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20. ABSTRACT (Continued).

connecting Lake Pontchartrain with the Gulf of Mexico and the lock/structure system between the lake and the Inner Harbor Navigation Canal (IHNC).

The basic approach to simulating the impact of structural alterations on the Lake Pontchartrain tidal prism can be outlined as follows:

- a. Develop a numerical model of the three basin system (Lakes Pontchartrain, Borgne, and Maurepas).
- b. Obtain and analyze field data to aid in calibrating and verifying the lake system model (Report 1 of the subject series, Outlaw 1982).
- c. Perform sectional model studies of each pass (Report 2 of the subject series, Butler et al. 1982) to provide descriptions of structure hydraulic characteristics to the numerical tidal prism model.
- d. Calibrate and verify the tidal prism model and test plan impact under mean, spring, and neap tide conditions.

Preliminary calculations with these tide conditions indicated difficulty in assessing the true impact of the hurricane protection plan on the tidal prism of Lake Pontchartrain. Consequently, a follow-up investigation of the effect of tidal range variation was made by simulating the structure system impact over a spring-to-neap-to-spring tidal period (semilunar month). In addition, computations were made to simulate the effect of a Bonnet Carre Floodway operation.

In the development of the numerical model, a new boundary condition treatment was formulated for the IHNC to permit simulation of construction changes in the model interior without being forced to move the model boundary beyond influence of the changes. The tidal prism model was shown to accurately portray tidal behavior through the passes and to reproduce observed astronomical surface elevations throughout the region.

Impact of the proposed control structures and the Seabrook Lock on the tidal prism of Lake Pontchartrain was shown to be minimal. Approximate percentage reductions in the tidal prism for the individual entrance passes are: Rigolets (9 percent), Chef Menteur (12 percent), and IHNC (21 percent). Model results showed a net reduction of 10 percent in the lake tidal prism with the barrier plan. When a 2 percent adjustment for omitting shallow navigation channels in The Rigolets and Chef Menteur plans is taken into account, the total impact of the barrier plan on net tidal exchange with the lake is to reduce the tidal prism about 8 percent.

It was found that lake circulation is unaffected by installation of the structures except in areas local to the individual structures. Impact of the proposed hurricane protection barrier plan during a Bonnet Carre Floodway operation is minimal. Simulation of a floodway operation (to full capacity) under existing conditions showed that a 1.5 ft rise in average lake stage would occur. With the barrier plan in place the average lake stage rose about 1.8 ft, an increase of only 0.3 ft.

Report reviews by project consultants are provided verbatim in Appendix B.

PREFACE

The study described herein was authorized by the U. S. Army Engineer District, New Orleans, under the general direction of Mr. F. Chatry, Chief of the Engineering Division. The investigation was conducted at the U. S. Army Engineer Waterways Experiment Station (WES) during the period August 1978 to September 1981 in the Hydraulics Laboratory by Mr. H. L. Butler under the direction of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory, and Dr. R. W. Whalin, former Project Manager and Chief of the Wave Dynamics Division (WDD), and Mr. C. E. Chatham, Jr., former acting Chief, WDD. The WDD and its personnel were transferred to the Coastal Engineering Research Center (CERC) of WES on 1 July 1983 under the direction of Dr. R. W. Whalin, Chief of CERC.

Numerical computations associated with this work were performed on CYBER 126 and CRAY 1 computers located at the Air Force Weapons Laboratory, Kirtland AFB, New Mexico.

Commanders and Directors of WES during the course of this investigations and the preparation and publication of this report were COL John L. Cannon, CE, COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

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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:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
cubic feet per second	0.02831685	cubic feet per second
feet	0.3048	metres
feet per second	0.3048	metres per second
inches	25.4	millimetres
miles (U. S. statute)	1.609344	kilometres

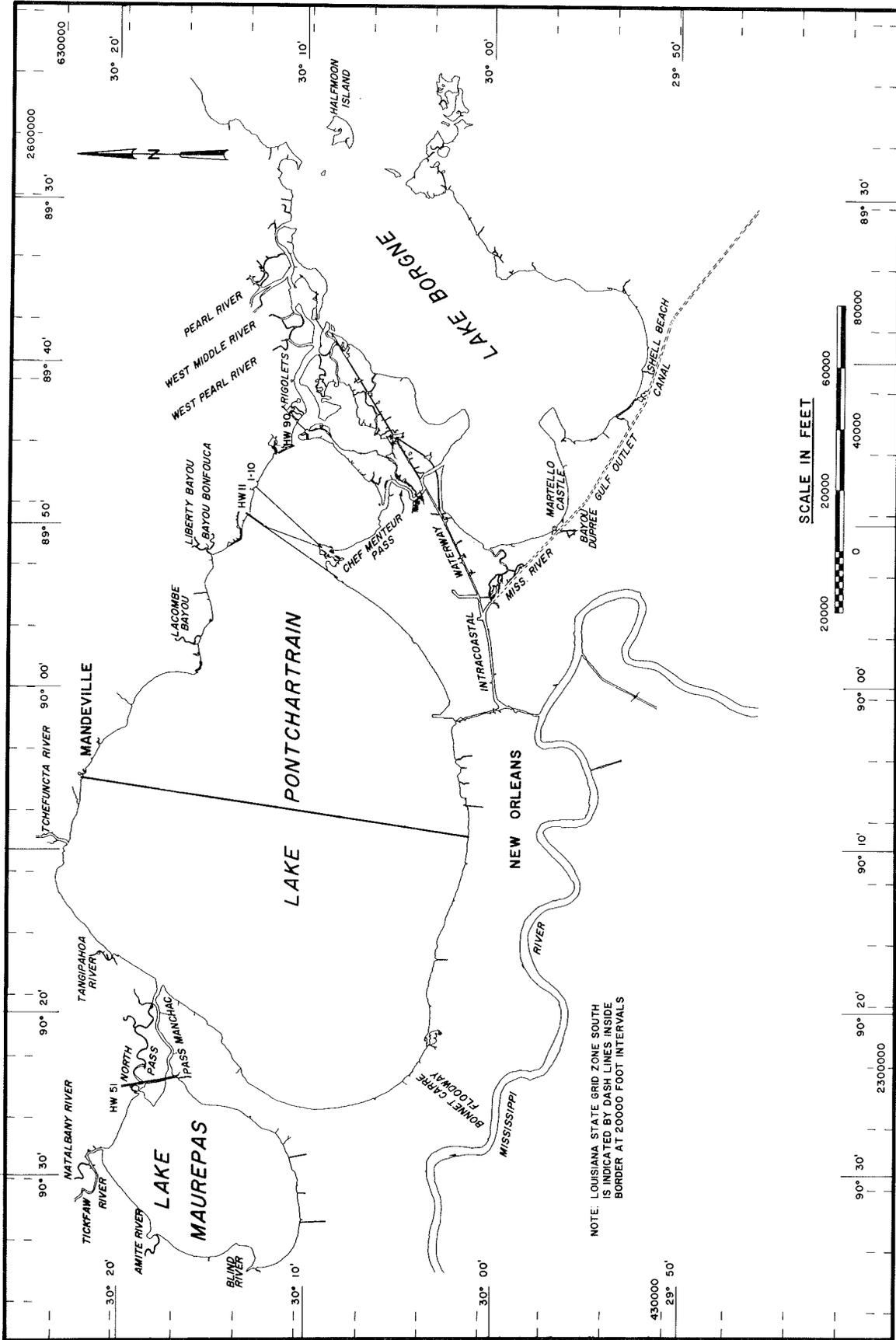


Figure 1. Vicinity map

LAKE PONTCHARTRAIN AND VICINITY HURRICANE PROTECTION PLAN

NUMERICAL MODEL INVESTIGATION OF PLAN IMPACT ON THE TIDAL PRISM OF LAKE PONTCHARTRAIN

PART I: INTRODUCTION

Background

1. A comprehensive study to evaluate effects of the Lake Pontchartrain and Vicinity Hurricane Protection Plan on the tidal prism and circulation in Lake Pontchartrain, hurricane surge levels, and water quality is being conducted by the U. S. Army Engineer Waterways Experiment Station (WES) under sponsorship of the U. S. Army Engineer District, New Orleans (LMN). Results of this study are to be presented in a series of reports published under the general title "Lake Pontchartrain and Vicinity Hurricane Protection Plan." The major tool employed in the numerous investigations carried out in the course of this study is a numerical hydrodynamic model (WES Implicit Flooding Model, WIFM), developed at WES, which is capable of simulating both tidal effects and hurricane surge flooding. This report, the third of the series, presents results pertinent to a detailed investigation of effects of proposed structures in the two major arteries (The Rigolets and Chef Menteur Pass) connecting Lake Pontchartrain with the Gulf of Mexico and the lock/structure system between the lake and the Inner Harbor Navigation Canal (IHNC or Seabrook Canal).

2. Lake Pontchartrain is adjacent to and just north of the city of New Orleans, Louisiana (Figure 1). The principal connections to the Gulf of Mexico are The Rigolets and Chef Menteur Pass (which are natural passes), and the IHNC and Mississippi River-Gulf Outlet (MR-GO) (which is a man-made gulf-level canal). The Rigolets and Chef Menteur Pass connect Lake Pontchartrain with Lake Borgne. The MR-GO eventually exits into the more saline Gulf of Mexico; consequently, this small canal serves as a major source of salinity for Lake Pontchartrain. In addition,

Lake Maurepas is connected to the west end of Lake Pontchartrain by Pass Manchac. Lakes Maurepas, Pontchartrain, and Borgne make up the three-lake system modeled.

3. An earlier investigation to study effects of proposed hurricane protection plans was conducted at WES (USAWES 1963). A fixed-bed hydraulic model, constructed to scales of 1:2000 horizontally and 1:100 vertically, was used to determine effects of gated structures (component parts of a proposed hurricane protection plan for New Orleans) to be placed in the three major arteries leading into Lake Pontchartrain. The study was conducted prior to construction of the MR-GO. These early tests indicated that the hurricane protection plan would have a minimal effect on lake hydraulic characteristics.

4. Later, tests of revised plans for The Rigolets structure were conducted by Berger and Boland (1976). Here an attempt to quantify the hydraulic characteristics of various structure alternatives for The Rigolets was made by constructing an undistorted-scale physical model of a portion of The Rigolets Pass near its entrance to Lake Pontchartrain. Results indicated a reduction in the lake tidal prism of less than 10 percent due solely to the adopted structure plan for The Rigolets.

5. A court action imposing an injunction restraining the U. S. Army Corps of Engineers from proceeding with certain portions of the Lake Pontchartrain and Vicinity Hurricane Protection Project precipitated this investigation. In particular, the Corps Environmental Impact Statement of 1974 was not found to be in compliance with Federal law requirements. In response to the court's concerns, LMN requested additional studies of the proposed protection plan utilizing state-of-the-art modeling techniques to quantify plan effects. The proposed study included the following tasks: prototype data acquisition and analysis, hydraulic model testing of the Chef Menteur Pass structure and the Seabrook Lock system, numerical model testing of plan effects on the tidal prism and circulation of Lake Pontchartrain, and numerical surge model testing of plan effects under storm attack.

Objective and Approach

6. The objective of this study was to evaluate effects of the hurricane protection plan on the tidal prism of and circulation within Lake Pontchartrain. This objective was met by utilizing results of related studies reported in the subject series of reports. The key to successful modeling of the lake hydrodynamics lies in correctly simulating water flow through the passes and the impact of a hydraulic structure, like a gated hurricane barrier, on that flow.

7. Gated control structures were proposed in The Rigolets and Chef Menteur Pass in concert with a planned lock and flow-control structure at the lake end of the IHNC at Seabrook as a part of a hurricane protection plan for the area. This plan would serve to protect areas contiguous to the shore of Lake Pontchartrain from flooding by limiting the uncontrolled entry of hurricane surges into the lake. During normal tide conditions, the gates of The Rigolets and Chef Menteur control structures would remain open, allowing the passage of normal flood and ebb tidal flow. Seabrook Lock (junction of Lake Pontchartrain and the IHNC) would be operated as required by navigation entering or exiting Lake Pontchartrain via the IHNC.

8. The basic approach to simulating the impact of structural alterations on the Lake Pontchartrain tidal prism can be outlined as follows:

- a. Develop a numerical model of the three basin system (Lakes Pontchartrain, Borgne, and Maurepas).
- b. Obtain and analyze field data to aid in calibrating and verifying the lake system model (Report 1 of the subject series, Outlaw 1982).
- c. Perform sectional model studies of each pass (Report 2 of the subject series, Butler et al. 1982) to provide descriptions of structure hydraulic characteristics to the numerical tidal prism model.
- d. Calibrate and verify the tidal prism model and test plan impact under mean, spring, and neap tide conditions.

The numerical grid used in this study is actually an embedded portion of an inland surge grid employed in another phase of the investigation.

Hereafter, this grid is referred to as the tidal prism model.

9. Preliminary calculations with these tide conditions indicated difficulty in assessing the true impact of the hurricane protection plan on the tidal prism of Lake Pontchartrain. Consequently, a follow-up investigation of the effect of tidal range variation was made by simulating the structure system impact over a spring-to-neap-to-spring tidal period (semilunar month). In addition, computations were made to simulate the effect of a Bonnet Carre Floodway operation. Included (Appendix B) are the verbatim comments on this report of five consultants who acted as an academic review committee for the entire study.

PART II: COMPUTATIONAL TECHNIQUES

Equations of Motion

10. The basic model (WIFM) used in this study is described in another report (Butler, in preparation). The theoretical background is summarized in the following paragraphs. Hydrodynamic equations used in WIFM are derived from the classical Navier-Stokes equations in a Cartesian coordinate system. By assuming that vertical accelerations are small and the fluid is homogeneous, and integrating the flow from sea bottom to water surface, the usual two-dimensional form of the equations of momentum and continuity is obtained. These assumptions are consistent with the overall homogeneous character of the three lake system and the study objectives.

11. A major advantage of WIFM is the capability of applying a smoothly varying grid to the study region, permitting simulation of complex landscapes by locally increasing grid resolution and/or aligning coordinates along physical boundaries. For each direction, a piece-wise reversible transformation that takes the form

$$x = a + b\alpha^c \quad (1)$$

where a , b , and c are arbitrary constants, is independently used to map prototype or real space into computational space. Many stability problems commonly associated with variable grid schemes are eliminated via the continuity of the transformation procedure. The resulting equations of motion in α -space can be written as:

Momentum:

$$\begin{aligned} u_t + \frac{1}{\mu_1} uu_{\alpha_1} + \frac{1}{\mu_2} vu_{\alpha_2} - fv \\ + \frac{g}{\mu_1} (\eta - \eta_a)_{\alpha_1} + \frac{gu}{C^2 d} (u^2 + v^2)^{1/2} \\ - \epsilon \left(\frac{1}{\mu_1} \right)^2 u_{\alpha_1 \alpha_1} + \frac{1}{\mu_1} \left(\frac{1}{\mu_1} \right)_{\alpha_1} u_{\alpha_1} + \left(\frac{1}{\mu_2} \right)^2 u_{\alpha_2 \alpha_2} \end{aligned}$$

$$+ \frac{1}{\mu_2} \left(\frac{1}{\mu_2} \right)_{\alpha_2} u_{\alpha_2} - F_{\alpha_1} = 0 \quad (2)$$

$$\begin{aligned} v_t + \frac{1}{\mu_1} uv_{\alpha_1} + \frac{1}{\mu_2} vv_{\alpha_2} + fu + \frac{g}{\mu_2} (\eta - \eta_a)_{\alpha_2} \\ + \frac{gv}{C^2 d} (u^2 + v^2)^{1/2} - \varepsilon \left(\frac{1}{\mu_1} \right)_{\alpha_1}^2 v_{\alpha_1 \alpha_1} + \frac{1}{\mu_1} \left(\frac{1}{\mu_1} \right)_{\alpha_1} v_{\alpha_1} \\ + \left(\frac{1}{\mu_2} \right)_{\alpha_2}^2 v_{\alpha_2 \alpha_2} + \frac{1}{\mu_2} \left(\frac{1}{\mu_2} \right)_{\alpha_2} v_{\alpha_2} - F_{\alpha_2} = 0 \end{aligned} \quad (3)$$

Continuity:

$$\eta_t + \frac{1}{\mu_1} (du)_{\alpha_1} + \frac{1}{\mu_2} (dv)_{\alpha_2} = R \quad (4)$$

where

$$\mu_1 = \frac{\partial x}{\partial \alpha_1} \text{ and } \mu_2 = \frac{\partial y}{\partial \alpha_2}$$

and η is the water-surface elevation above the α_1 - α_2 datum plane (located at NGVD); η_a is the hydrostatic elevation corresponding to the atmospheric pressure anomaly; u and v are the vertically integrated velocities at time t in the α_1 and α_2 directions, respectively; $d = \eta - h$ is the total water depth; h is the still-water elevation; f is the Coriolis parameter; C is the Chezy frictional coefficient; g is the acceleration due to gravity; ε is a generalized eddy viscosity coefficient; R represents the rate at which additional water is introduced into or taken from the system (for example, through rainfall and evaporation); and F_{α_1} and F_{α_2} are terms representing external forcing functions such as wind stress in the α_1 and α_2 directions. Quantities μ_1 and μ_2 define the stretching of regular-spaced computational grid in α -space to approximate a study

region in real space. Directions α_1 and α_2 correspond to x and y , respectively. The vertical (Z) axis is directed upwards with $Z = 0$ at NGVD.

Numerical Approach

12. The differential equations (Equations 2-4) are to be approximated by difference equations. Various solution schemes, including implicit and explicit formulations, could be used. Prior to the subject study, WIFM employed a typical alternating direction implicit (ADI) scheme (Butler 1978) similar to Leendertse (1970). The difficulty with applying this procedure was maintaining stability when the advective inertia terms were included in the solution algorithm. Weare (1976) indicated that the problem lay in the differencing techniques used, namely, in approximating the advective terms with expressions not centered in time. To develop a remedy, Weare (1979) introduced methods of analyzing ADI schemes. In particular, he suggested a stabilizing correction scheme (SC scheme) employing three full time levels. The scheme is second order accurate in time and space, and imposition of consistent (second order accuracy) boundary conditions on the intermediate solution level is possible. Details of the development can be found in Weare (1979) and in a report by Butler (in preparation) documenting the WIFM model. A summary of SC scheme development is presented in the following paragraphs.

13. If the linearized equations of motion are written in matrix form, one obtains

$$U_t + AU_x + BU_y = 0 \quad (5)$$

where

$$U = \begin{pmatrix} \eta \\ u \\ v \end{pmatrix}, \quad A = \begin{pmatrix} 0 & d & 0 \\ g & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad B = \begin{pmatrix} 0 & 0 & d \\ 0 & 0 & 0 \\ g & 0 & 0 \end{pmatrix}$$

The SC scheme for solving Equation 5 is

$$(1 + \lambda_x) U^* = (1 - \lambda_x - 2\lambda_y) U^{k-1} \quad (6)$$

$$(1 + \lambda_y) U^{k+1} = U^* + \lambda_y U^k \quad (7)$$

where

$$\lambda_x = \frac{1}{2} \frac{\Delta t}{\Delta x} A \delta_x \quad \text{and} \quad \lambda_y = \frac{1}{2} \frac{\Delta t}{\Delta y} B \delta_y$$

The quantities δ_x and δ_y are centered difference operators and superscript k counts time levels. The starred quantities can be considered approximate values for corresponding variables at the $(k+1)$ time level.

