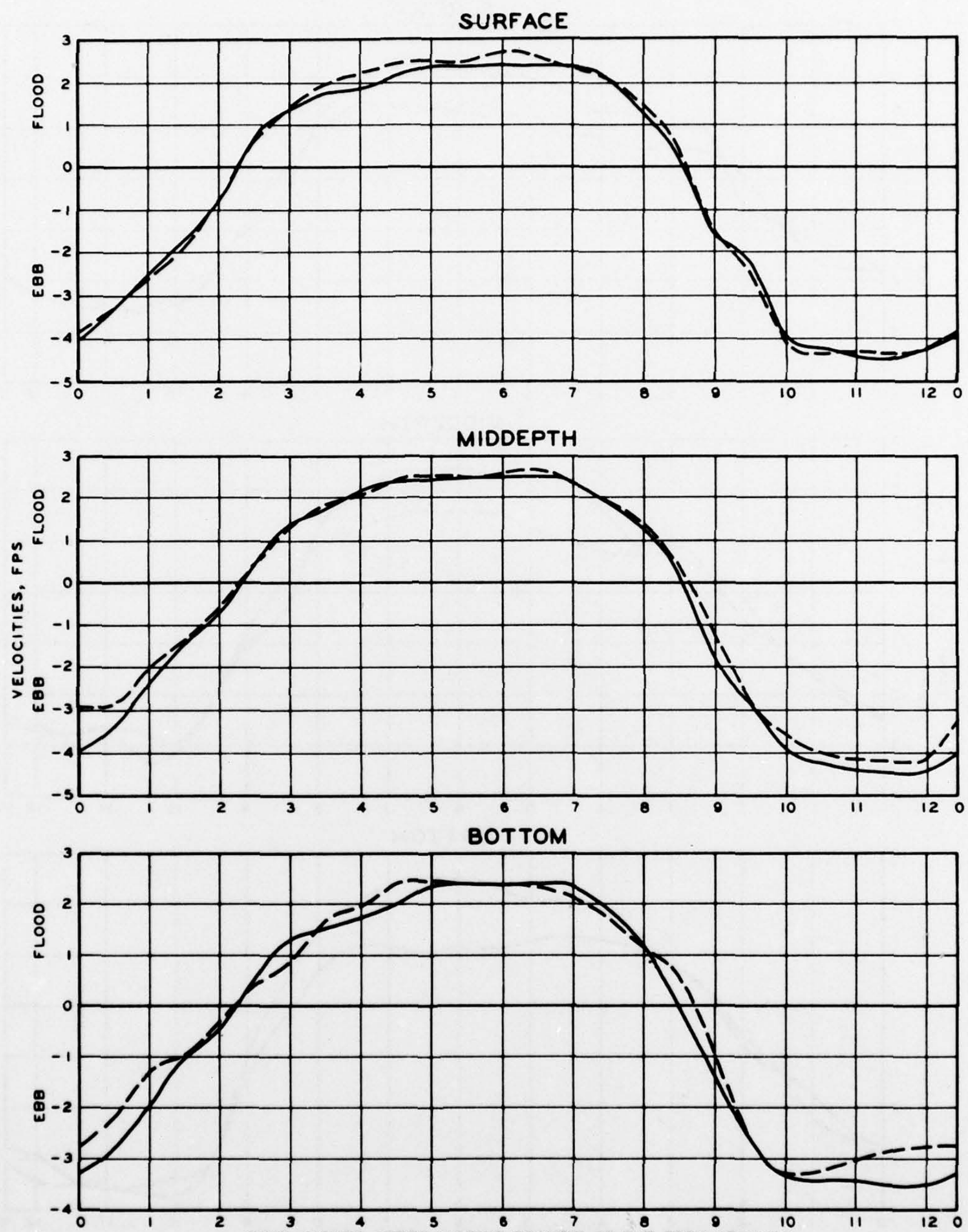
LEGEND

——— BASE
– – – PLAN 1

1964 PREJETTY CONDITIONS

EFFECTS OF PLAN ON VELOCITIES

STATION 2N



TEST CONDITIONS

TIDAL RANGE 3.8 FT, MEAN TIDE
BASE = 1964 PREJETTY CONDITIONS
PLAN 1 = 1964 CONDITIONS WITH CHANNEL NORTH JETTY AND DEPOSITION BASIN INSTALLED IN THE MODEL.