14. The first step in the procedure is carried out by sweeping the grid in the x-direction, and the second step is computed by sweeping in the y-direction. Completing both sweeps constitutes a full time-step, advancing the solution from the k^{th} time level to the $(k+1)$ time level. The form of the difference equations for the x-sweep is given by

$$\frac{1}{2\Delta t} (\eta^* - \eta^{k-1}) + \frac{1}{2\Delta x} \delta_x (u^*d + u^{k-1}d) + \frac{1}{\Delta y} \delta_y (v^{k-1}d) = 0 \quad (8)$$

$$\frac{1}{2\Delta t} (u^* - u^{k-1}) + \frac{g}{2\Delta x} \delta_x (\eta^* + \eta^{k-1}) = 0 \quad (9)$$

$$\frac{1}{2\Delta t} (v^* - v^{k-1}) + \frac{g}{\Delta y} \delta_y (\eta^{k-1}) = 0 \quad (10)$$

and the y-sweep by

$$\frac{1}{2\Delta t} (\eta^{k+1} - \eta^*) + \frac{1}{2\Delta y} \delta_y (v^{k+1}d - v^{k-1}d) = 0 \quad (11)$$

$$u^{k+1} = u^* \quad (12)$$

$$\frac{1}{2\Delta t} (v^{k+1} - v^*) + \frac{g}{2\Delta y} \delta_y (\eta^{k+1} - \eta^{k-1}) = 0 \quad (13)$$

where Equations 8 and 11 are written at grid cell centers and Equations 9, 10, 12, and 13 are written at u or v grid cell faces.

15. Noting that v^* in Equation 10 is only a function of previously computed variables at the $(k-1)$ time level, the above equations can be simplified to give

x-sweep

$$\frac{1}{2\Delta t} (\eta^* - \eta^{k-1}) + \frac{1}{2\Delta x} \delta_x (u^{k+1}_d + u^{k-1}_d) + \frac{1}{\Delta y} \delta_y (v^{k-1}_d) = 0 \quad (14)$$

$$\frac{1}{2\Delta t} (u^{k+1} - u^{k-1}) + \frac{g}{2\Delta x} \delta_x (\eta^* + \eta^{k-1}) = 0 \quad (15)$$

y-sweep

$$\frac{1}{2\Delta t} (\eta^{k+1} - \eta^*) + \frac{1}{2\Delta y} \delta_y (v^{k+1}_d - v^{k-1}_d) = 0 \quad (16)$$

$$\frac{1}{2\Delta t} (v^{k+1} - v^{k-1}) + \frac{g}{2\Delta y} \delta_y (\eta^{k+1} + \eta^{k-1}) = 0 \quad (17)$$

16. Expanding the SC scheme to the full equations of motion, Equations 2-4, and defining the appropriate variables on each grid cell in a space-staggered fashion is depicted in Figure 2,

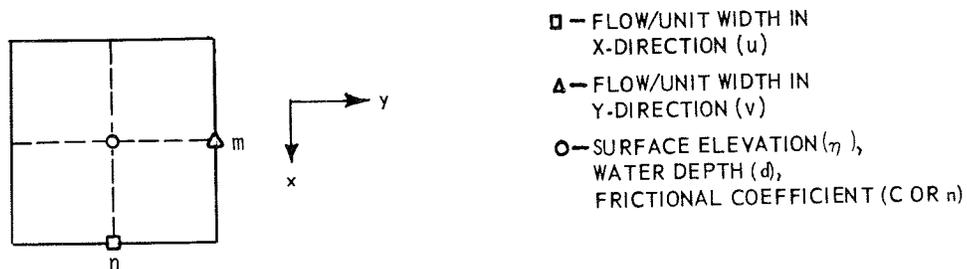


Figure 2. Space staggered grid

difference equations for the x-sweep (along a grid cell column parallel to the x-axis) can be written as

$$\begin{aligned} \frac{1}{2\Delta t} (\eta^* - \eta^{k-1}) + \frac{1}{2\mu_1 \Delta \alpha_1} [\delta_{\alpha_1} (u^{k+1} \bar{d}^k + u^{k-1} \bar{d}^k)] \\ + \frac{1}{\mu_2 \Delta \alpha_2} \delta_{\alpha_2} (v^{k-1} \bar{d}^k) = R^k \text{ at } (n,m) \end{aligned} \quad (18)$$

$$\begin{aligned} \frac{1}{2\Delta t} (u^{k+1} - u^{k-1}) + \frac{1}{2\mu_1 \Delta \alpha_1} u^k \delta_{2\alpha_1} (u^k) + \frac{1}{2\mu_2 \Delta \alpha_2} \bar{v}^k \delta_{2\alpha_2} (u^k) \\ - f \bar{v}^k + \frac{g}{2\mu_1 \Delta \alpha_1} [\eta^* + \eta^{k-1} - 2\eta_a^k] \\ + \frac{g}{(\bar{c}^2 \bar{d})^k} u^{k+1} [(u^{k-1})^2 + (\bar{v}^{k-1})^2]^{1/2} - \epsilon \left[\frac{1}{(\mu_1 \Delta \alpha_1)^2} \delta_{\alpha_1 \alpha_1} (u^k) \right. \\ + \frac{1}{(\mu_2 \Delta \alpha_2)^2} \delta_{\alpha_2 \alpha_2} (u^k) + \frac{1}{2\mu_1 \Delta \alpha_1} \delta_{\alpha_1} \left(\frac{1}{\mu_1} \right) \delta_{2\alpha_1} (u^k) \\ \left. + \frac{1}{2\mu_2 \Delta \alpha_2} \delta_{\alpha_2} \left(\frac{1}{\mu_2} \right) \delta_{2\alpha_2} (u^k) \right] - F_{\alpha_1}^k = 0 \text{ at } (n, m + \frac{1}{2}) \end{aligned} \quad (19)$$

In these expressions, a single bar represents a two-point average and a double bar a four-point average. The subscripts m and n correspond to spatial locations and superscript k to time levels. The difference operator δ_α is defined as

$$\delta_\alpha (Z) = Z_{\alpha+1/2} - Z_{\alpha-1/2}$$

for any α and variable Z .

17. Applying these equations at each grid cell in a given column results in a system of linear algebraic equations whose coefficient matrix is tridiagonal. The y-sweep is formulated in an analogous manner.

Stability and Nonlinear Aspects

18. The influence of the time-step on accuracy of the difference scheme is very important. It is characterized by the dimensionless quantity $k = \frac{|c|\Delta t}{\Delta x}$ where c is the maximum wave speed. When using explicit schemes, linear stability investigations require $k \leq 1$. With implicit schemes, this restriction usually does not apply but accuracy does diminish with increasing k . It is usually recommended that k be less than five for implicit schemes to maintain an accurate solution. Yet another phenomenon can occur, namely, the introduction of nonlinear instabilities that totally destroy the solution. These instabilities have been shown (Kuipers and Vreugdenhil 1973) to be directly related to inclusion of the advective terms in the difference equations. Omitting the advective terms may make the instabilities disappear but also make it impossible to compute accurate circulation currents and horizontal eddies.

19. Since the existence of the nonlinear instabilities in previously applied difference schemes were shown to stem from the imperfect time-centering of difference representations of the nonlinear terms (Weare 1976), a fully time-centered scheme was adopted and encoded into WIFM. The horizontal diffusion terms (lateral viscous effects) also were included in the difference scheme to contribute to the numerical stability (Vreugdenhil 1973). These terms, strictly speaking, should be included in the momentum equations. Vreugdenhil demonstrates that such terms actually are representations of the effective stress terms usually neglected. An order of magnitude for the eddy coefficient is given by $\epsilon = 6d \sqrt{g(u^2 + v^2)} / C$. In practice a percentage influence of this expression is taken such that the computer flow pattern is nearly unaffected. Other methods of parameterizing these viscous effects are recognized and compared by Kuipers and Vreugdenhil (1973). The coefficients obtained by the adopted method are comparable in magnitude with those from other methods for the Lake Pontchartrain application.

Boundary Conditions

20. A variety of boundary conditions can be employed throughout the computational grid. These include prescribing water levels, velocities, or flow rates, fixed or movable land-water boundaries, and subgrid barrier conditions.

- a. Open boundaries: Water levels, velocities, or flow rates are prescribed as functions of location and time and are given as tabular input to the code or in tidal constituent form.
- b. Water-land boundaries: These conditions relate the normal component of flow at the boundary to the state of the water level at the boundary. Hence, water-land boundaries are along cell faces. Fixed land boundaries are treated by specifying $u = 0$ or $v = 0$ at the appropriate cell face. Low-lying terrain may alternately dry and flood within a tidal cycle or surge history. Inundation is simulated by making the location of the land-water boundary a function of local water depth. By checking water levels in adjacent cells, a determination is made regarding the possibility of inundation. Initial movement of water onto dry cells is controlled by using a broad-crested weir formula (Reid and Bodine 1968). Once the water level on the dry cell exceeds some small prescribed value, the boundary face is treated as open and computations for η , u , and v are made for that cell. The drying of cells is the inverse process. Mass conservation is maintained within these procedures.
- c. Subgrid barriers: Such barriers are defined along cell faces and are of three types: exposed, submerged, and overtopping. Exposed barriers are handled by simply specifying no-flow conditions across the appropriately flagged cell faces. Submerged barriers are simulated by controlling flow across cell faces with the use of a time-dependent friction coefficient. The term "overtopping barrier" is used to distinguish barriers which can be submerged during one phase of the simulation and totally exposed during another. Actual overtopping is treated by using a broad-crested weir formula to specify the proper flow rate across the barrier. Once the barrier is submerged (or conversely, exposed), procedures described for submerged barriers (or exposed) are followed.

21. In order to simulate the interaction between the IHNC and Lake Pontchartrain, with and without effects of the proposed lock/structure system, a new boundary condition was developed. The condition

entails applying a forcing tide at a boundary within the IHNC and use of the scalar wave equation at the boundary to extract the incident wave form. It is assumed that the incident wave arriving at the IHNC (for a given tidal condition) is independent of the lake system. In subsequent simulations the boundary formulation forces the model with this incident wave form and permits wave components emanating from the model interior to radiate out through the boundary. Changes to the interior system can be modeled for the same tidal condition since any outgoing wave they produce will be passed through the boundary without undergoing distortion. A detailed description of the condition (wave separation/radiation boundary condition) and application for treating the Seabrook lock/structure are presented in Appendix A.

PART III: MODEL DEVELOPMENT, CALIBRATION,
AND VERIFICATION

Field Data Requirements

22. Prototype data (tidal elevations, currents, wind speed and direction, temperature, conductivity, dissolved oxygen, and pH) in Lake Pontchartrain and the surrounding study area were collected and analyzed (Report 1, Outlaw 1982) as a part of the overall study to evaluate effects of the Lake Pontchartrain and Vicinity Hurricane Protection Plan on:

- a. Tidal prism and circulation in Lake Pontchartrain.
- b. Hurricane surge levels in Lake Pontchartrain and vicinity.
- c. Water quality in Lake Pontchartrain.

Survey studies were performed under various contracts to establish a common datum for all tide gages.

23. Tidal elevations and current data are of primary importance in the tidal prism investigation, namely, to provide a means of demonstrating the numerical model's ability to simulate tidal events in the study region. Additionally, these data are required to establish boundary conditions at the open-water model extremities. Data from all originally planned gages were not available due to gage damage. In general, the overall quality of the data was good and thus a sufficient data base for calibration and verification of the tidal prism model was provided.

24. A decision was made to verify the tidal prism model to data reconstructed from analyzed constituents. This procedure avoids the problem of defining the meteorology affecting the extensive model region. Figure 3 displays the locations of tide gage stations for which a constituent analysis was available. The major inconsistency in the analyses was noted in the phase components for sta P3. This could have resulted from a mechanical malfunction in the gage clock. Phase relationships, shown in Report 1 (Outlaw 1982) for the tidal constituent P_1 , are questionable, particularly in the Lake Pontchartrain interior where signals

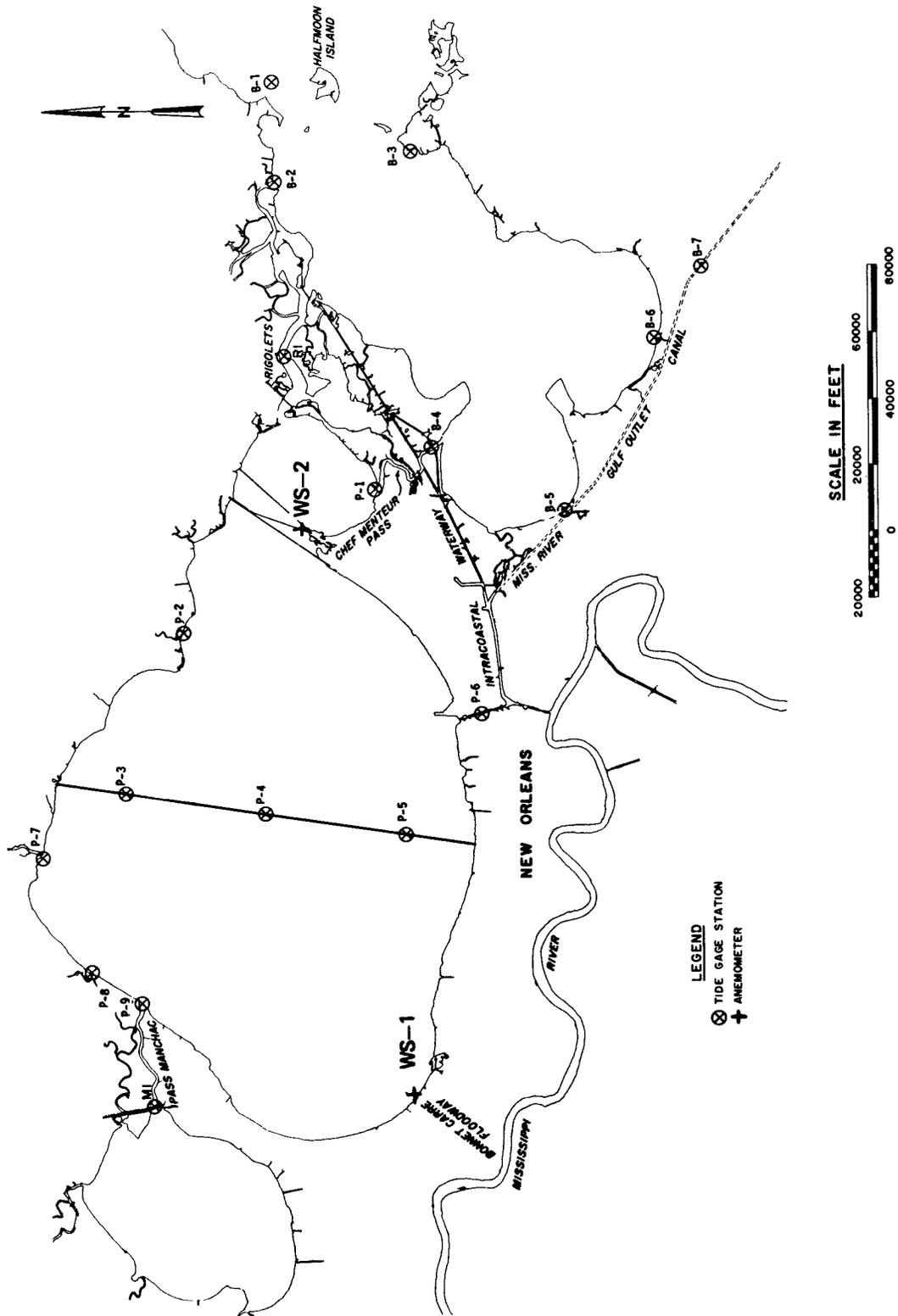


Figure 3. Location of tide gage and weather stations

are weak, making analysis more difficult and less accurate.

25. The offset factors (determined in the level circuit survey and given in Report 1) required to relate the zero of each gage to a common datum (Simmesport Free Plane datum) display numerous incongruities. These factors range from 0.78 ft* at gage B2 in Lake Borgne to 2.03 ft at gage P7 in Lake Pontchartrain and 0.67 ft at nearby Pass Manchac. Even accounting for the purported error in the readings, it would be difficult to maintain a tidal exchange under these conditions. Consequently, in all tidal comparisons made throughout this study no offsets were assumed. The datum for the tidal prism model was taken as the 1929 National Geodetic Vertical Datum (NGVD), usually referred to as mean sea level; thus the zero of all prototype tide stations was taken at NGVD.

26. Current data were taken at locations (Figures 4-6) in two 30-day survey periods. Many problems were experienced in acquiring these data, the two most prominent being equipment malfunctioning and equipment loss. Lake currents were too small to measure and thus only currents taken in the major arteries to Lake Pontchartrain are available.

27. Regional bathymetry is obviously required. The basic sources of these data are 1:80,000-scale NOAA navigation chart numbers 11369 and 11371 and 1:40,000-scale chart number 11367, and USGS 1:24,000-scale topographic maps. These data were supplemented with additional transect data taken in the entrance passes at various times.

Grid Development

28. Various considerations necessary in selecting a computational grid for the tidal prism problem are outlined as follows:

- a. Determining resolution required to model each of the three passes controlling lake hydrodynamics.
- b. Determining model limits consistent with proposed boundary conditions and effects of proposed interior alterations.

* A table of factors for converting U. S. customary units of measurements to metric (SI) units is presented on page 3.

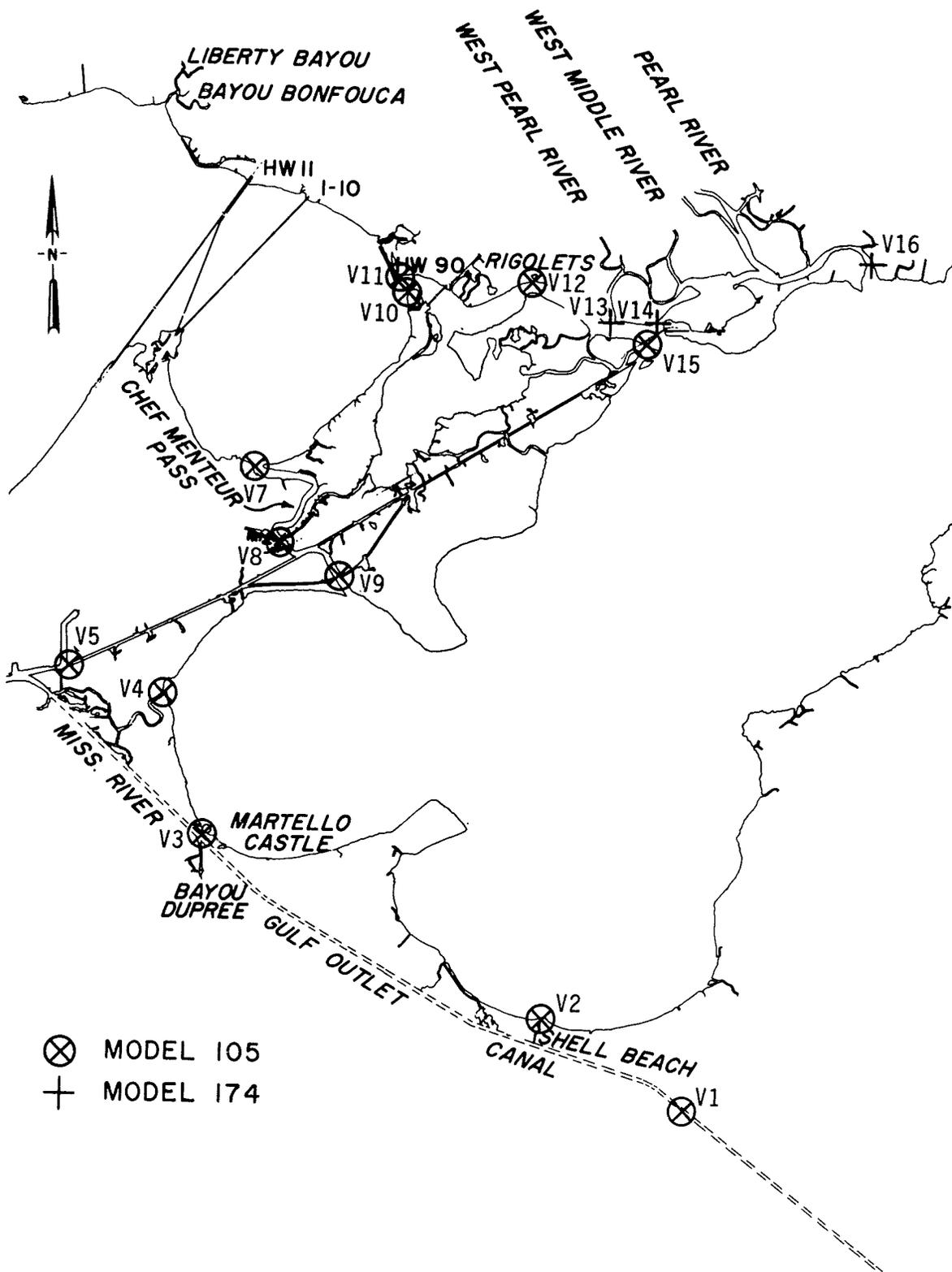


Figure 4. Location of intensive data acquisition program current meter stations in the eastern part of the study area

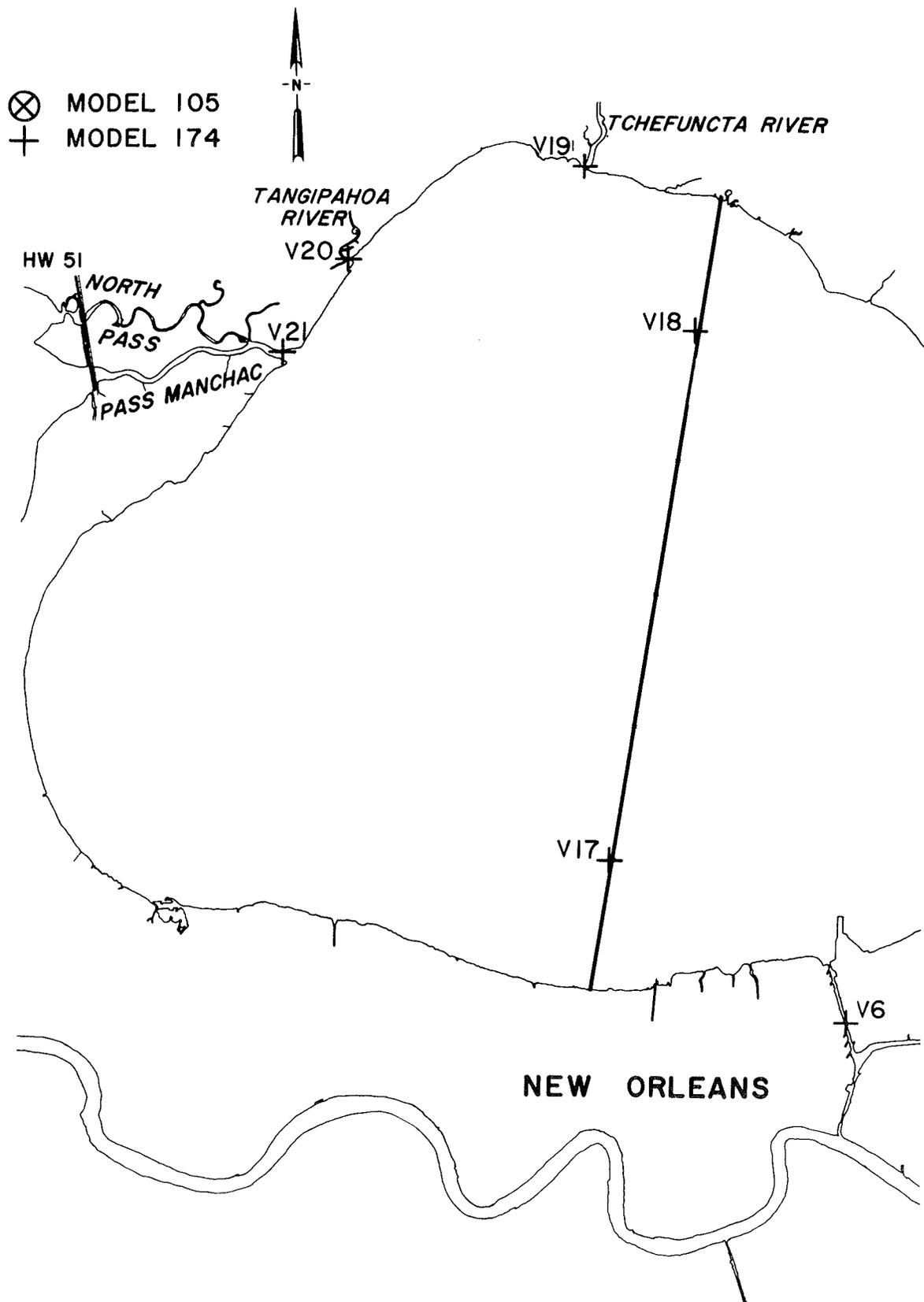
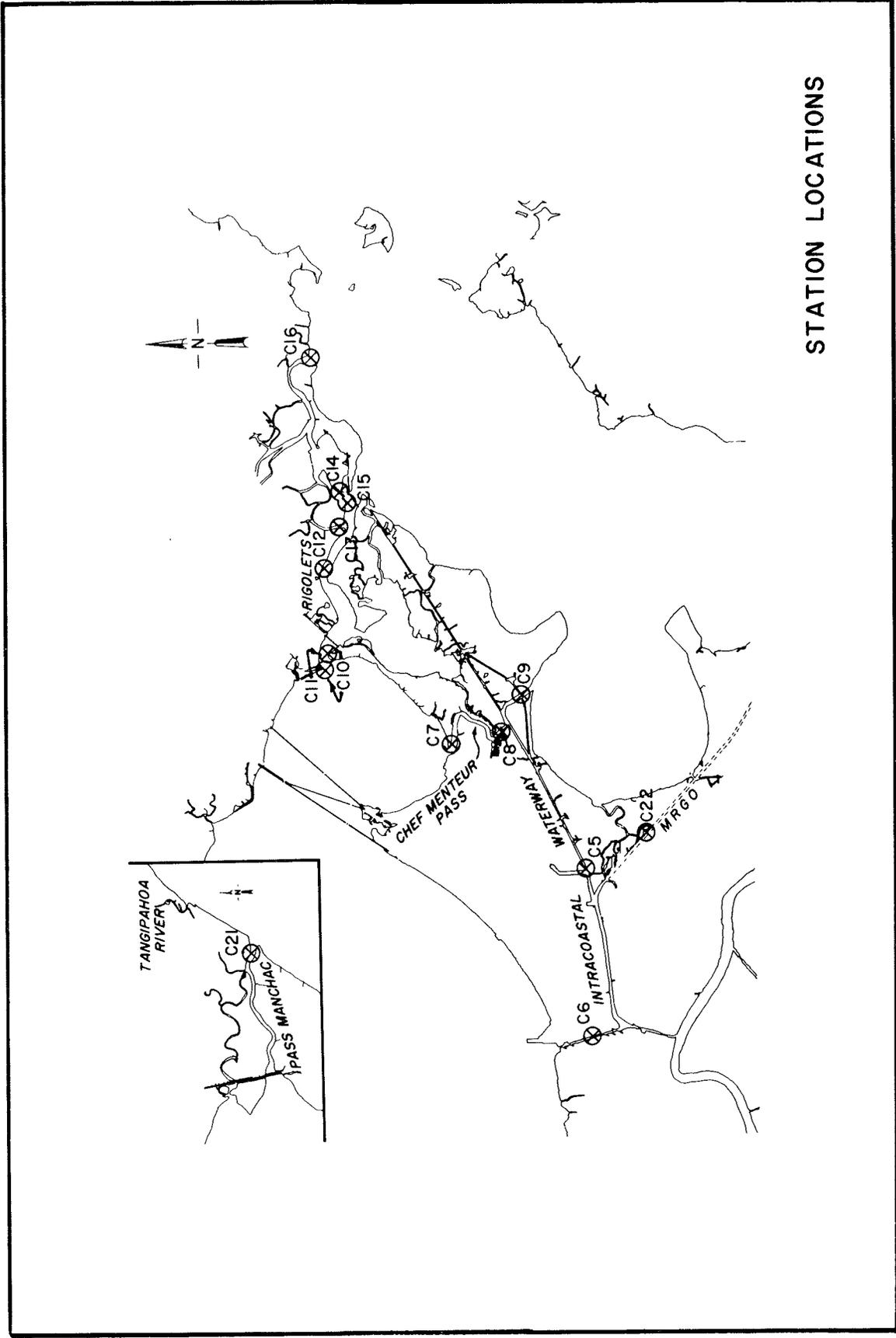


Figure 5. Location of intensive data acquisition program current meter stations in the western part of the study area



STATION LOCATIONS

Figure 6. Location of supplementary data acquisition program current meter stations

- c. Guaranteeing conformity with computational grid to be used in hurricane surge modeling.

29. The feasibility of a specific model, once a method for solving the equations of motion is deemed satisfactory, is directly a function of the cost of operation and available computer time. This limits the expanse and resolution of the model region. The passes into Lake Pontchartrain are small relative to the dimensions of the three-lake system, while at the same time having high flow rates, large depths, and meandering channel geometry. Thus these passes control both grid resolution and maximum time-step. Since the cost of running a model is proportional to the number of grid cells and the time-step, cost optimization requires that grid resolution in the passes areas be chosen in a fashion such that the hydrodynamics are correctly represented with a minimum number of grid cells. Results from several grids of each pass were compared with one another in a sensitivity study. It was found that both Chef Menteur Pass and the IHNC could be modeled (with and without proposed structures in place) by a one-dimensional system. Due to its overall size, The Rigolets was modeled in two dimensions. Modeling of the passes was reported in detail in Report 2 of the subject series (Butler et al. 1982).

30. Having discovered grid resolution required for the passes, a variable-spaced tidal prism grid can be constructed. Locations of tide gages in Lake Borgne limit the position of the eastern boundary of the grid. Tests with a simple grid system of the three-lake system (with and without full closure of the passes) indicated that a reasonable eastern boundary for the tidal prism model would be located 3 miles east of the mouth of the Pearl River in Lake Borgne. Since tide data were acquired at Martello Castle and Shell Beach, these data were used to force the model at these entrances to Lake Borgne. The remaining open-water boundary condition is in the IHNC. Establishing a boundary condition in the IHNC is discussed in detail in Appendix A.

31. Following these sensitivity tests, a variable-spaced grid was devised such that sections covering the three major passes approximated the individual optimum passes grids with grid coordinates aligned with

the earth coordinate system. Limits of this grid (outlined within Figure 7) were chosen such that the annular boundary cells matched cells within the open-coast hurricane surge model (Figure 7); this inner grid also will be used for detailed inland surge modeling. The tidal prism grid (outlined within Figure 8) is taken as a subgrid of the inland surge grid (Figure 8). Minimum cell width in the tidal prism was 353 ft in the IHNC and a maximum width was 8,350 ft in Lake Maurepas. Enlargements of the grid in the area of The Rigolets, Chef Menteur, and IHNC are depicted in Figures 9-11, respectively. In order to correctly model the actual length of Chef Menteur Pass, a special mapping was made to define unique weighting coefficients for use in the equations of motion only to be applied for the grid column simulating the Chef Menteur channel. Frictional coefficients are used to account for the channel bends.

Structure Modeling

32. Before running the tidal prism model with proposed structures in place, knowledge of structure hydraulic characteristics was required. This knowledge was obtained by performing separate experiments with sectional models of each pass with and without the proposed structures installed as detailed in Report 2. These tests ensured accurate representation of the proposed protection plan in the tidal prism model. In each case, structures are represented by a submerged barrier characterized by a distinct Manning's n . The shallow, narrow navigation channels associated with The Rigolets and Chef Menteur plans were not represented in the tidal prism grid. An analysis to assess the impact of omitting these channels was presented in Report 2. Results of the analysis indicated that the total impact of including the navigation channels into both The Rigolets and Chef Menteur plans will effect an increase in the lake tidal prism of about two percent.

33. Sectional models of each pass were calibrated for existing conditions and structure representation. Friction coefficients and model channel cross sections were adjusted to obtain agreement between

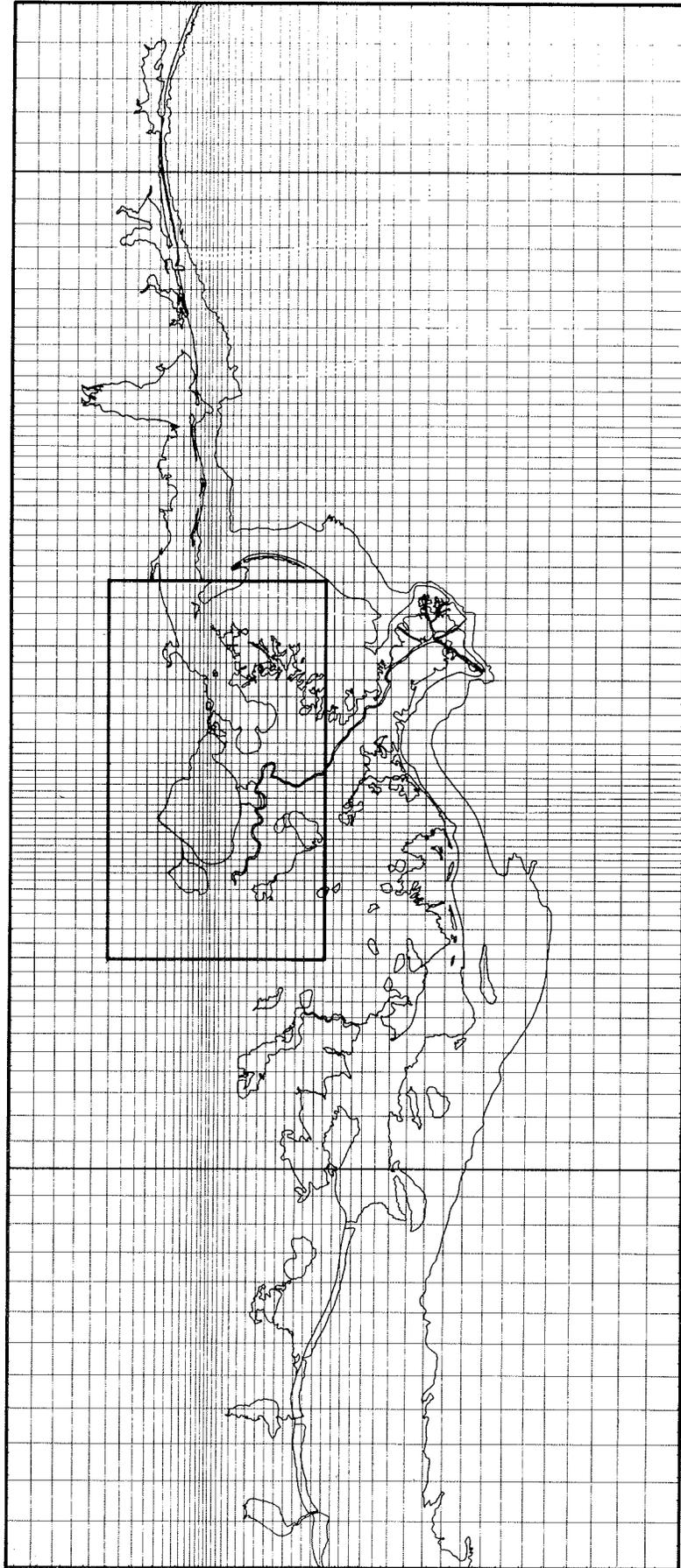


Figure 7. Open-coast storm surge grid depicting region of the inland surge embedded grid

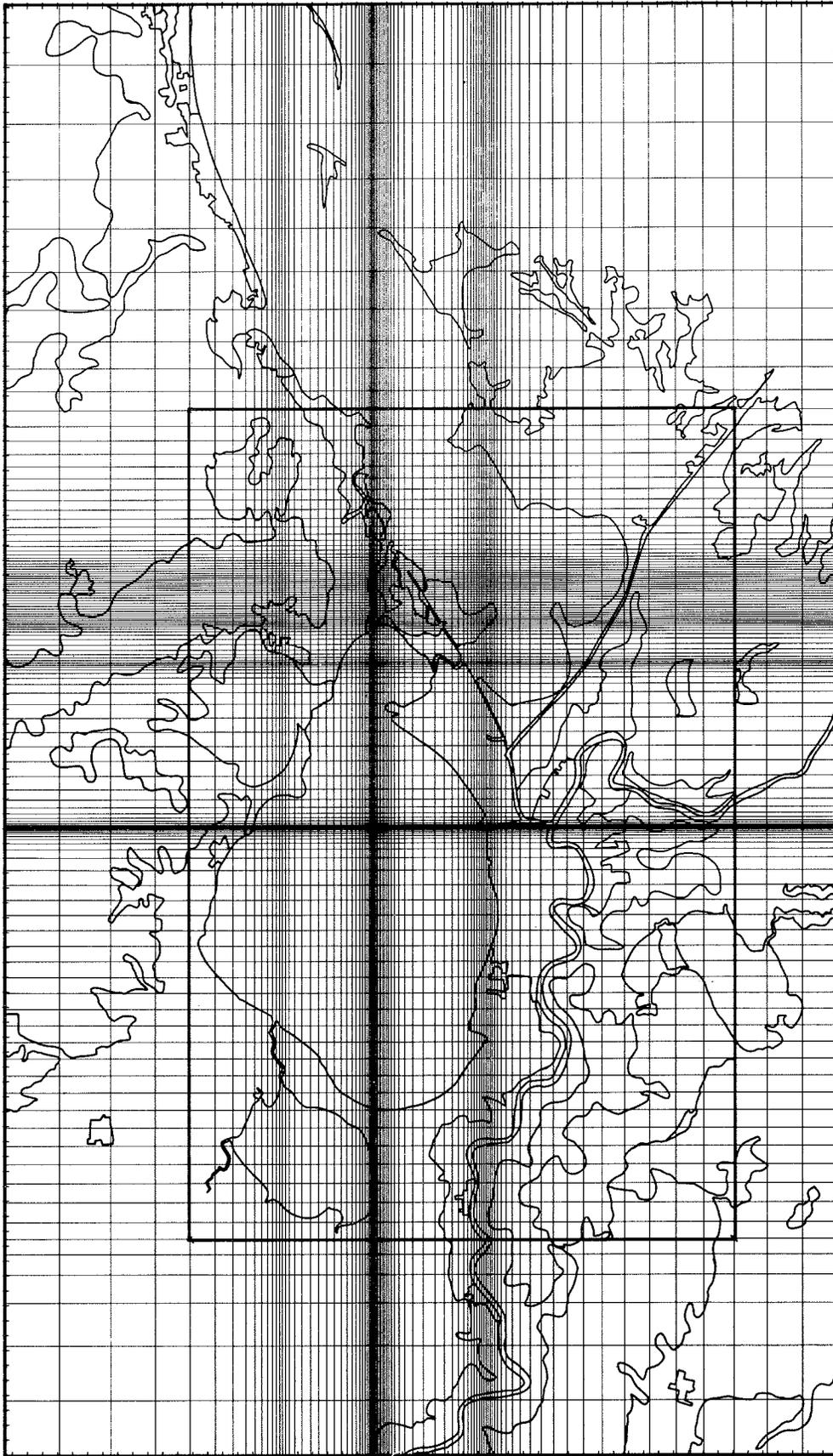


Figure 8. Embedded storm surge grid of the three-lake system depicting the tidal prism subgrid