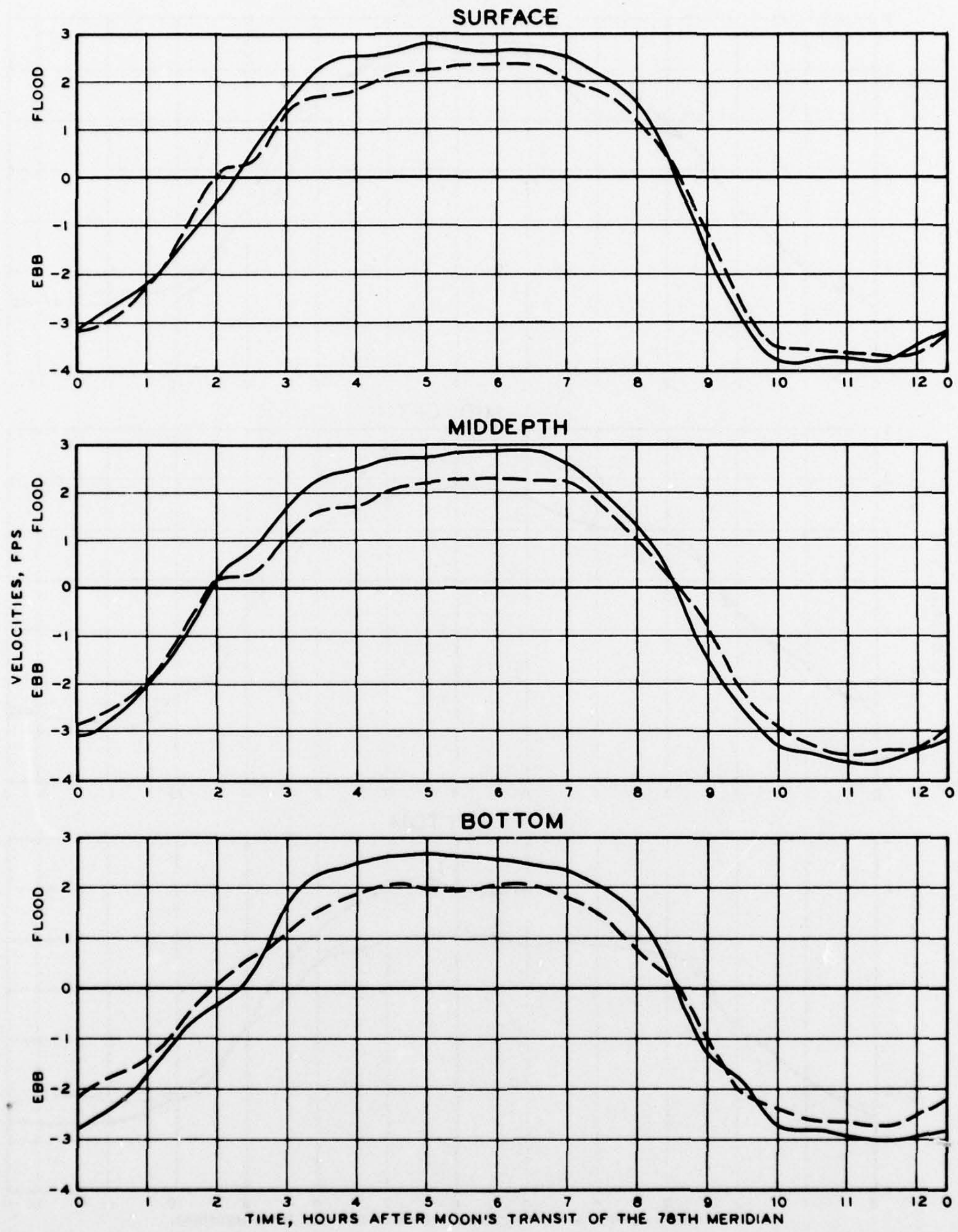
LEGEND

——— BASE
– – – PLAN 1

1964 PREJETTY CONDITIONS

EFFECTS OF PLAN ON VELOCITIES

STATION 2C



TEST CONDITIONS

TIDAL RANGE 3.8 FT, MEAN TIDE
BASE = 1964 PREJETTY CONDITIONS
PLAN 1 = 1964 CONDITIONS WITH CHANNEL NORTH JETTY AND DEPOSITION BASIN INSTALLED IN THE MODEL.