Figure 9. Sectional grid for The Rigolets computational model

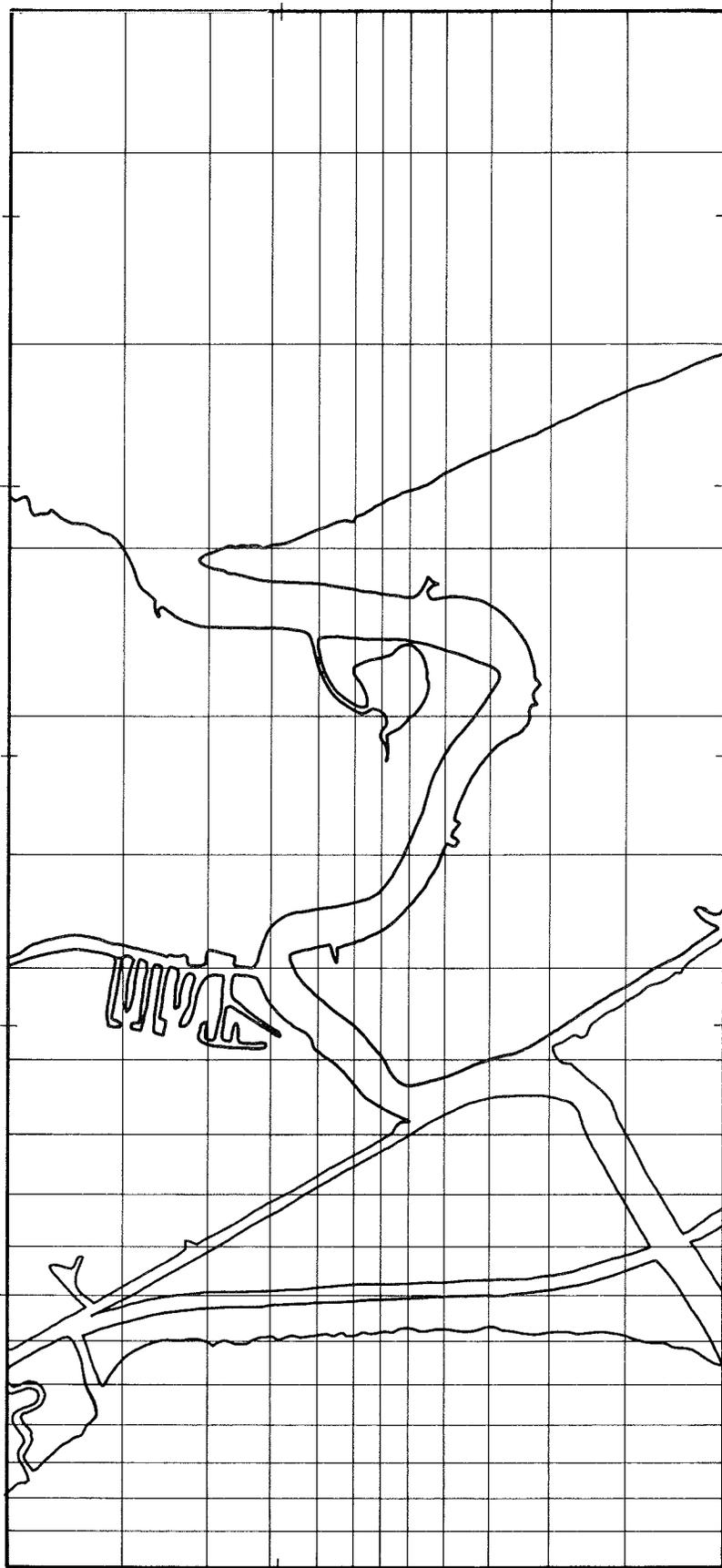


Figure 10. Sectional grid for the Chef Menteur computational model

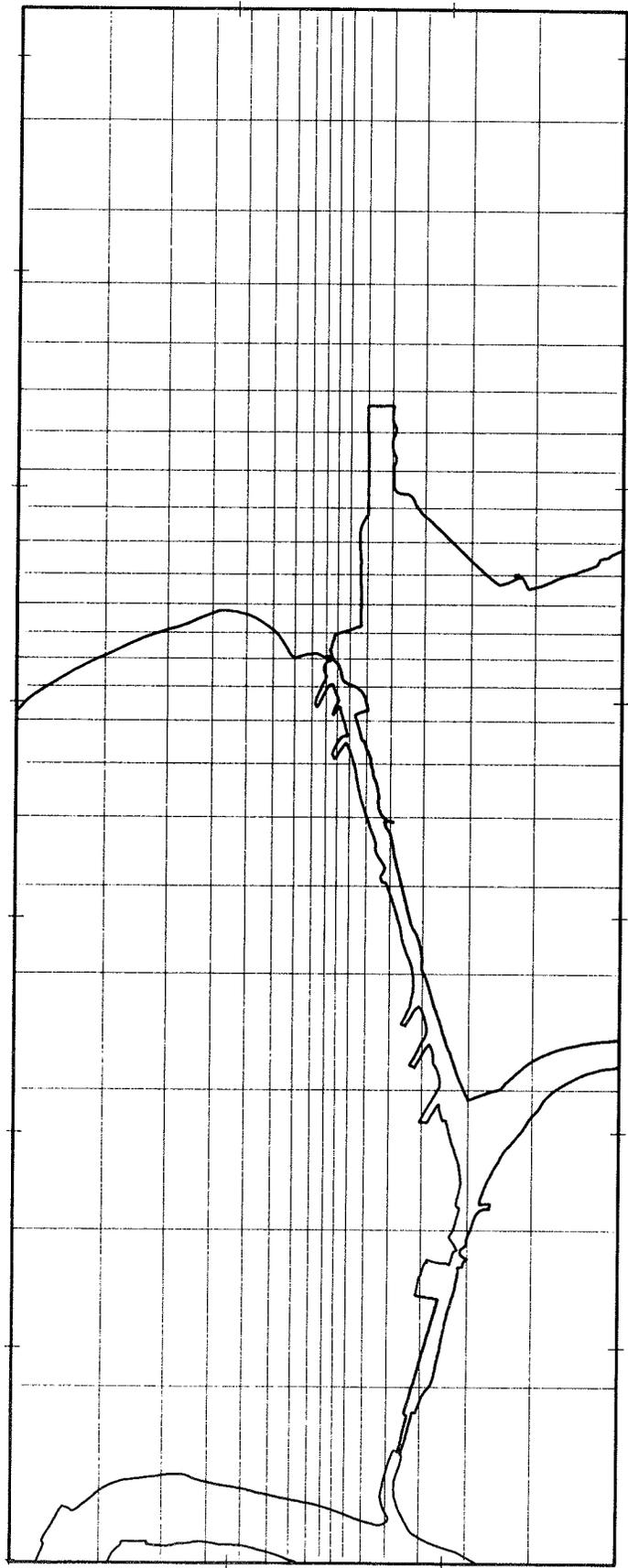


Figure 11. Sectional grid for the Seabrook Lock and structure computational model

numerical model, physical model, and observed prototype data. Results for each structure are:

<u>Structure</u>	<u>Manning's n</u>
The Rigolets	0.110
Chef Menteur Pass	0.112
Seabrook Lock (gates open)	0.230
Seabrook Lock (existing conditions)	0.190

Since the IHNC was modeled with a one-dimensional system and a constriction is present at the canal's entrance to Lake Pontchartrain, a submerged barrier was used to model the constriction for existing conditions. Detailed discussion of tests and results of structure sectional models is presented in Report 2.

Calibration

34. A decision was made to calibrate the tidal prism model using a single forcing tidal constituent, O_1 . Since the O_1 constituent is the dominant component of the tide with an isolated frequency, it is the easiest to analyze and extract from observed tide or current data. The basic data required to run the model include:

- a. Various parameter constants -- time- and space-steps, latitude, print controls, etc.
- b. Grid stretching weights.
- c. Topography.
- d. Number-coded terrain grid.
- e. Gage locations.
- f. Friction and flood cell admittance coefficients.
- g. Boundary and internal barrier locations and character.
- h. Tidal forcing data (constituent form).
- i. Location of ranges for computing integrated discharge.

35. Model gages were placed at all locations where prototype data were collected. Analyzed prototype data at sta B5 and B6 (Figure 3) were used to force the narrow southern entrances to Lake Borgne.

Analyzed data at sta P5 and P6 were used in the Seabrook Canal sectional model to develop a boundary condition in the IHNC (Appendix A). An average signal from sta B1, B2, and B3 originally was used to force the major open boundary in Lake Borgne (aligned north-south just to the east of Half Moon Island). Generally acceptable values for Manning's n corresponding to the various types of terrain in the model area were used. For example, values of n between 0.02 and 0.025 were used for wetted area bottom friction coefficients. Model parameters for the entrance passes were fixed in the sectional model investigations and were not changed in this study. The lateral diffusion coefficient, ϵ in ft^2/sec , was approximated by the expression given in paragraph 19. For lake waters around 15 ft in depth, ϵ is approximately equal to $5V$, where V is the magnitude of the current (typically 0.05 to 0.5 ft/sec). For the passes at depths of about 60 ft, ϵ is approximately equal to $15V$, with typical peak current speeds of 1.0 to 1.5 ft/sec. Tests were made halving and doubling the diffusion coefficient. No significant differences in elevations, currents, or circulation patterns were noted. Initial conditions for the model region were $\eta = u = v = 0$ at each water point of the grid.

36. Preliminary results from these test conditions indicated that the model was sensitive to tide portrayal at the major Lake Borgne boundary. To ensure accurate tide representation at this boundary, the model boundary was moved toward the west such that the southern tip of the boundary was at sta B3. The northern tip of the boundary was near sta B2. Boundary conditions were then defined as follows:

- a. The tide from the north shoreline across St. Joe Pass was taken as invariant (using data from sta B2).
- b. The tide from the south side of St. Joe Pass to sta B3 was determined by interpolating amplitudes and phases between sta B2 and B3.

This forcing condition at the eastern model boundary produced a good comparison between model and analyzed prototype data (O_1 constituent only). Plates 1-5 depict surface elevation results for all interior model gages. Sta B2, B5, and B6 are presented to demonstrate how the data were initially feathered to construct boundary conditions

consistent with quiescent initial conditions. An obvious conclusion on first inspection of these results is that the model requires a 2- or 3-day spin-up time. Agreement of amplitude and phase between model and prototype shows continual improvement over the 4-day run. Agreement in the third and fourth day looks quite good. A poor agreement in phase is found only for sta P3; but as previously stated, a problem with the gage clock was suspected.

37. As stated previously, lake currents were too small to measure. The only current data available for comparison with model results were taken in the major arteries leading into Lake Pontchartrain. Plates 6 and 7 show such comparisons for gaging stations in the IHNC (V6), in the Chef Menteur Pass (V8 and V9), and in The Rigolets (V10, V12, and V15) for the O_1 constituent. All of these passes into the lake were somewhat idealized. Both the IHNC and the Chef Menteur Pass are represented by one-dimensional model channels. The Rigolets is modeled with a minimal two-dimensional representation. Current measurements are very site-specific and model resolution in the major arteries cannot be expected to yield accuracy in current comparison results similar to the accuracy in tide elevation comparisons. However, comparisons shown for gages in each pass are quite good. Gage V6 was actually located outside the model boundary in the IHNC. The comparison shown was made with model results at the first interior cell.

Verification

38. Having calibrated the model to reproduce tidal hydrodynamics of the subject three-lake system, attention was directed toward verification for a 9-constituent tide. The model was run without changing input parameters except the forcing tides. Again, the eastern boundary condition was developed by interpolating amplitudes and phases of tidal constituents from gages B2 and B3. Comparison of computed model surface elevations with reconstructed constituent prototype tides are displayed in Plates 8-12. Agreement between computed and observed data was good but differences between the two for this condition are larger than those

noted in the O_1 calibration comparisons. Agreement improved in the later hours of the run. Difficulty in analyzing weaker tidal energy in the lake may account for the larger differences since the prototype tides are formed from a combination of these signals.

39. Again, available data for velocity comparisons are limited. Plates 13 and 14 show comparisons of model currents versus reconstructed constituent prototype currents at six gages located in the major arteries connecting Lake Pontchartrain with the gulf. For the model resolution used, agreement between computed and observed data is quite good.

40. Circulation patterns were plotted for various subregions of the computational grid. Since velocity magnitudes in Lake Pontchartrain are small and the area of the lake is large, it is difficult to portray lake circulation. Plates 15 and 16 display two accentuated patterns showing lake circulation during mean tide flood and ebb stages, respectively. A vector with length equal to 0.1 in. (approximately) represents a velocity of 0.15 ft/sec. If velocities greater than 0.5 ft/sec appeared in the region, they were reset to zero in the display to avoid exceeding plotter screen dimensions.

41. A portion of the tidal prism grid, including The Rigolets and Chef Menteur Pass, was singled out for depicting circulation through the two major entrances to Lake Pontchartrain. Plates 17-22 show "snapshots" of flood tide, slack water, and ebb tide (including a Rigolets channel enlargement) for a mean tide condition. Inspection of these patterns suggests greater resolution of The Rigolets could more accurately portray the flow regime. Nevertheless, the model is capable of simulating the correct tidal exchange through The Rigolets as demonstrated in Report 2.

PART IV: TIDAL PRISM SIMULATION: PLAN IMPACT

Problem Definition

42. The Lake Pontchartrain and Vicinity Hurricane Protection Plan consists of a system of levees surrounding flood-prone areas to the south and east of the lake and control structures in the three passes to the lake. Of interest is the impact of the gated control structures proposed in The Rigolets and Chef Menteur Passes in concert with a planned lock and structure at the lake end of the IHNC on the tidal prism of Lake Pontchartrain. During normal tide conditions, the gates of The Rigolets and Chef Menteur control structures would remain open, allowing the passage of normal flood and ebb tidal flow. The Seabrook Lock (junction of Lake Pontchartrain and the IHNC) would be operated as required by navigation entering or exiting the lake via the canal. All tests were made with the Seabrook Lock and control structure fully opened. A more detailed description of the three structures and operation procedures is given in Report 2.

Short-Term Events

43. Control structure impact on the Lake Pontchartrain tidal prism is highly influenced by the strength of the forcing tidal potential. To test this impact, three 4-day short-term events were simulated in the model with and without plan installation. These events included the mean tide event used in the verification procedure as well as a spring tide event (3-7 November 1978) and a neap tide event (24-28 July 1979).

44. The first attempt to quantify impact of the proposed channel barrier plan on the tidal prism of Lake Pontchartrain consisted in simulating the above-mentioned tidal events with and without the barriers in place. Base conditions were constructed by simulating these 4-day tidal events for existing conditions. Tidal prism computations during the third and fourth day were made in two ways:

- a. For the individual passes, total flood and ebb discharges were computed over the same lunar day (covering a period of time during the third and fourth days.
- b. Net flood and ebb discharge into/out of the lake was computed over the last complete tidal cycle for the net computation in a 4-day run.

Table 1 shows tidal prism computations for the three entrance passes and the whole lake. Plates 23-40 depict plan versus base time-history comparisons for surface elevations and discharges at various tide stations around the lake, discharge ranges in the entrance passes, and net discharge to/from the lake. These results cover spring, mean, and neap tide conditions. The only noticeable effect on surface elevations was near or in the entrance passes (gages R1, P1, P6, and B4). As expected, the largest effect was the increase in surface elevation in the IHNC (about one foot for a spring tide). Care must be taken in using these results since they represent plan impact for specific 1-day events. Simulation of a semilunar month event is discussed in a later section.

45. The proposed structures have no effect on Lake Pontchartrain circulation. Differences between plan and base are noted only in areas of local influence. Plates 41-52 for spring and neap tide conditions show circulation snapshot plots similar to those for the mean tide condition (Plates 17-22). The area includes both The Rigolets and Chef Menteur Passes and a Rigolets channel enlargement. Plates 53-70 display corresponding circulation snapshots with barriers in place for the same flood and ebb tides and slack water during spring, mean, and neap tide test events.

Impact Analysis

46. The impact of proposed control structures for each major artery into Lake Pontchartrain is best displayed in discharge versus time plots (Plates 35-40). In addition, the integrated net discharge into or from the lake is shown. Spring, mean, and neap tide conditions were simulated, and as expected, minimal impact on discharge through the passes was experienced during a neap tide. Table 1 summarizes net flood

and ebb integrated discharges for base and plan conditions during the three selected tidal events. Computations were made for each pass and the integrated net for the lake over a lunar day. Percent impact, representing a decrease in the lake's natural tidal prism, is given for each pass and for the integrated net lake tidal prism. Overall impact of the system of control structures tested herein is to reduce the lake's natural tidal prism by 10 percent while not measurably affecting tide elevations or lake circulation, except in proximity to the structures.

47. As discussed in Report 2 of the subject series, the shallow, narrow navigation channels connecting Lake Pontchartrain with Lake Borgne were not modeled. An analysis was performed to assess the effect of omitting their contributions to the lake's tidal prism. Results of this analysis indicate that their combined contribution would increase the lake's tidal prism by about 2 percent. Thus the overall impact of the proposed structure/channel systems would be to reduce the lake's natural tidal prism by about 8 percent.

PART V: SUPPLEMENTARY TESTS

Semilunar Month Simulation

48. Quantification of impact of the proposed hurricane protection barriers on the tidal prism of Lake Pontchartrain was attempted by simulating three typical tidal scenarios. As stated previously, structure impact is a function of the daily tidal range. Consequently, it was recommended to supplement the previous calculations by modeling tidal range variation over a spring and neap tidal period, namely, a semilunar month (just less than 15 days) for base and plan conditions. In this procedure, the net discharge into and out of Lake Pontchartrain was calculated over this period to obtain a more representative estimate of the tidal prism and the effect of the proposed protection plan on the tidal prism. This calculation procedure is still somewhat subjective since a specific semilunar event must be chosen.

49. In order to conserve computational costs, model conditions at the end of the 4-day mean tide short-term event were used as initial conditions for the semilunar month simulation. To reduce computational stability problems for such a long simulation the advective terms in the momentum equations as well as the horizontal diffusion terms were omitted. Plates 71-76 show a comparison between model and reconstructed prototype surface elevations at six stations.

50. Initial conditions for the semilunar month simulation with structures were taken from the end of the 4-day mean tide computations with structures. Plates 77-82 depict a comparison of surface elevations for base versus plan conditions. Plan effects are noted to be minimal except for the IHNC where, again, water is piled up in the IHNC because of a more constricted entrance into Lake Pontchartrain. Plates 83-86 show base versus plan discharge comparisons for ranges in the entrance passes and for the net discharge to/from the lake. Table 2 summarizes the tidal prism computations. A reduction in impact percentage for the Chef Menteur Pass and IHNC relative to the figures for a spring or mean tide short-term event (Table 1) was obtained as expected. There was a

slight increase in percentage impact for The Rigolets structure. Absence of the nonlinear advective terms in the computations would have less effect in one-dimensional channel models (Chef Menteur and IHNC) than in a two-dimensional models (Rigolets). Absence of these terms tends to increase the discharge, but why a slightly greater impact of The Rigolets structure occurs cannot be answered by these tests.

51. From results shown in Tables 1 and 2, we can infer that short-lived neap tide periods do not significantly reduce the percent impact of the control structures on the lake's tidal prism over a semi-lunar month. Again, actual impact on the lake's tidal prism is less (about 2 percent less) due to omitting the proposed navigation channels in the Chef Menteur and Rigolets structure plans.

Bonnet Carre Operation

52. The Bonnet Carre Spillway connects the Mississippi River near river mile 130 to Lake Pontchartrain at Bayou LaBranche in the southwest corner of the lake. The spillway is operated during dangerously high river stages to reduce potential flooding downriver. In general, opening of the spillway takes 3 days with the flow increasing at a rate of one-third capacity per day. It is then operated at full capacity for about 30 days with closure requiring an additional 36 days. Full capacity of the Bonnet Carre is approximately 250,000 cfs.