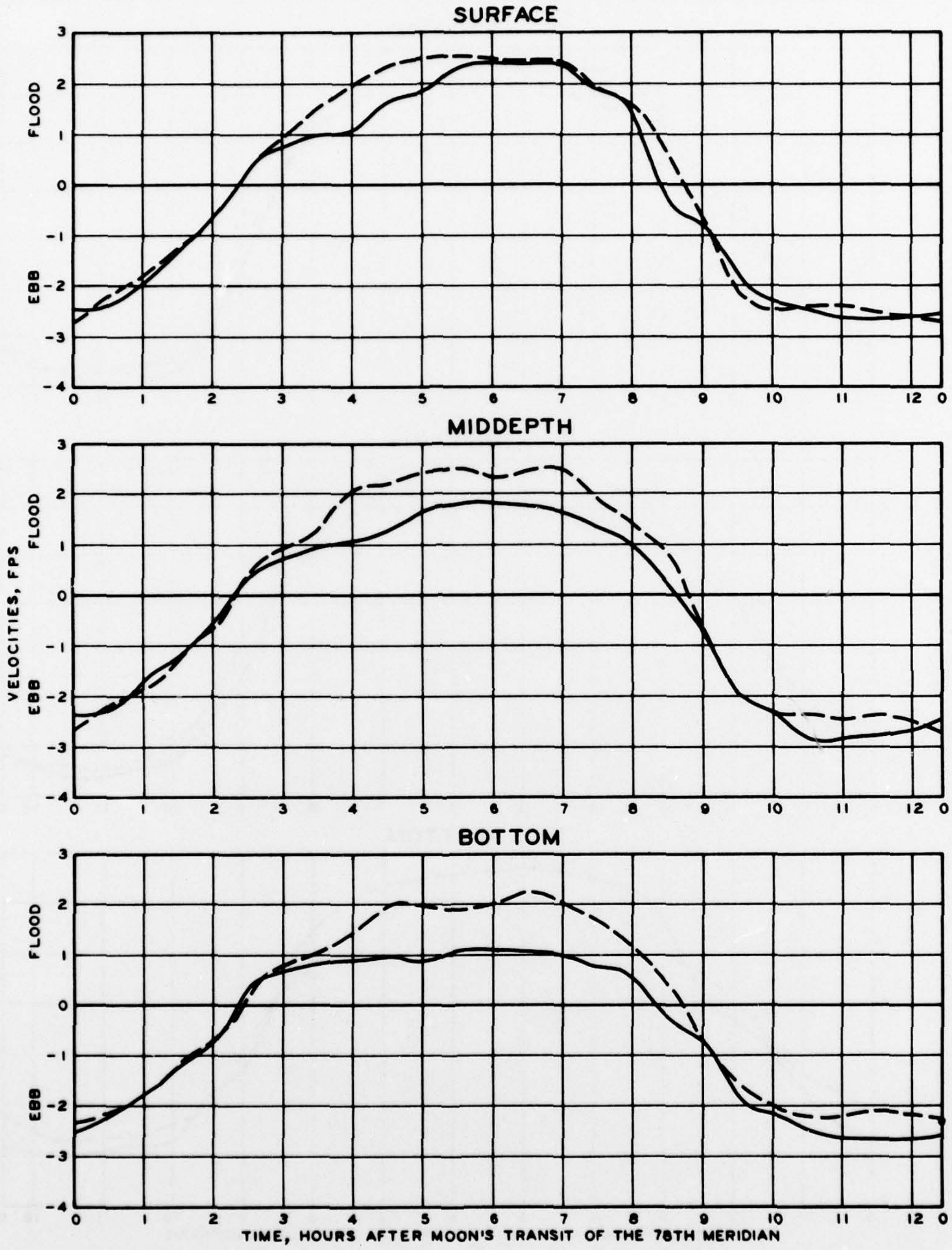
LEGEND

——— BASE
– – – PLAN 1

1964 PREJETTY CONDITIONS

EFFECTS OF PLAN ON VELOCITIES

STATION 2S



TEST CONDITIONS

TIDAL RANGE 3.8 FT, MEAN TIDE
BASE = 1964 PREJETTY CONDITIONS
PLAN 1 = 1964 CONDITIONS WITH CHANNEL NORTH JETTY AND DEPOSITION BASIN INSTALLED IN THE MODEL.

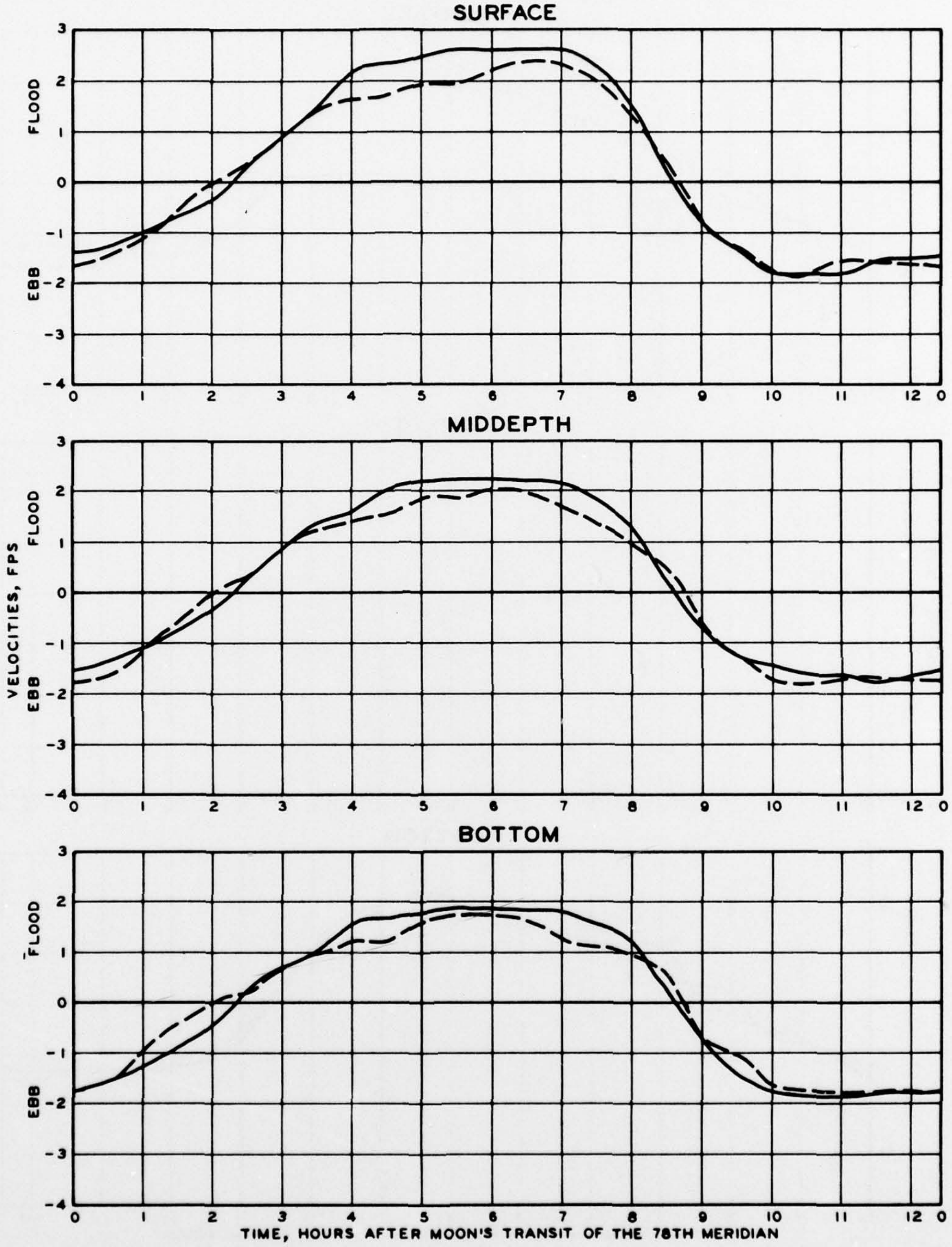
LEGEND

——— BASE
– – – PLAN 1

1964 PREJETTY CONDITIONS

EFFECTS OF PLAN ON VELOCITIES

STATION 3N



TEST CONDITIONS

TIDAL RANGE 3.8 FT, MEAN TIDE
BASE = 1964 PREJETTY CONDITIONS
PLAN 1 = 1964 CONDITIONS WITH CHANNEL NORTH JETTY AND DEPOSITION BASIN INSTALLED IN THE MODEL.