53. Tests were made with the Bonnet Carre Spillway in operation. Reproducing an entire operation scenario (69 days) was infeasible. Instead, the opening and 7 days of operation were simulated. An attempt to develop separation/radiation boundary conditions to permit simultaneous tide and spillway simulation proved unsuccessful during the scope of this project. To investigate lake water level under normal spillway operation and with the proposed control structures installed, a free-wave test was devised. Radiation boundary conditions were applied at all open boundaries without any tidal forcing. Bonnet Carre was opened over a 3-day period, increasing the discharge 83,300 cfs per day until a discharge of 250,000 cfs was reached (Plate 87). Over the following

days, the discharge was held at 250,000 cfs until a steady-state condition was reached. The typical lake elevation decay occurring during gate closure or a natural lower discharge was not modeled since the computations were costly and our intention was to assess impact under maximum discharge conditions. Plates 88-94 display time-histories of water-surface elevations at selected gages in the three-lake system with and without the protection structures in place. The mean level of Lake Pontchartrain was raised about 1.5 ft while the mean level of Lake Borgne was raised about 0.4 ft for existing conditions. With the structures in place, an additional increase of 0.3 ft occurred in Lake Pontchartrain while the mean level in Lake Borgne remained unchanged. Table 3 displays detailed comparisons for steady-state levels developed at various stations within the model for these tests.

54. The Bonnet Carre Flood Control Structure was opened from 19 April (Julian day 109) through 20 May 1979 to divert floodwater from the Mississippi River through Lake Pontchartrain to the Gulf of Mexico. Observations of this event are detailed in Report 1, Appendix C, of the subject series (Outlaw 1982). Plates 95 and 96 are taken from Report 1 and depict surface elevation measurements for sta P4 (mid-Lake Pontchartrain) and B4 (Lake Borgne at the entrance to Chef Menteur Pass) during the 1979 Bonnet Carre operation. A storm event occurred during Julian days 110 and 115 and caused an anomalous high-surface elevation in Lake Pontchartrain and throughout the central gulf coast. Nevertheless, days 120-126 represent a period when the average discharge from the Bonnet Carre Spillway was 240,000 cfs. During this time, the mean level of mid-Lake Pontchartrain was 1.8 ft while that of Lake Borgne near Chef Menteur was 1.1 ft. The expected tide appears to be superimposed over the lake rise due to the Bonnet Carre. Residual effects of the storm are unknown and thus no direct comparison with the free wave test can be made; yet the observed data conform quite well to model data, keeping in mind that an additional increase in lake levels is possible when the spillway and tide event occur simultaneously in nature.

55. Table 4 depicts the proportional distribution of discharge from Bonnet Carre through the three major arteries connecting Lake

Pontchartrain to the gulf. Redistribution due to the placement of protection control structures in the passes follows the redistribution of discharge with control structures during tidal events. Distribution of flow through the passes is primarily a function of the relative cross-sectional area of each pass.

PART VI: DISCUSSION AND CONCLUSIONS

56. Tests and subsequent analyses have been made to reach the following conclusions:

- a. The model developed for simulating the three-lake system was shown to accurately portray tidal behavior through the passes and to reproduce observed astronomical surface elevations throughout the region.
- b. Impact of the proposed control structures and the Seabrook Lock on the tidal prism of Lake Pontchartrain is minimal. Approximate percentage reductions in the tidal prism for the individual entrance passes are: Rigolets (9 percent), Chef Menteur (12 percent), and IHNC (21 percent). Model results showed a net reduction of 10 percent in the lake tidal prism with the barrier plan. When a 2 percent adjustment for omitting shallow navigation channels in The Rigolets and Chef Menteur plans is taken into account, the total impact of the barrier plan on net tidal exchange with the lake is to reduce the tidal prism about 8 percent. Analysis of the navigation channel assessment is given in Report 2.
- c. Lake circulation is unaffected by installation of the structures except in areas local to the individual structures.
- d. Impact of the proposed hurricane protection barrier plan during a Bonnet Carre Spillway operation is minimal. Simulation of a floodway operation (to full capacity) under existing conditions showed that a 1.5 ft rise in average lake stage would occur. With the barrier plan in place the average lake stage rose about 1.8 ft, an increase of only 0.3 ft.

57. The data developed during this investigation have been saved and will provide a data base for investigating other hydrodynamic phenomena that may perturb the lake system. An important discovery in the study concerned the development of a boundary condition that permitted simulation of construction changes in the model interior without being forced to move the model boundary beyond influence of the changes. The additional water quality data collected as discussed in Report 1 (Outlaw 1982), together with the model discussed herein, can be used for a possible water quality modeling effort.

REFERENCES

Berger, R. G., and Boland, R. A. 1976 (Sep). "Hydraulic Characteristics of Rigolets Pass, Louisiana, Hurricane Surge Control Structures; Hydraulic Model Investigation," Technical Report H-76-16, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Butler, H. L. 1978 (Jun). "Numerical Simulation of Tidal Hydrodynamics: Great Egg Harbor and Corson Inlets, New Jersey," Technical Report H-78-11, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Butler, H. Lee. "WIFM-WES Implicit Flooding Model: Theory and Program Documentation" (in preparation), U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Butler, H. Lee, et al. 1982 (Jun). "Lake Pontchartrain and Vicinity Hurricane Protection Plan; Physical and Numerical Model Investigation of Control Structures and the Seabrook Lock; Hydraulic and Mathematical Model Investigation," Technical Report HL-82-2, Report 2, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Hildebrand, F. B. 1956. Introduction to Numerical Analysis, McGraw-Hill, New York.

Kuipers, J., and Vreugdenhil, C. B. 1973 (Oct). "Calculating of Two-Dimensional Horizontal Flow," Report No. S163, Part 1, Delft Hydraulics Laboratory, Delft, The Netherlands.

Leendertse, J. J. 1970 (Feb). "A Water-Quality Simulation Model for Well-Mixed Estuaries and Coastal Seas; Volume 1, Principles of Computation," RM-6230-rc, Rand Corporation, Santa Monica, Calif.

Orlanski, I. 1976. "A Simple Boundary Condition for Unbounded Hyperbolic Flows," Journal of Computational Physics, Vol 21, pp 251-269.

Outlaw, D. G. 1982 (Jan). "Lake Pontchartrain and Vicinity Hurricane Protection Plan; Prototype Data Acquisition and Analysis," Technical Report HL-82-2, Report 1, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Reid, R. O., and Bodine, B. R. 1968 (Feb). "Numerical Model for Storm Surges in Galveston Bay," Journal, Waterways and Harbors Division, American Society of Civil Engineers, Vol 94, No. WW1.

U. S. Army Engineer Waterways Experiment Station, CE. 1963 (Nov). "Effects of Lake Pontchartrain, Louisiana, of Hurricane Surge Control Structures and Mississippi River-Gulf Outlet Channel; Hydraulic Model Investigation," Technical Report 2-636, Vicksburg, Miss.

Vreudgenhil, C. B. 1973 (Nov). "Secondary-Flow Computations," Publication No. 114, Delft Hydraulics Laboratory, Delft, The Netherlands.

Weare, T. John. 1976 (May). "Instability in Tidal Flow Computational Schemes," Journal, Hydraulics Division, American Society of Civil Engineers, Vol 102, No. HY5, Proc. Paper 12100, pp. 569-580.

_____. 1979. "Errors Arising from Irregular Boundaries in ADI Solutions of the Shallow-Water Equations," International Journal for Numerical Methods in Engineering, Vol 14, pp 921-931.

Table 1

Tidal Exchange Through Entrance
Passes and Net Lake Exchange
for a Lunar Day

Tidal Event	Entrance Pass	Discharge x 10 ⁹ ft ³				Percent Impact
		Base Conditions		With Structures		
		Flood	Ebb	Flood	Ebb	
Spring	Rigolets	2.790	3.059	2.539	2.798	8.76
	Chef Menteur	1.649	1.731	1.434	1.519	12.63
	IHNC	0.597	0.546	0.476	0.418	21.78
	Lake (net)	4.730	4.965	4.216	4.439	10.73
Mean	Rigolets	2.504	2.810	2.274	2.570	8.84
	Chef Menteur	1.489	1.544	1.301	1.358	12.33
	IHNC	0.521	0.491	0.415	0.381	21.34
	Lake (net)	4.233	4.551	3.784	4.090	10.36
Neap	Rigolets	0.901	0.502	0.828	0.497	5.56
	Chef Menteur	0.560	0.269	0.553	0.281	0.60
	IHNC	0.225	0.177	0.189	0.147	16.42
	Lake (net)	1.489	0.711	1.376	0.707	5.32

Table 2

Tidal Exchange Through Entrance
Passes and Net Lake Exchange for
a Semilunar Month, 22 Oct-6 Nov 1978

Entrance Pass	Discharge x 10 ¹⁰ ft ³				Percent Impact
	Base Conditions		With Structures		
	Flood	Ebb	Flood	Ebb	
Rigolets	3.014	2.927	2.735	2.645	9.44
Chef Mentuer	1.927	1.748	1.697	1.549	11.67
IHNC	0.635	0.562	0.505	0.439	21.15
Lake (net)	5.399	5.382	4.829	4.808	10.61

Table 3

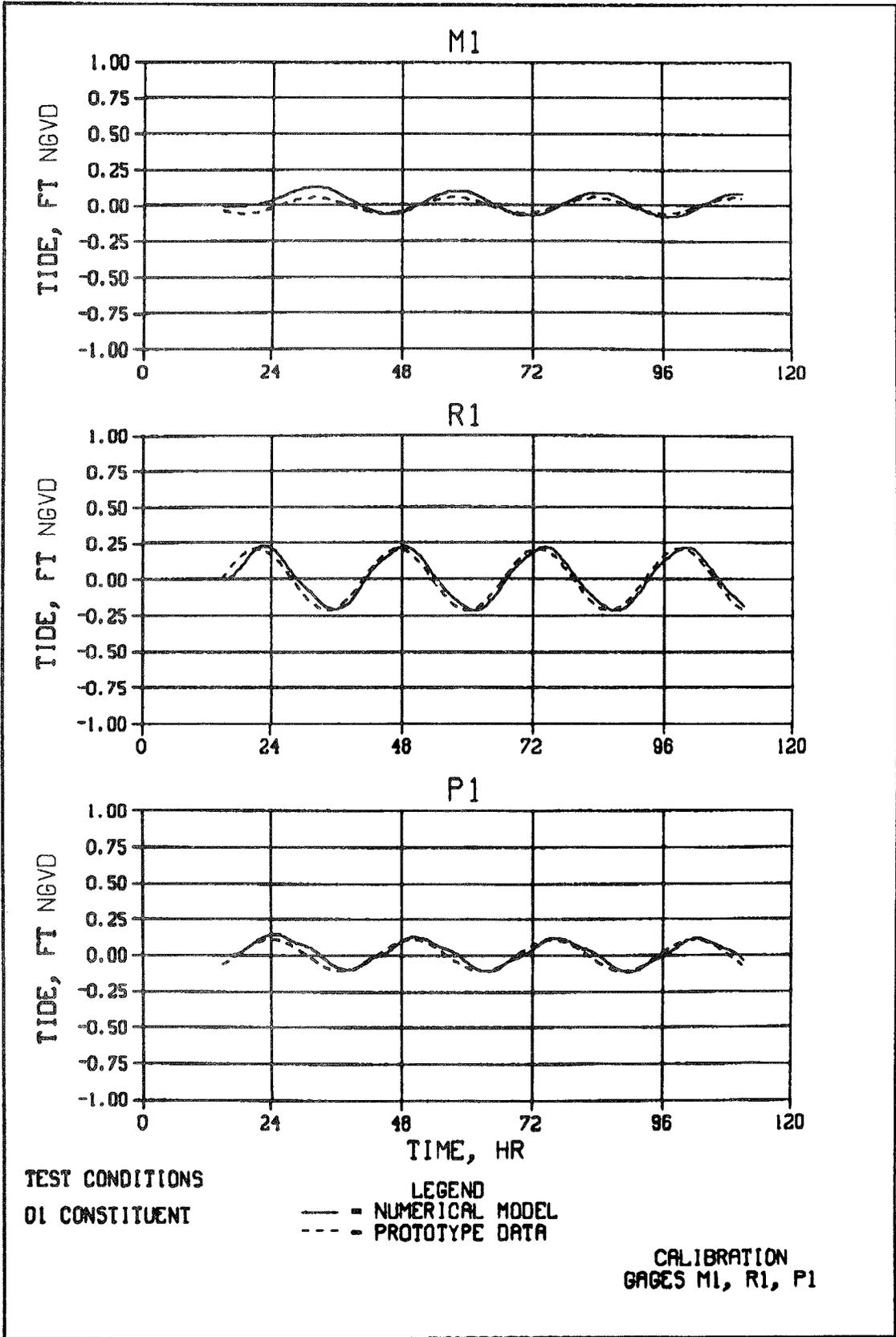
Steady-State Surface Elevations Developed
by a Bonnet Carre Spillway Operation

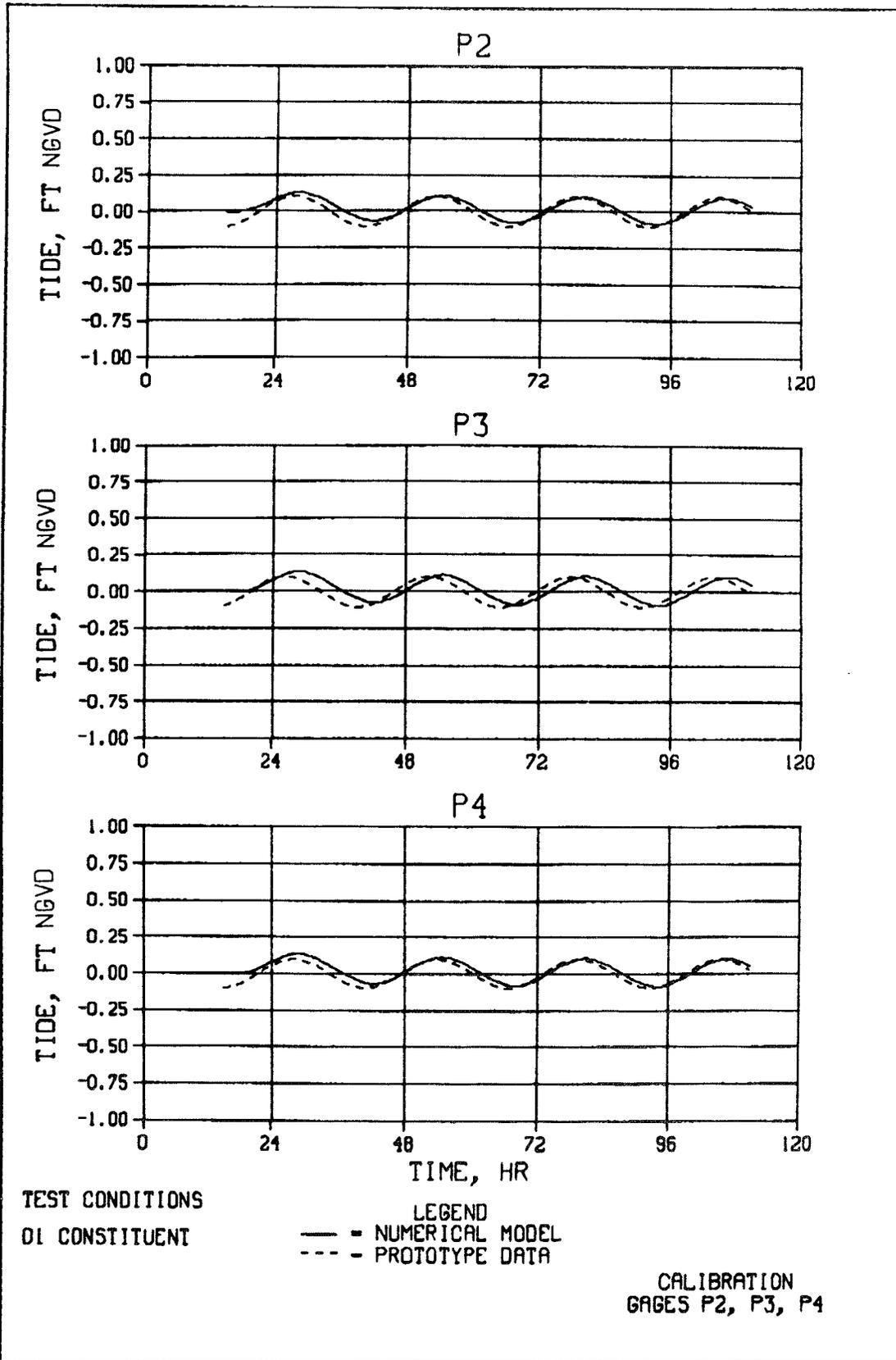
<u>Station</u>	<u>Base Conditions ft</u>	<u>With Structures ft</u>
R1	0.77	0.81
P1	1.18	1.54
P4	1.52	1.81
P6	1.31	1.11
P9	1.51	1.80
B2	0.25	0.24
B4	0.57	0.57

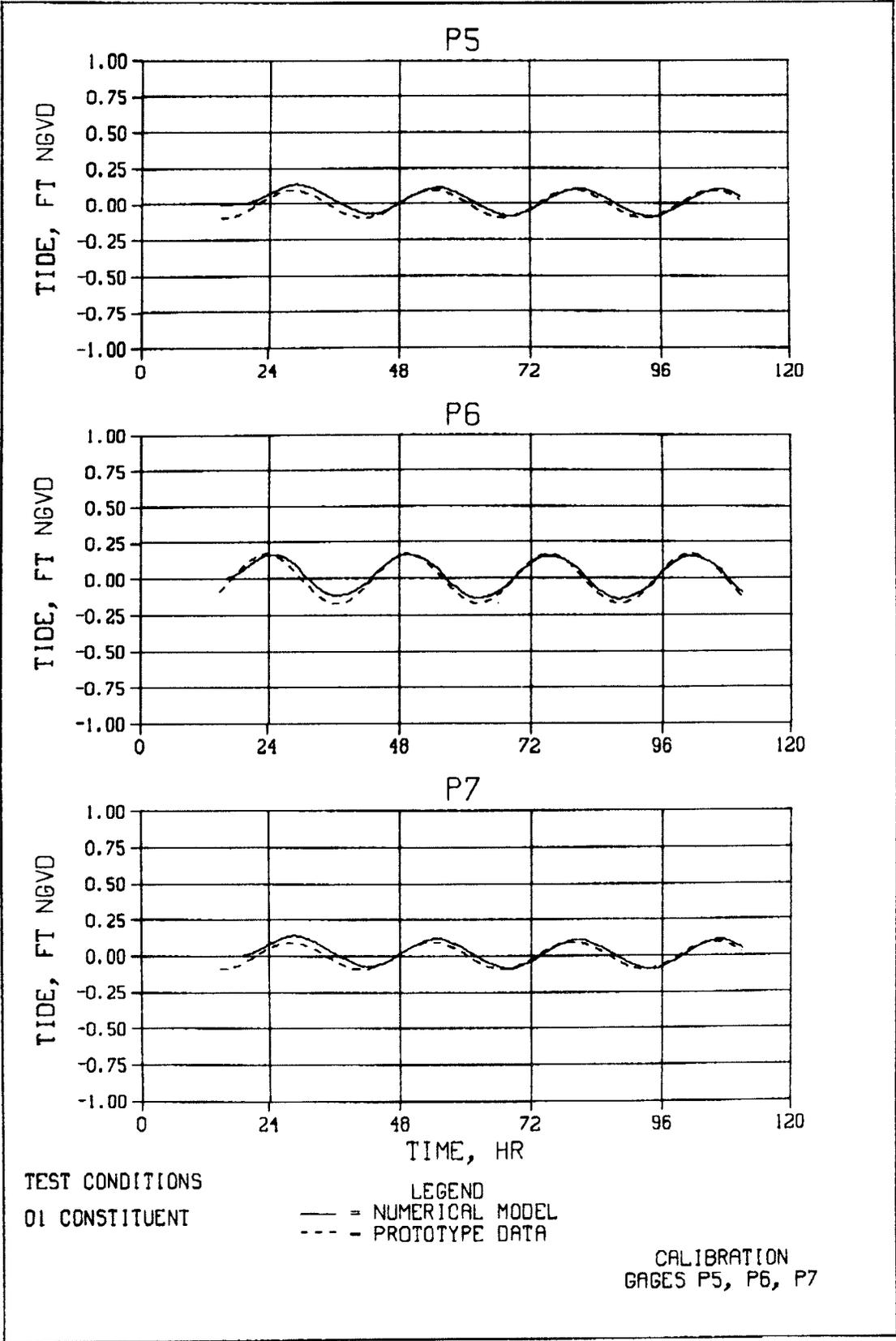
Table 4

Distribution of Total Discharge Through
Lake Pontchartrain Entrance Passes
from a Bonnet Carre Spillway Operation