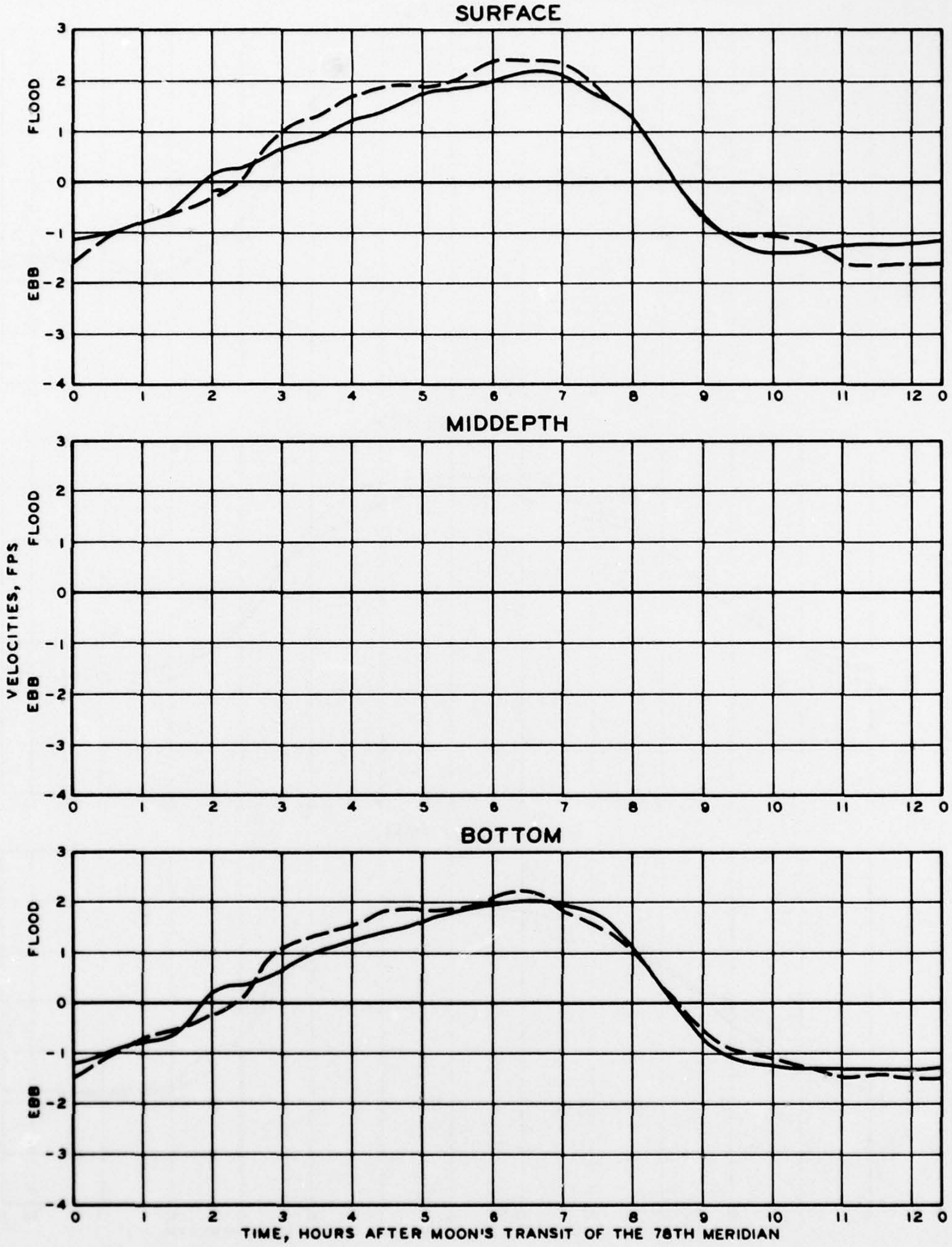
LEGEND

——— BASE
– – – PLAN 1

1964 PREJETTY CONDITIONS

EFFECTS OF PLAN ON VELOCITIES

STATION 3C



TEST CONDITIONS

TIDAL RANGE 3.8 FT, MEAN TIDE
BASE = 1964 PREJETTY CONDITIONS
PLAN 1 = 1964 CONDITIONS WITH CHANNEL NORTH JETTY AND DEPOSITION BASIN INSTALLED IN THE MODEL.

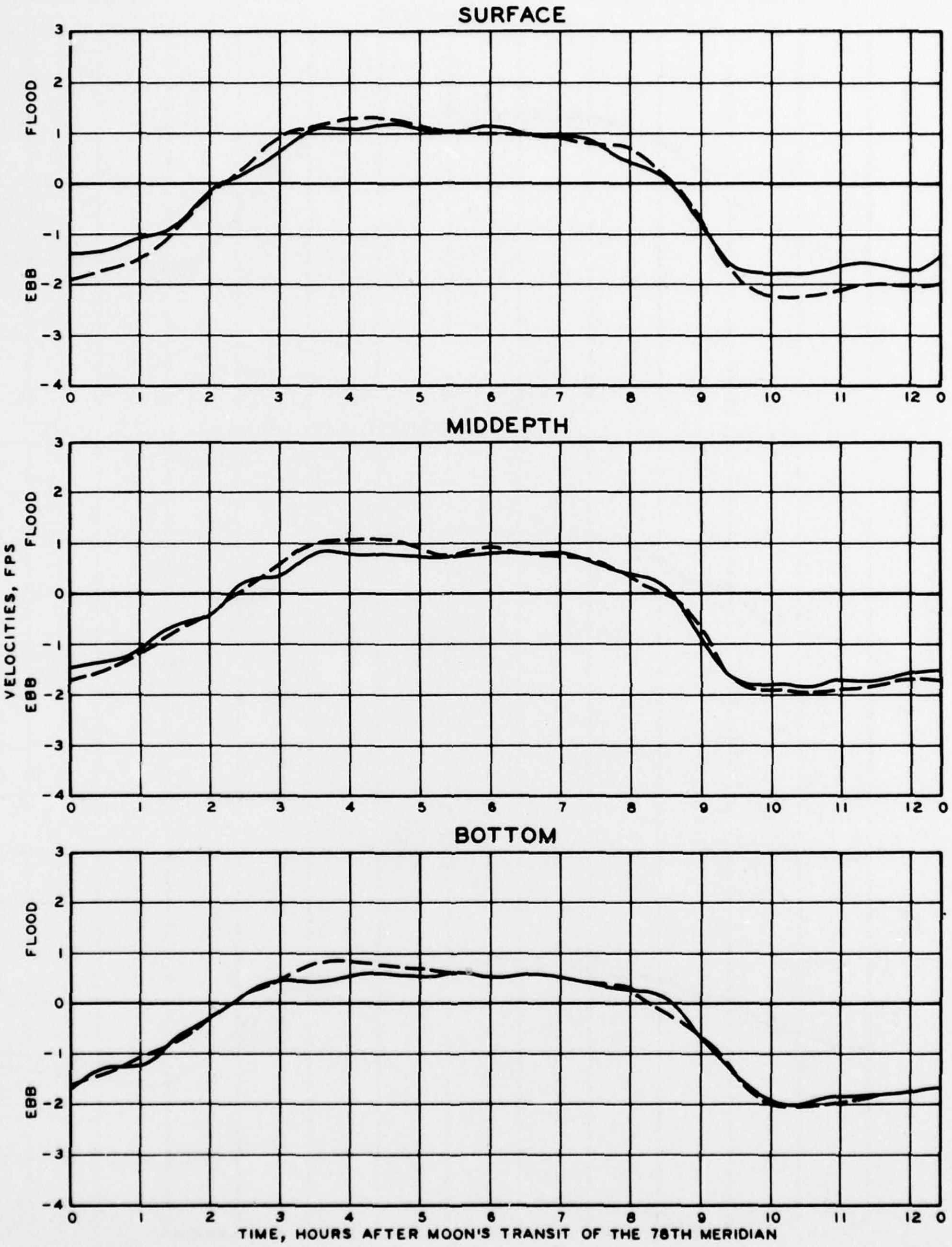
LEGEND

——— BASE
– – – PLAN 1

1964 PREJETTY CONDITIONS

EFFECTS OF PLAN ON VELOCITIES

STATION 3S



TEST CONDITIONS

TIDAL RANGE 3.8 FT, MEAN TIDE
BASE = 1964 PREJETTY CONDITIONS
PLAN 1 = 1964 CONDITIONS WITH CHANNEL NORTH JETTY AND DEPOSITION BASIN INSTALLED IN THE MODEL.