<u>Entrance Pass</u>	<u>Base Conditions Percent Discharge</u>	<u>With Structures Percent Discharge</u>
Rigolets	58.7	60.9
Chef Menteur	35.2	34.0
IHNC	6.1	5.1







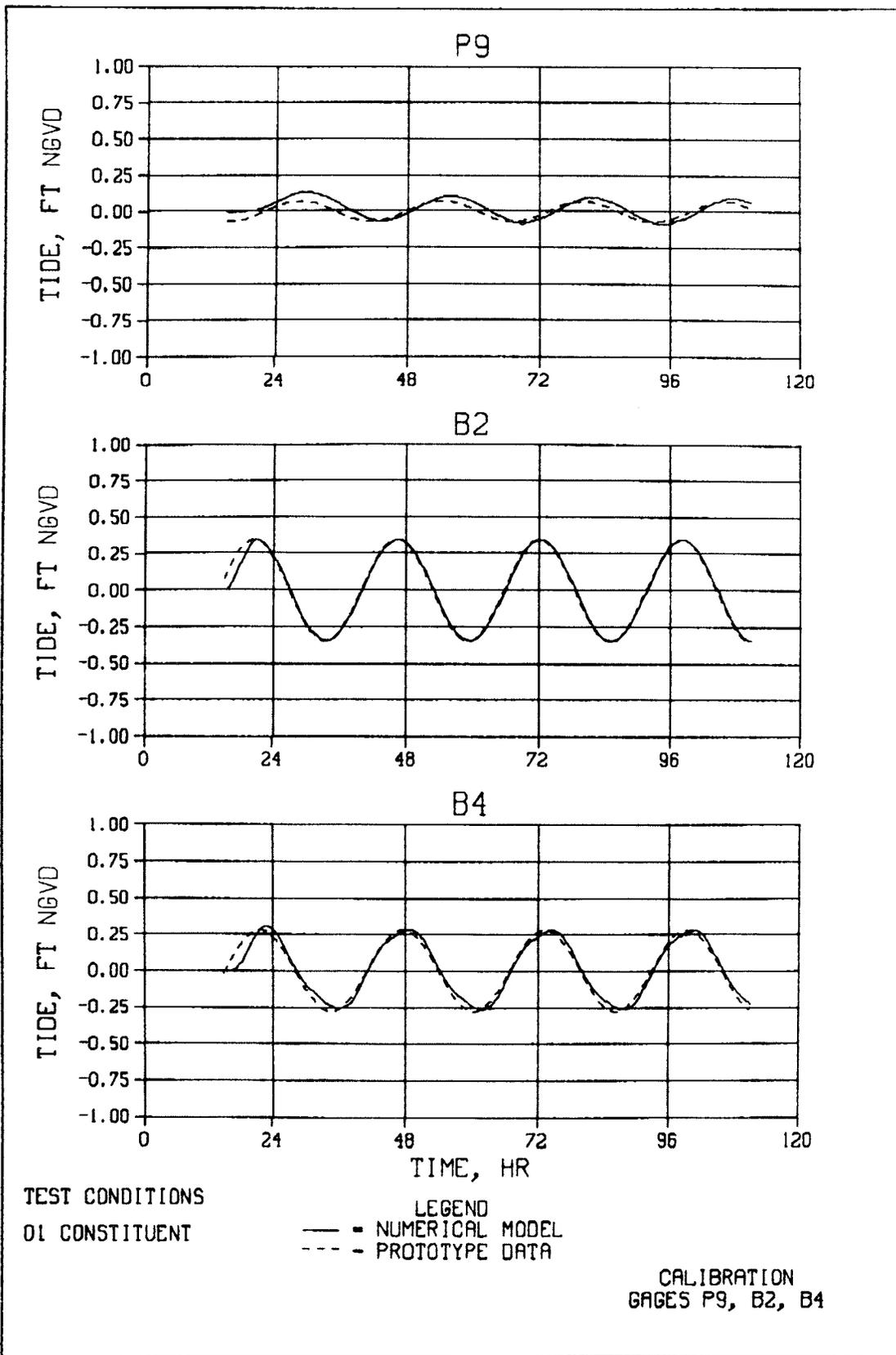
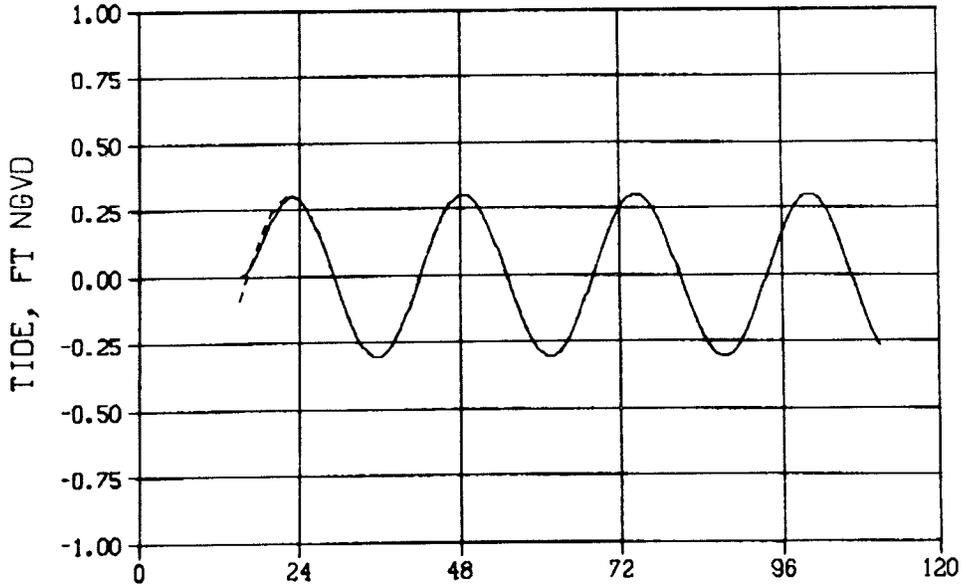
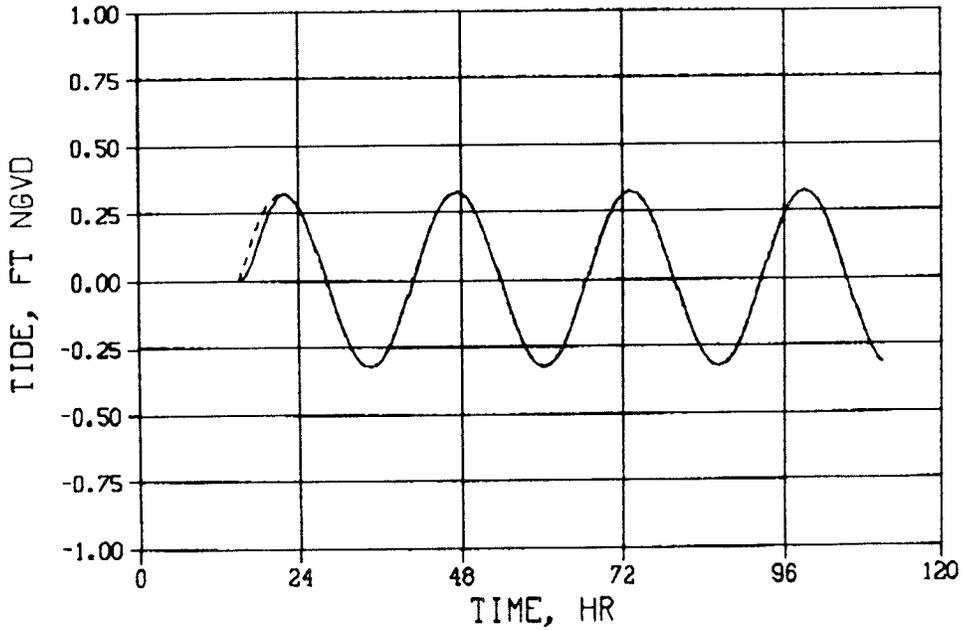


PLATE 4

B5



B6



TEST CONDITIONS
01 CONSTITUENT

LEGEND
—— - NUMERICAL MODEL
- - - - PROTOTYPE DATA

CALIBRATION
GAGES B5, B6

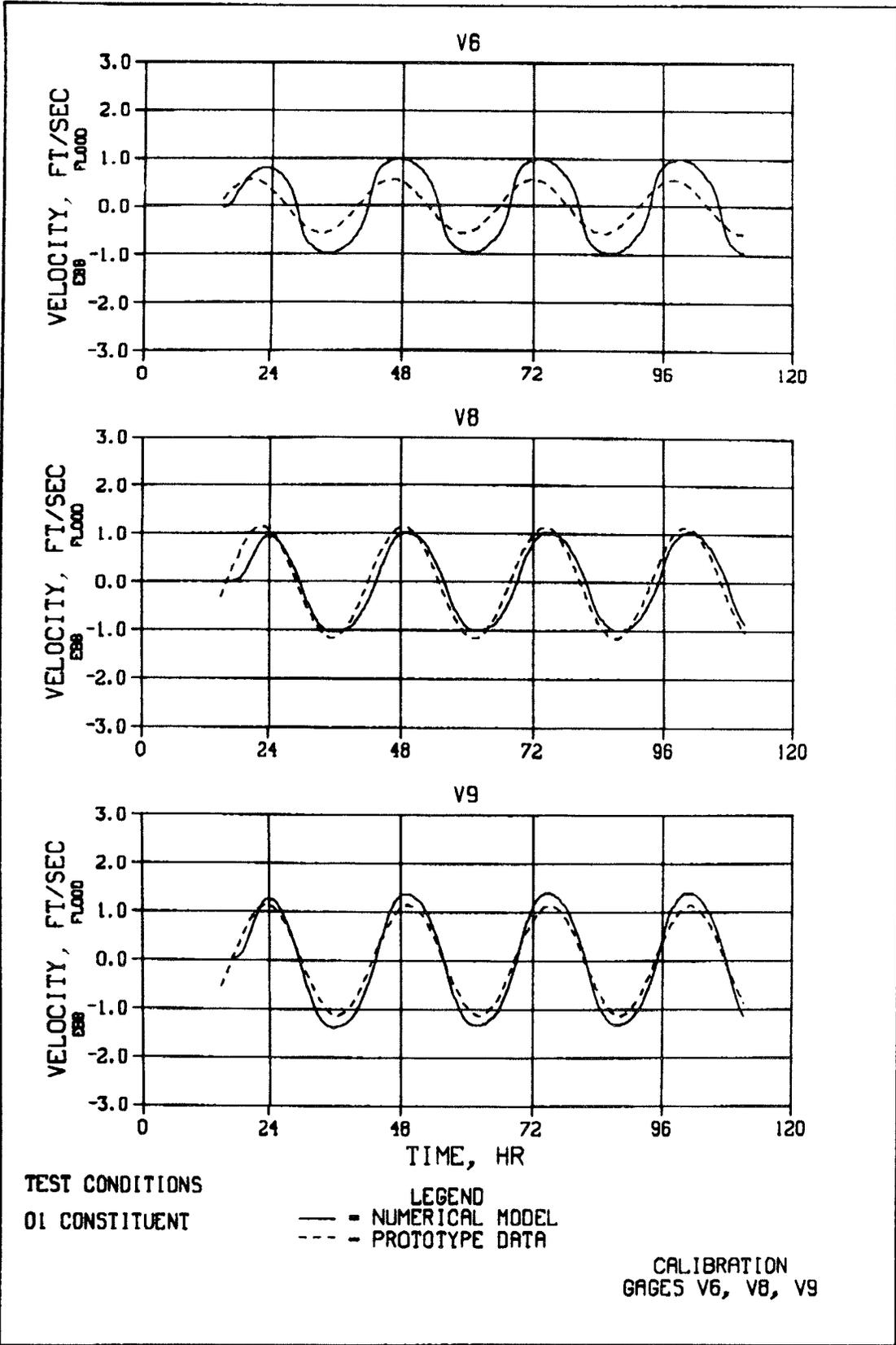
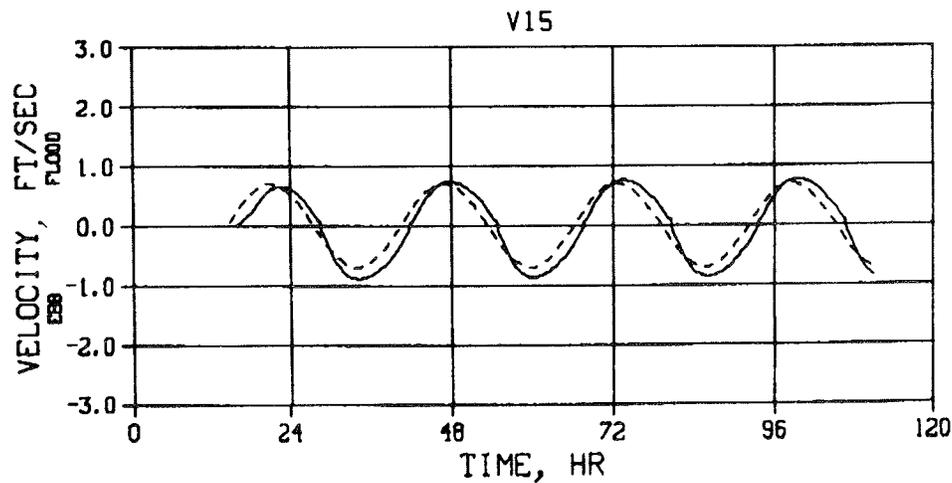
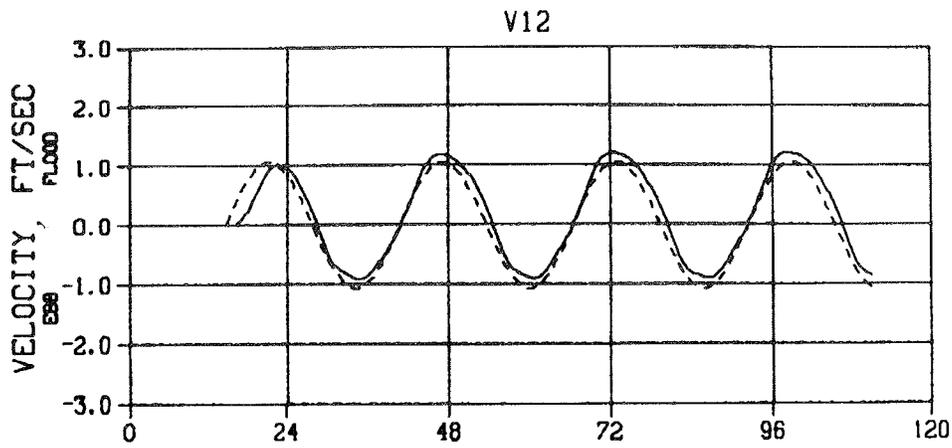
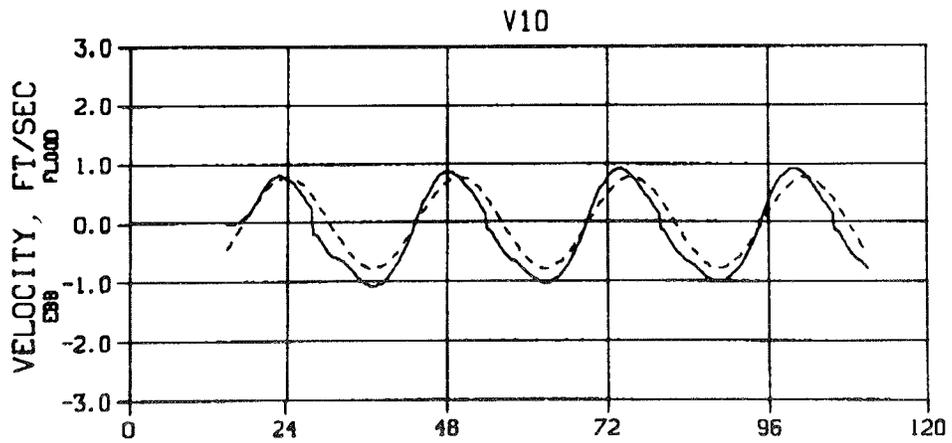