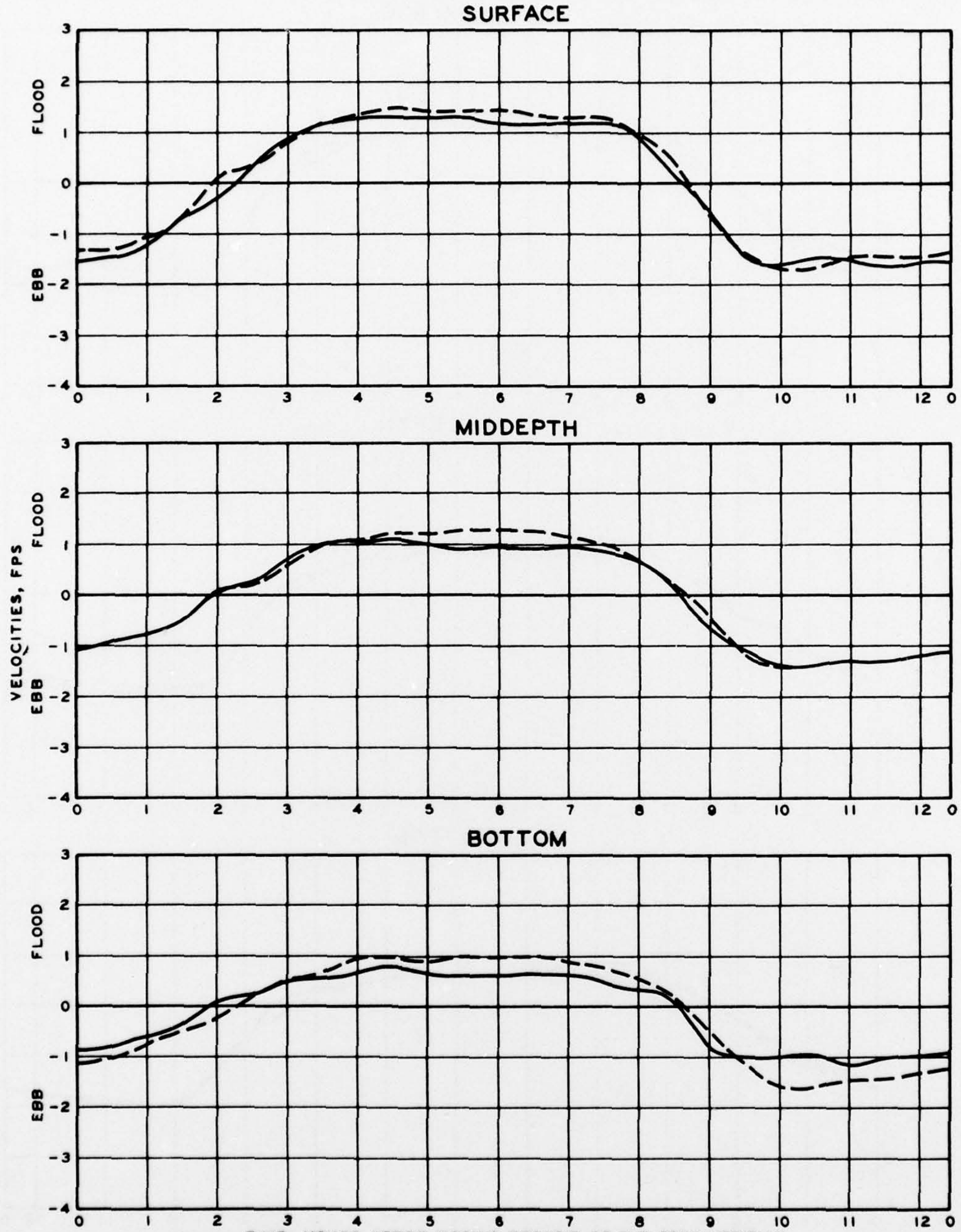
LEGEND

——— BASE
– – – PLAN 1

1964 PREJETTY CONDITIONS

EFFECTS OF PLAN ON VELOCITIES

STATION 4E



TEST CONDITIONS

TIDAL RANGE 3.8 FT, MEAN TIDE
BASE = 1964 PREJETTY CONDITIONS
PLAN 1 = 1964 CONDITIONS WITH CHANNEL NORTH JETTY AND DEPOSITION BASIN INSTALLED IN THE MODEL.

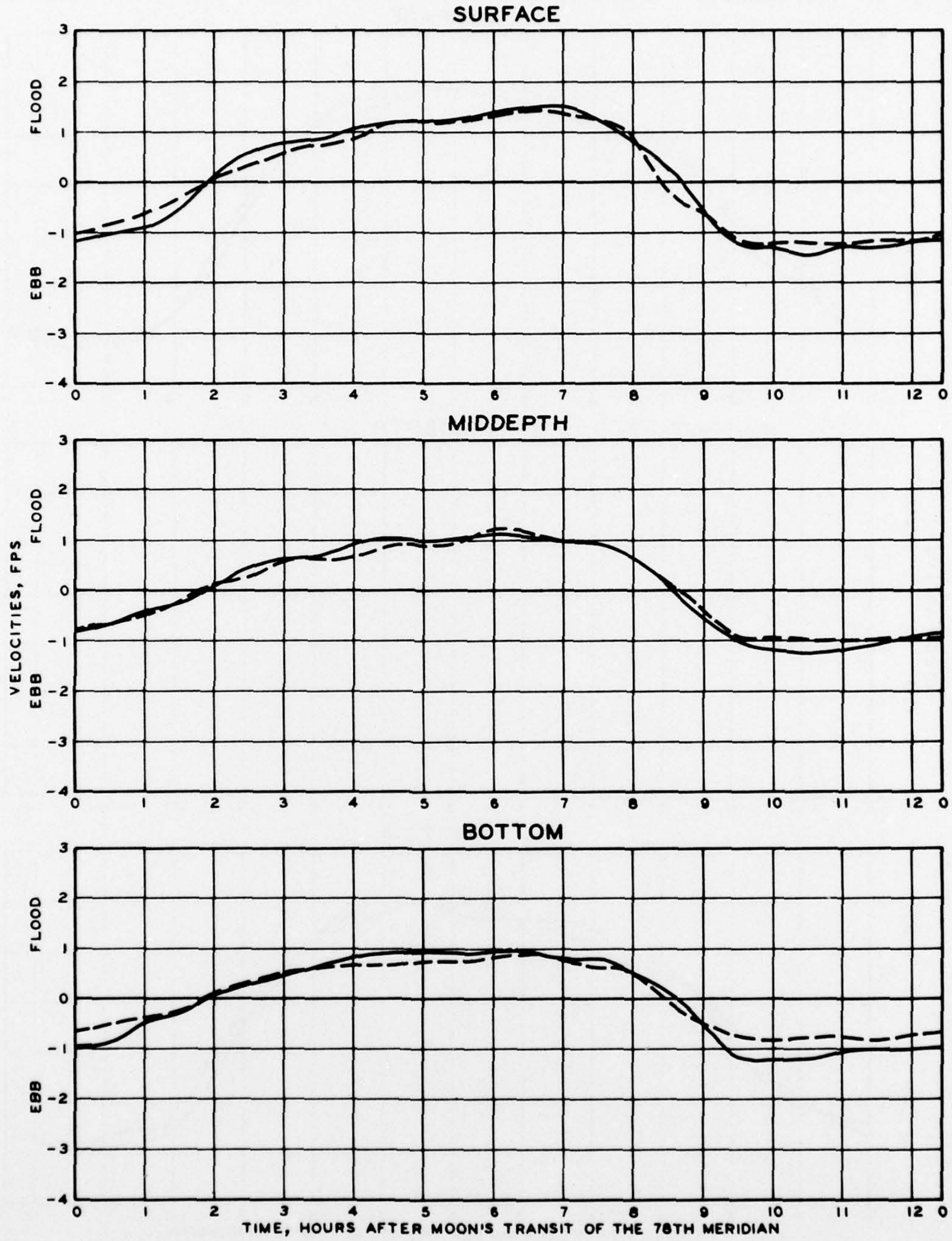
LEGEND

——— BASE
– – – PLAN 1

1964 PREJETTY CONDITIONS

EFFECTS OF PLAN ON VELOCITIES

STATION 4C



TEST CONDITIONS

TIDAL RANGE 3.8 FT, MEAN TIDE
BASE = 1964 PREJETTY CONDITIONS
PLAN 1 = 1964 CONDITIONS WITH CHANNEL NORTH JETTY AND DEPOSITION BASIN INSTALLED IN THE MODEL.

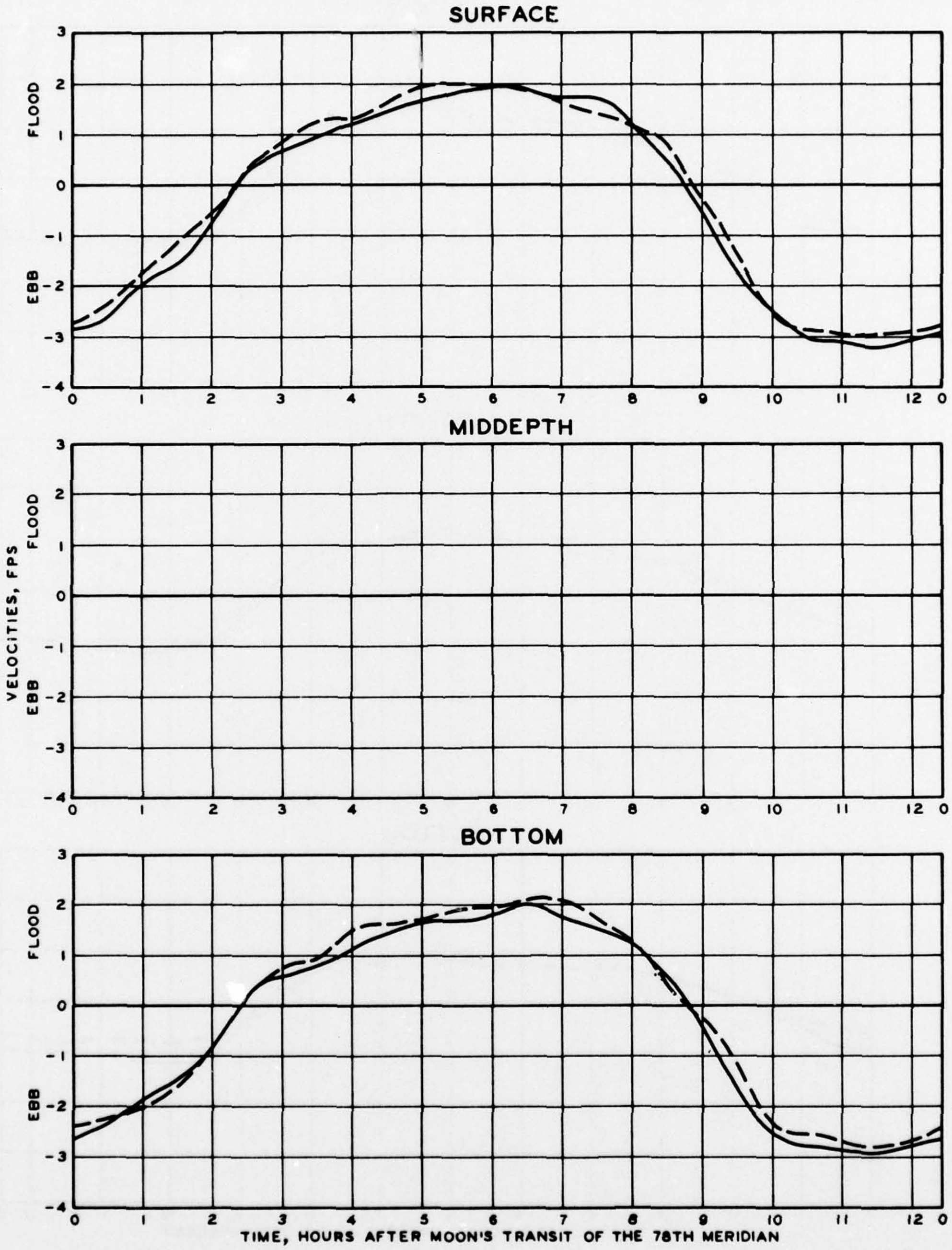
LEGEND

——— BASE
– – – PLAN 1

1964 PREJETTY CONDITIONS

EFFECTS OF PLAN ON VELOCITIES

STATION 4W



TEST CONDITIONS

TIDAL RANGE 3.8 FT, MEAN TIDE
BASE = 1964 PREJETTY CONDITIONS
PLAN 1 = 1964 CONDITIONS WITH CHANNEL NORTH JETTY AND DEPOSITION BASIN INSTALLED IN THE MODEL.