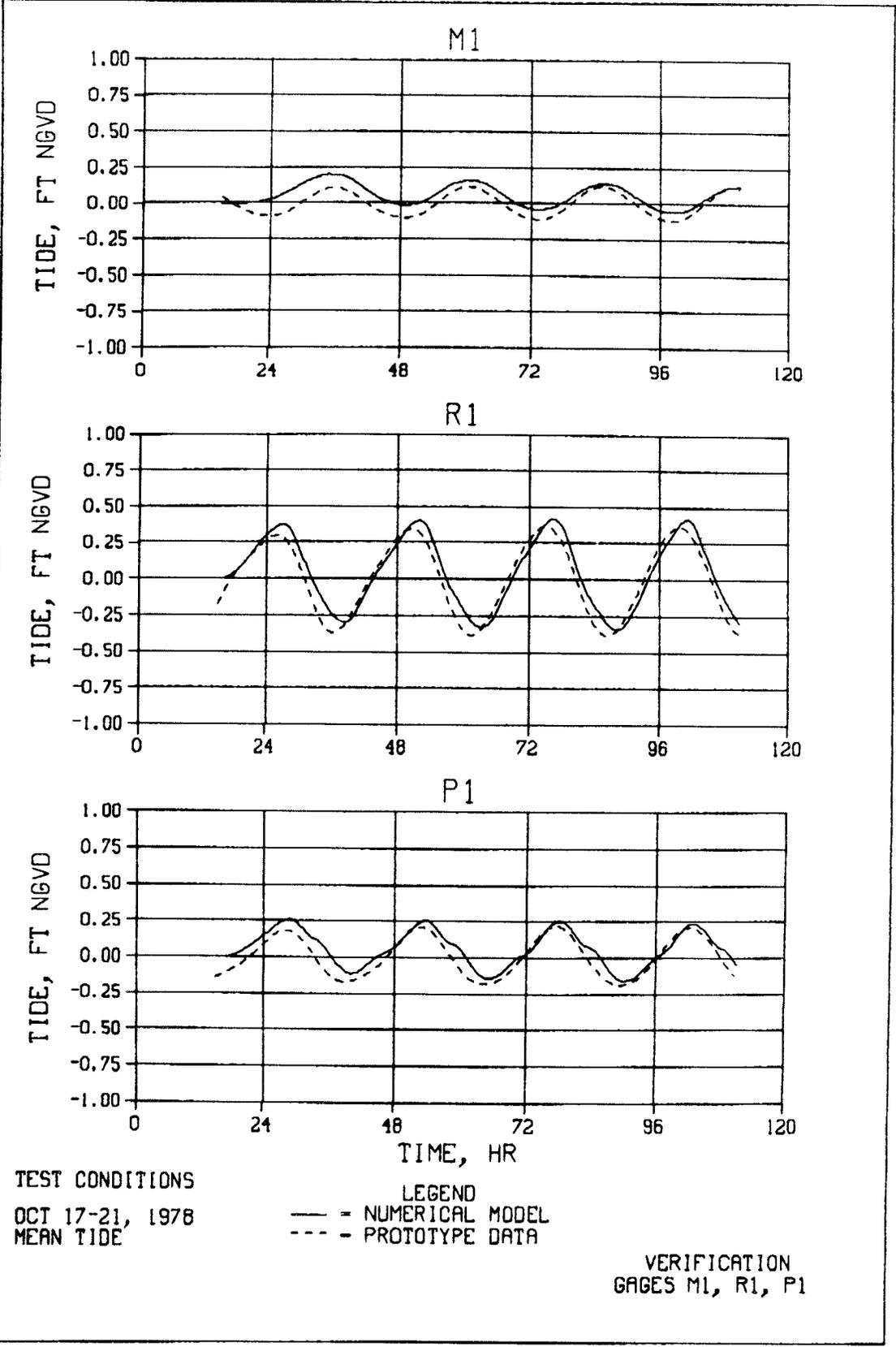
PLATE 6

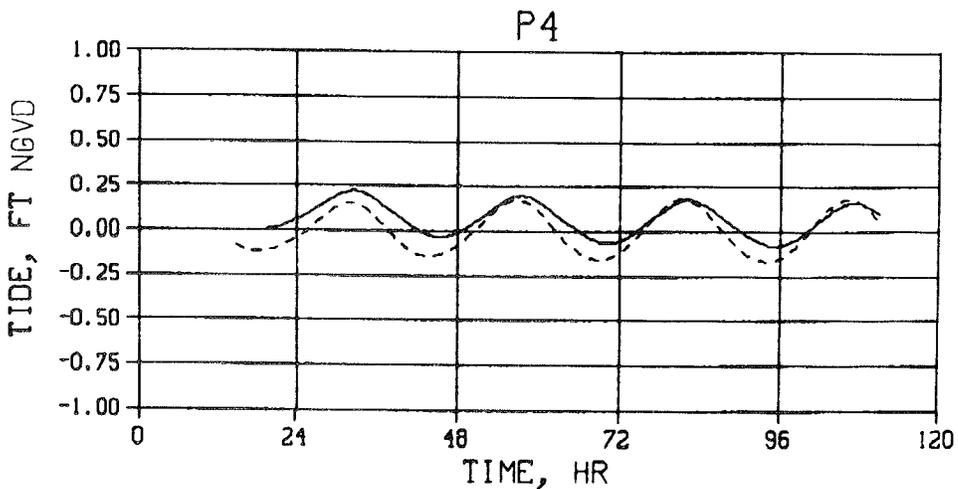
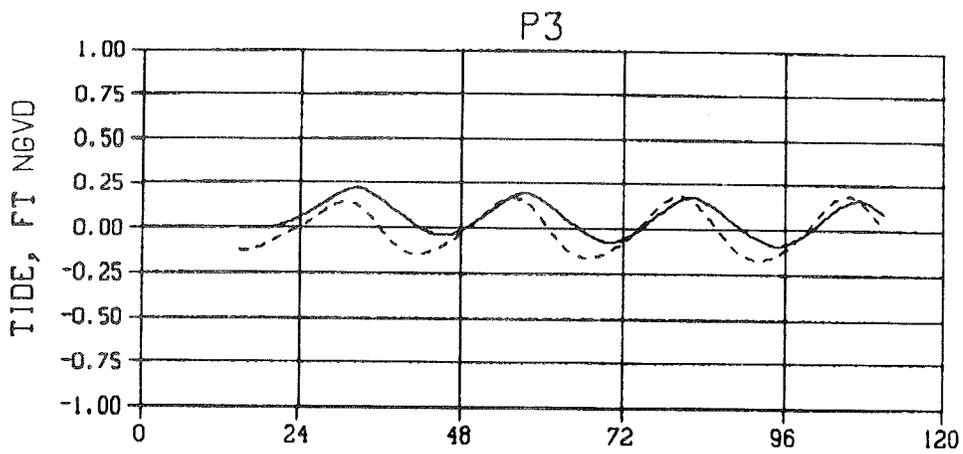
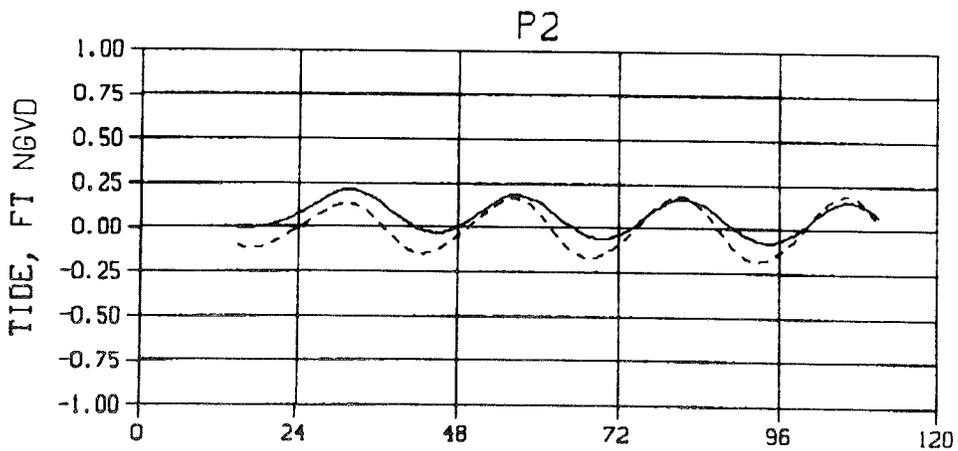


TEST CONDITIONS
OI CONSTITUENT

LEGEND
 — = NUMERICAL MODEL
 - - - = PROTOTYPE DATA

CALIBRATION
GAGES V10, V12, V15

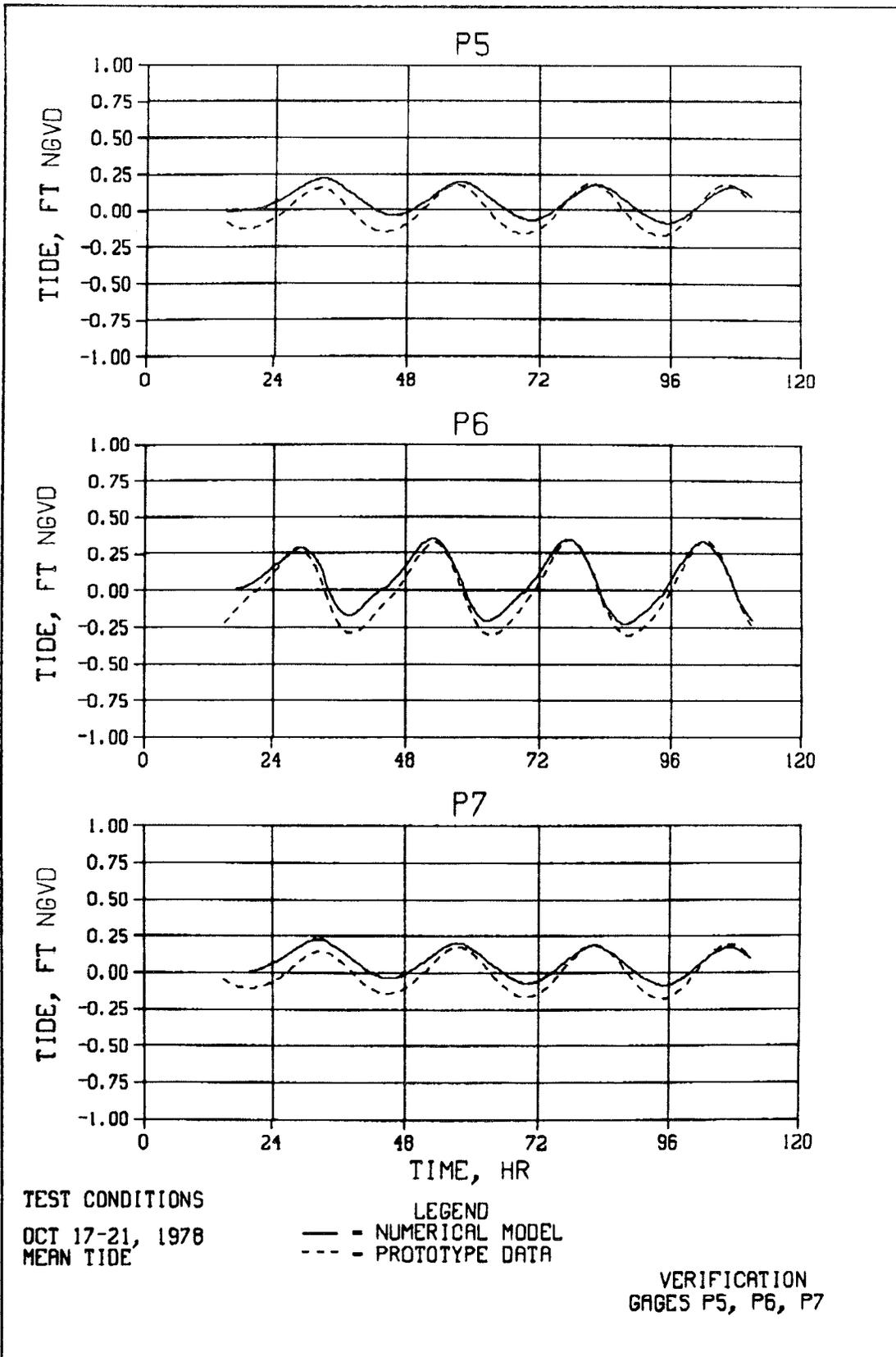


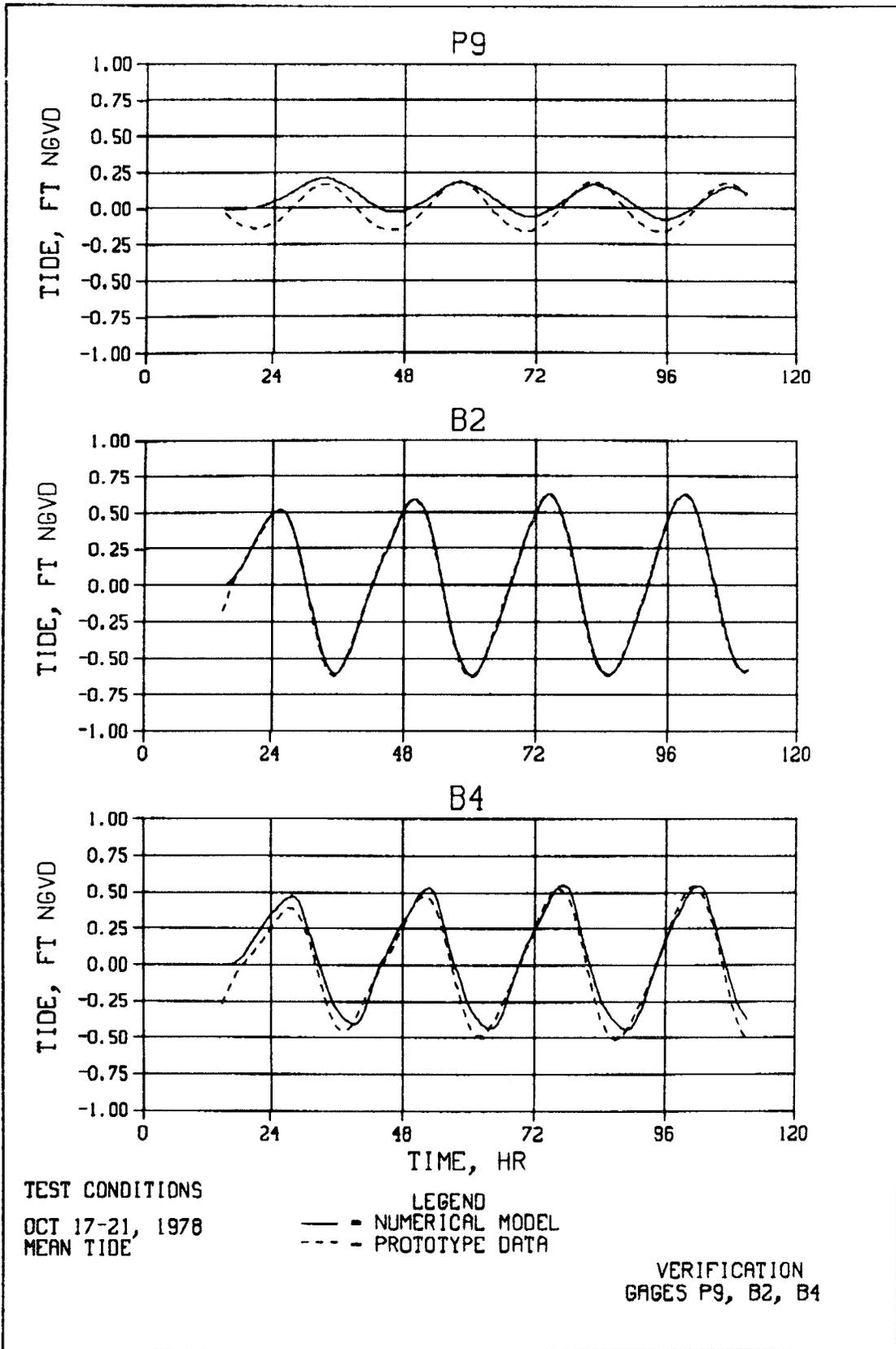


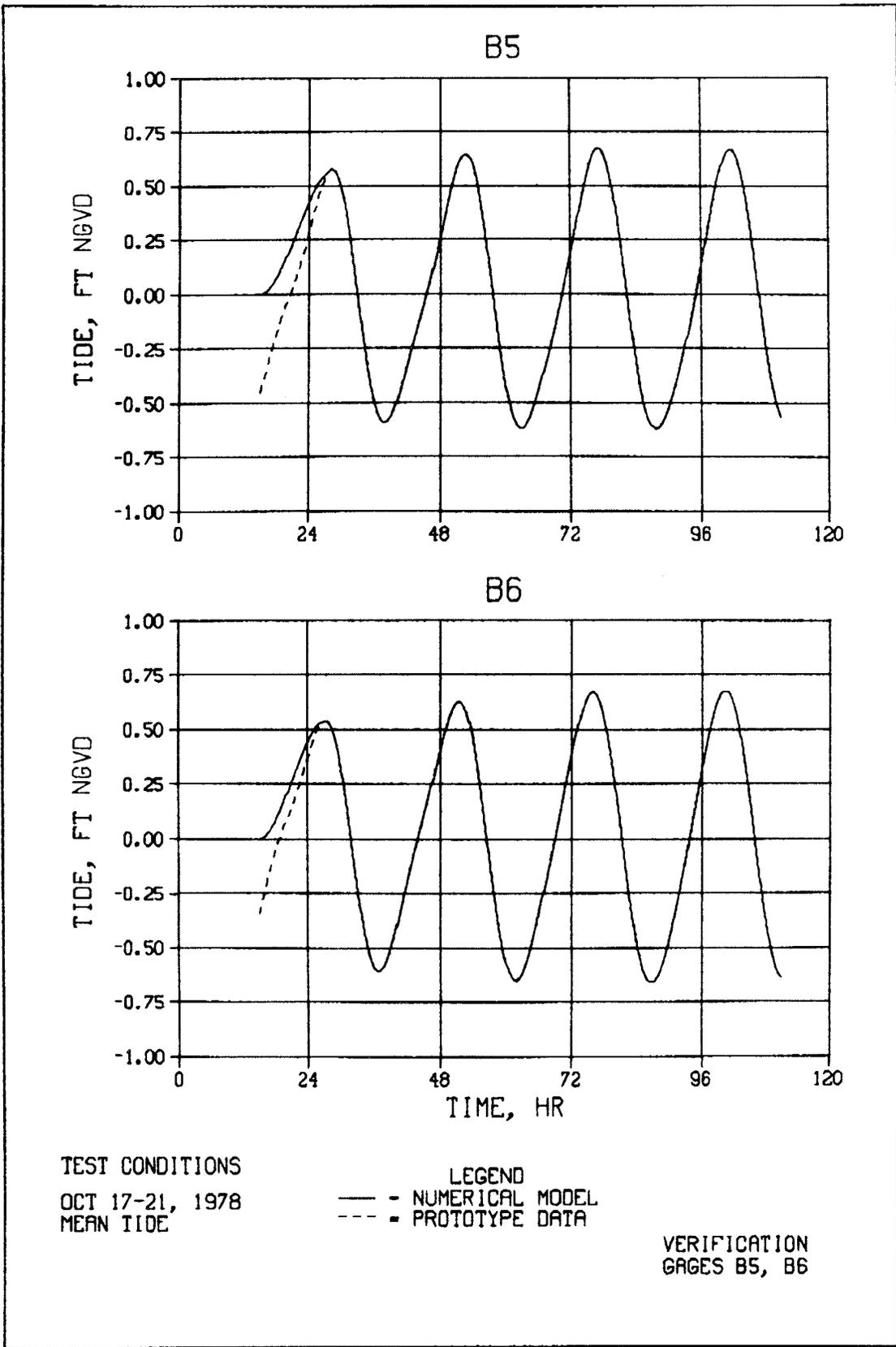
TEST CONDITIONS
OCT 17-21, 1978
MEAN TIDE

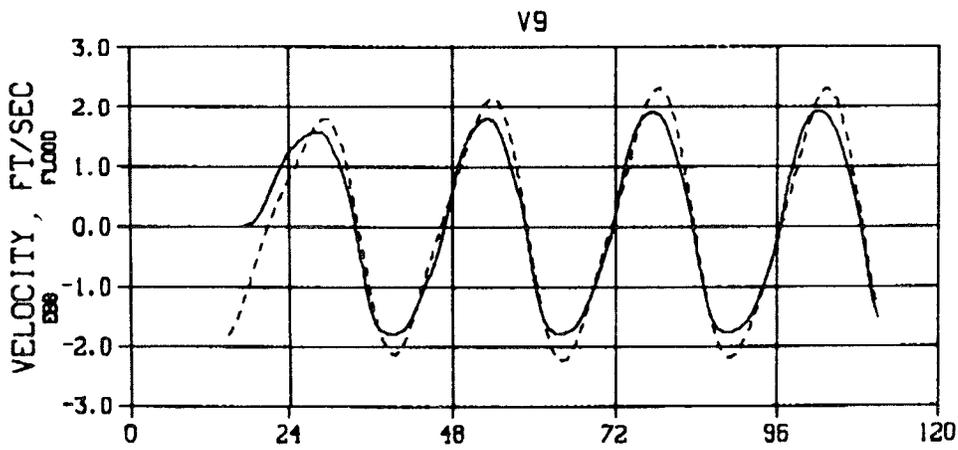
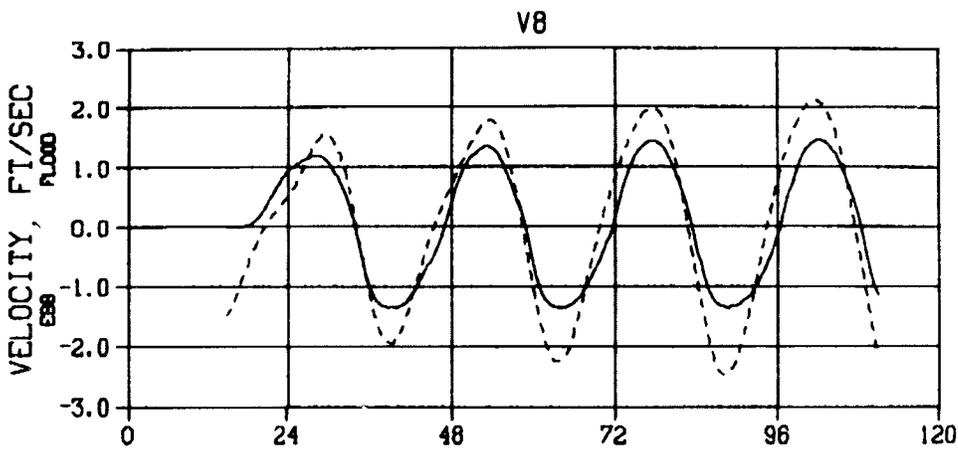
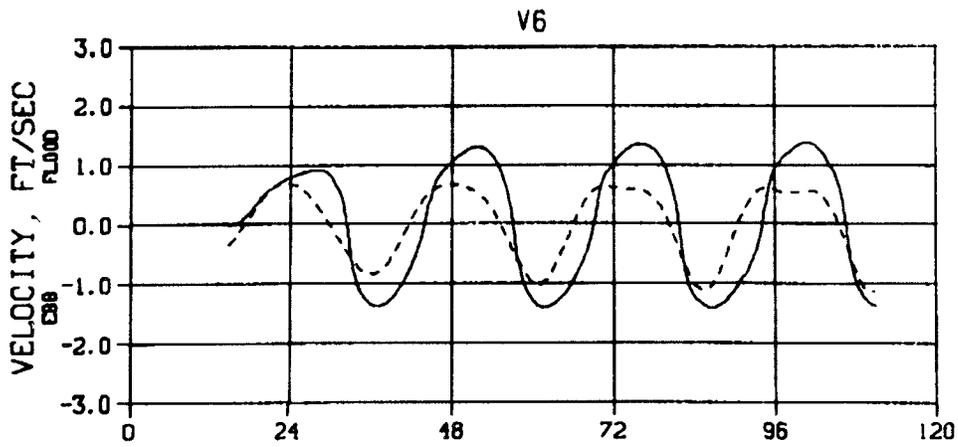
LEGEND
— - NUMERICAL MODEL
- - - - PROTOTYPE DATA