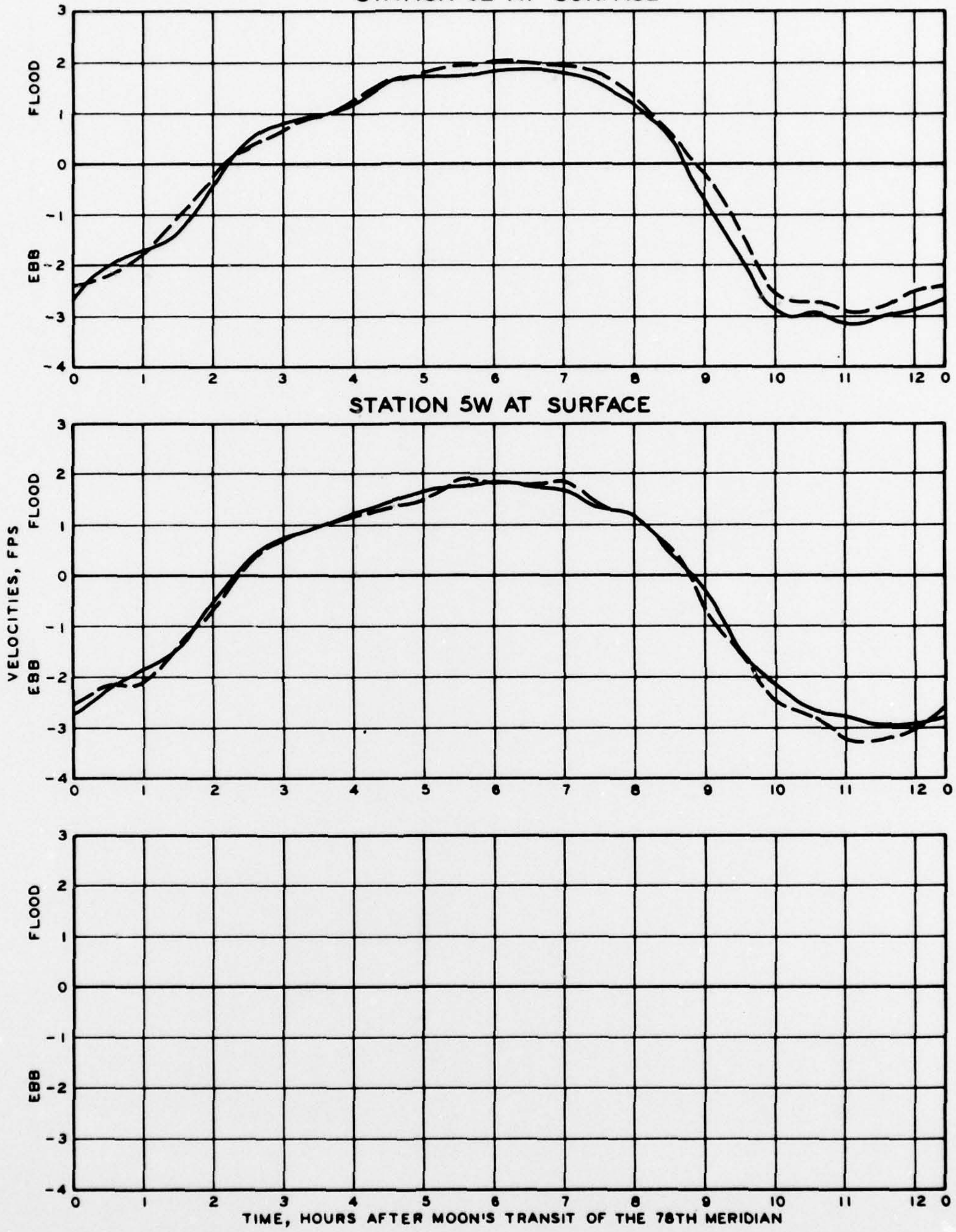
LEGEND

——— BASE
— — — PLAN 1

1964 PREJETTY CONDITIONS

EFFECTS OF PLAN ON VELOCITIES

STATION 5C



TEST CONDITIONS

TIDAL RANGE 3.8 FT, MEAN TIDE
BASE = 1964 PREJETTY CONDITIONS
PLAN 1 = 1964 CONDITIONS WITH CHANNEL NORTH JETTY AND DEPOSITION BASIN INSTALLED IN THE MODEL.

LEGEND

——— BASE
– – – PLAN 1

1964 PREJETTY CONDITIONS

EFFECTS OF PLAN ON VELOCITIES

STATIONS 5E AND 5W

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Sager, Richard Allan

Comparison of numerical and physical hydraulic models, Masonboro Inlet, N. C.; Appendix 1: Fixed-bed hydraulic model results / by Richard A. Sager, William C. Seabergh. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1977.

30, [6] p., 33 leaves of plates : ill. ; 27 cm. (GITI report - U. S. Army. Corps of Engineers ; 6, Appendix 1)

General investigation of tidal inlets; a program of research conducted jointly by U. S. Army Coastal Engineering Research Center, Fort Belvoir, Virginia, [and] U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

1. Fixed-bed models. 2. Hydraulic models. 3. Masonboro Inlet, N. C. 4. Mathematical models. 5. Model tests. 6. Tidal inlets. 7. Tidal models. I. Seabergh, William C., joint author. II. United States. Coastal Engineering Research Center. III. United States. Waterways Experiment Station, Vicksburg, Miss. IV. Series: United States. Army. Corps of Engineers. GITI report ; 6, Appendix 1.

GB454.T5.U5 no.6 Appendix 1