VERIFICATION
GAGES P2, P3, P4





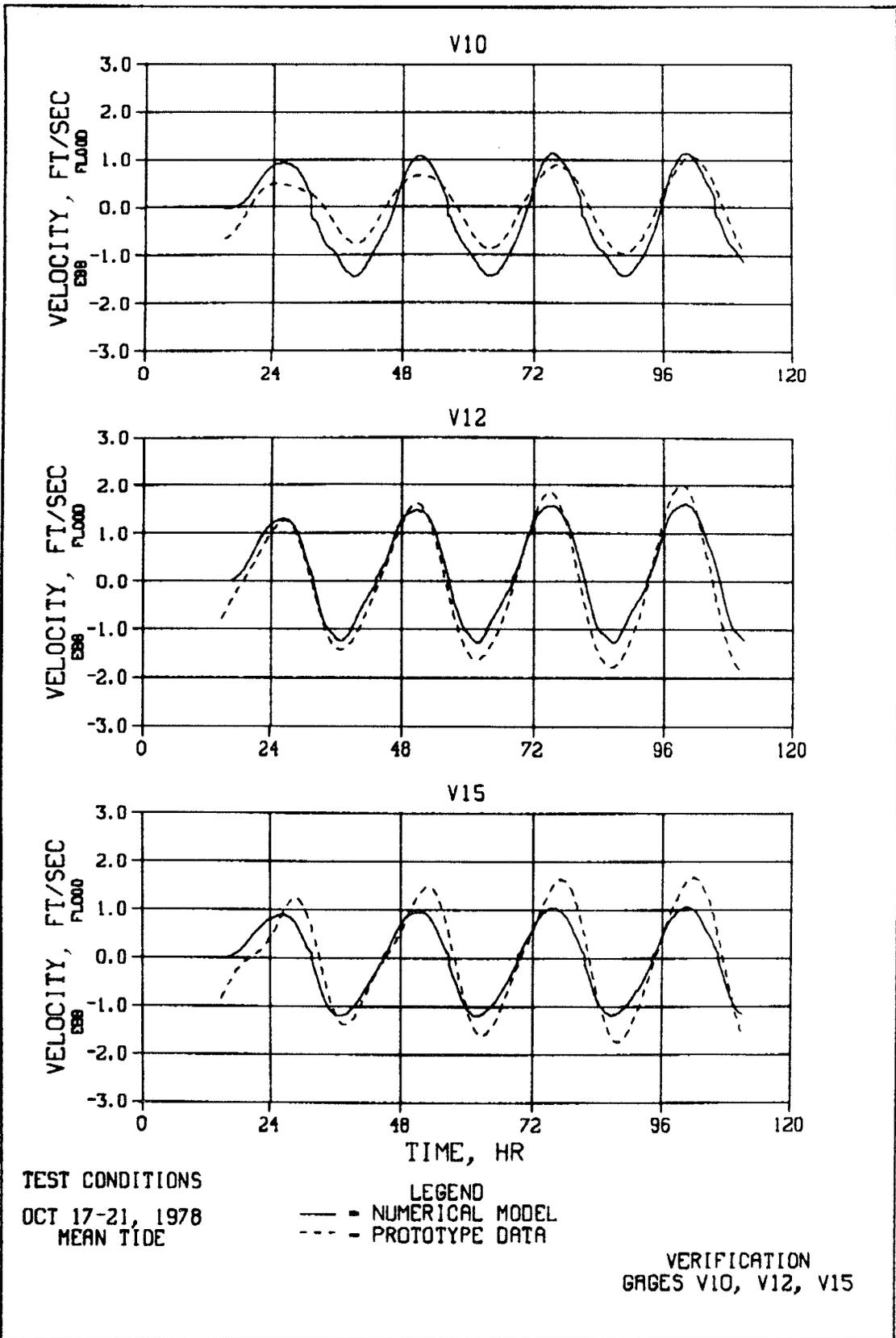


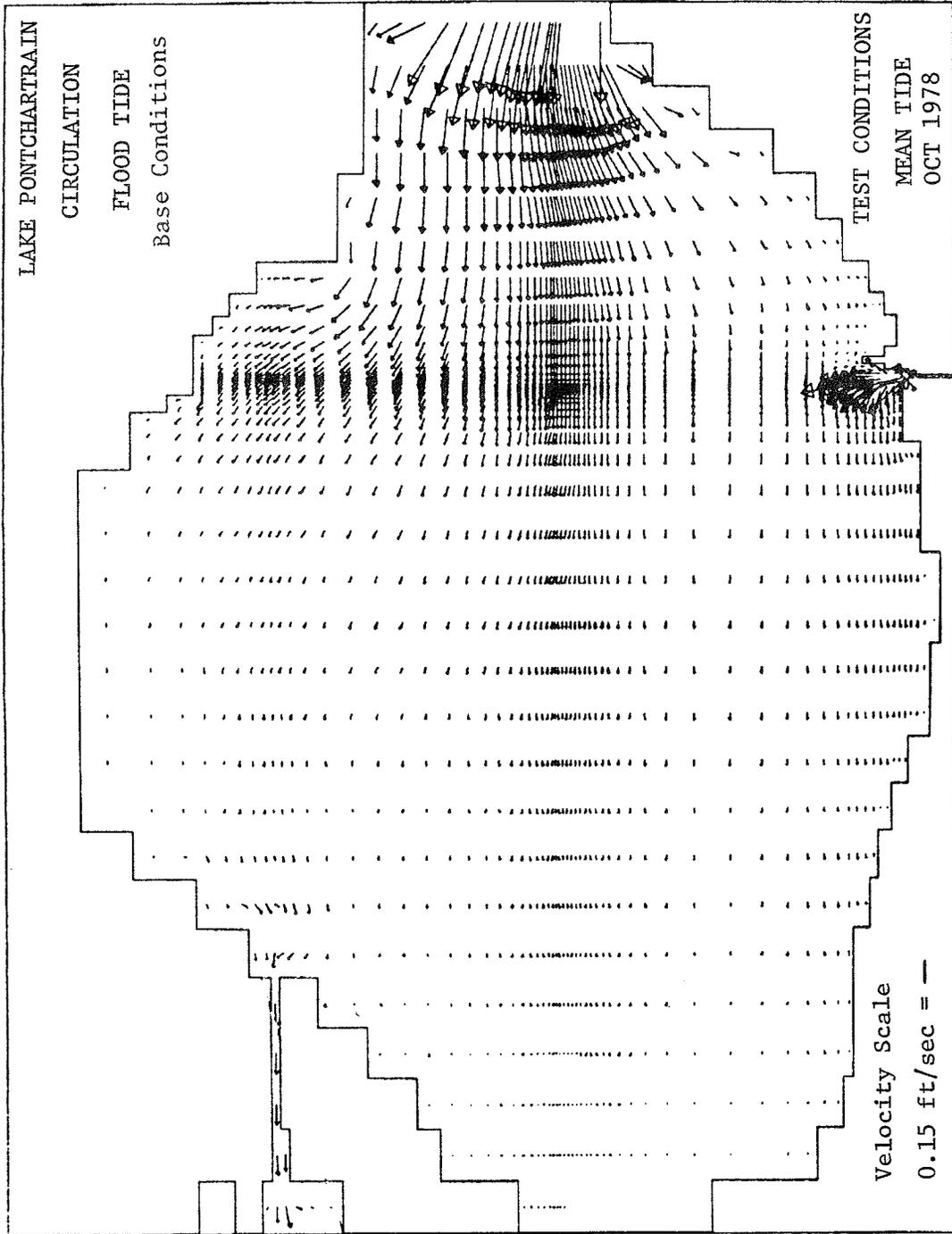


TEST CONDITIONS
 OCT 17-21, 1978
 MEAN TIDE

LEGEND
 — — — — — NUMERICAL MODEL
 - - - - - PROTOTYPE DATA

VERIFICATION
 GAGES V6, V8, V9





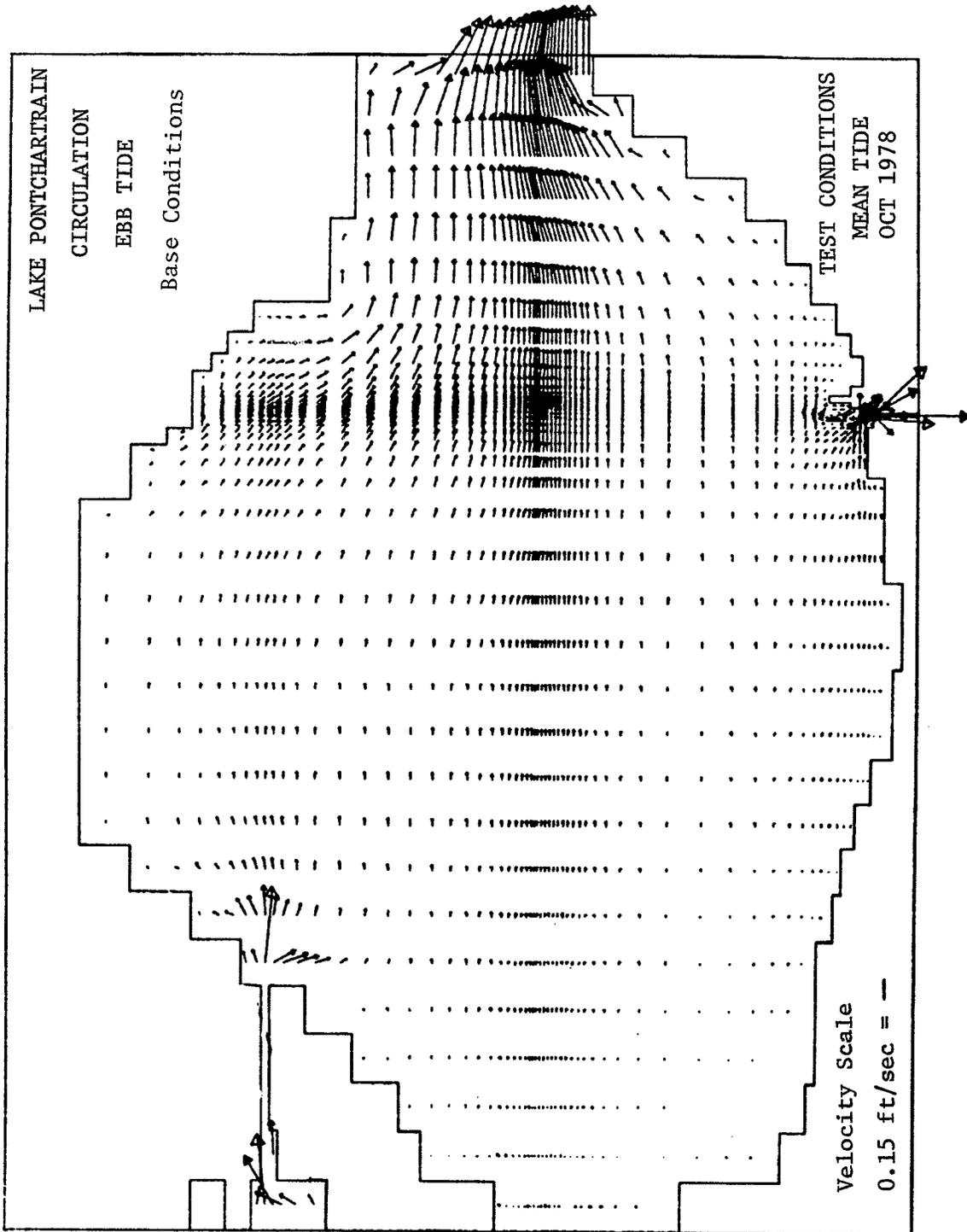
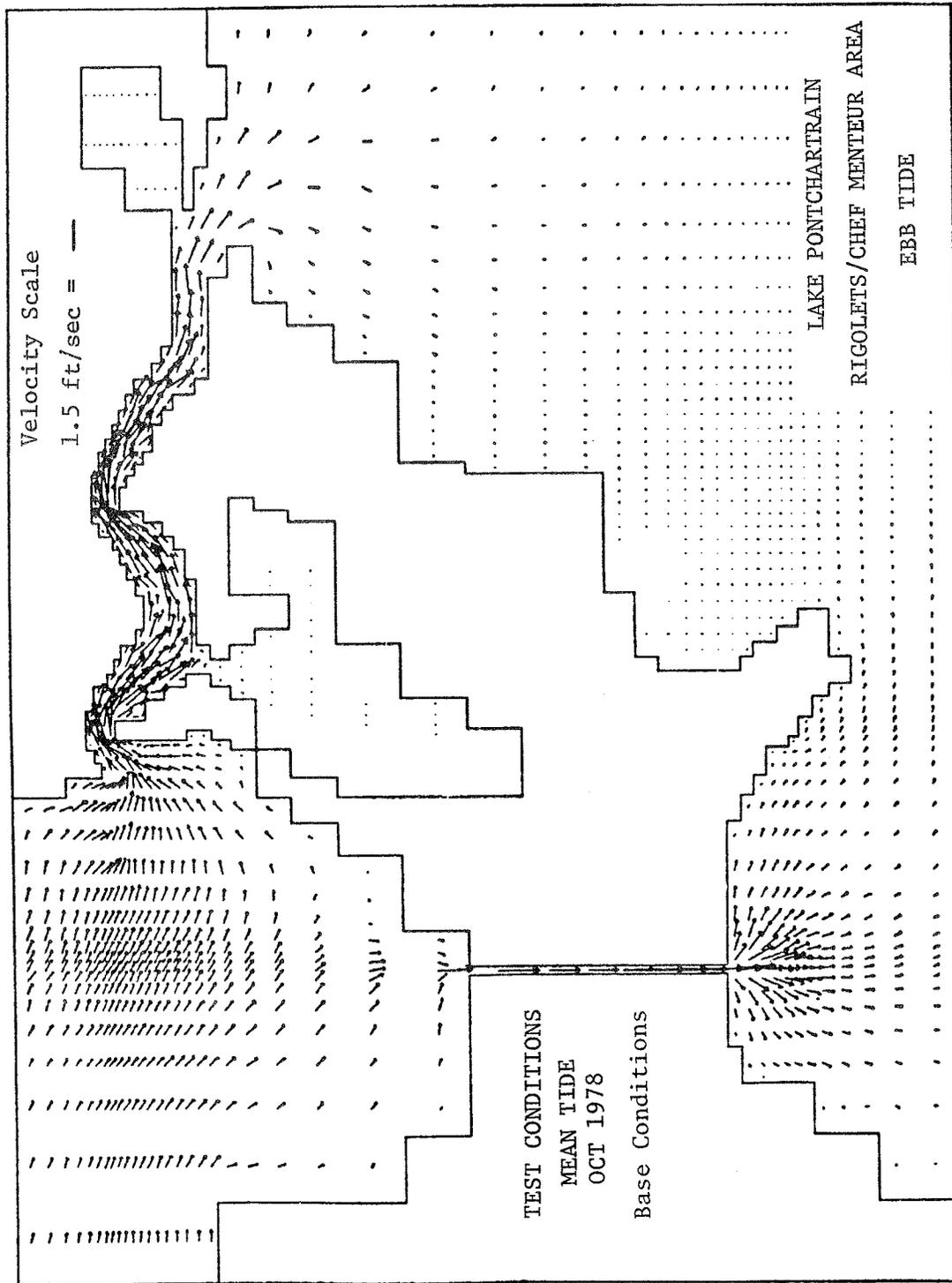


PLATE 16



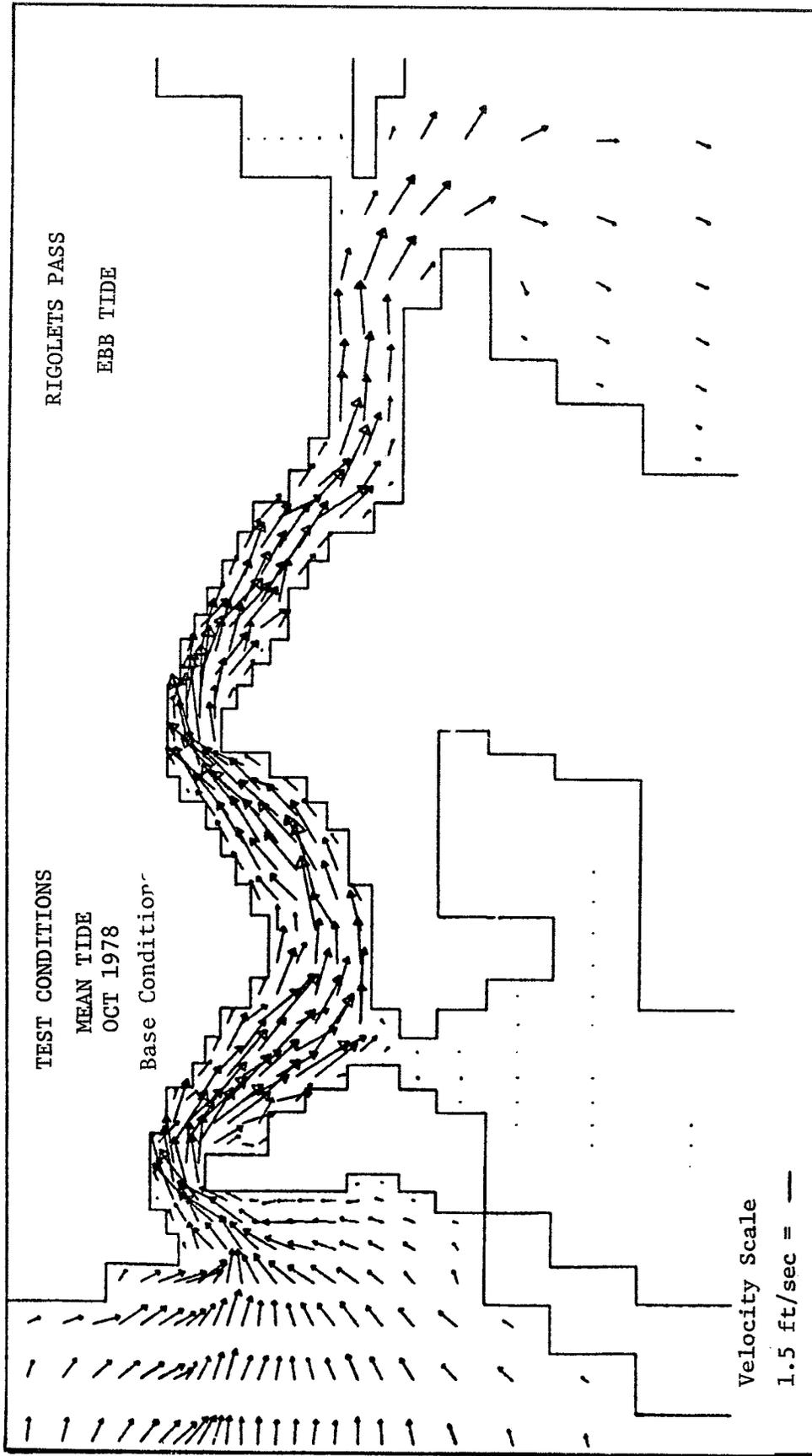
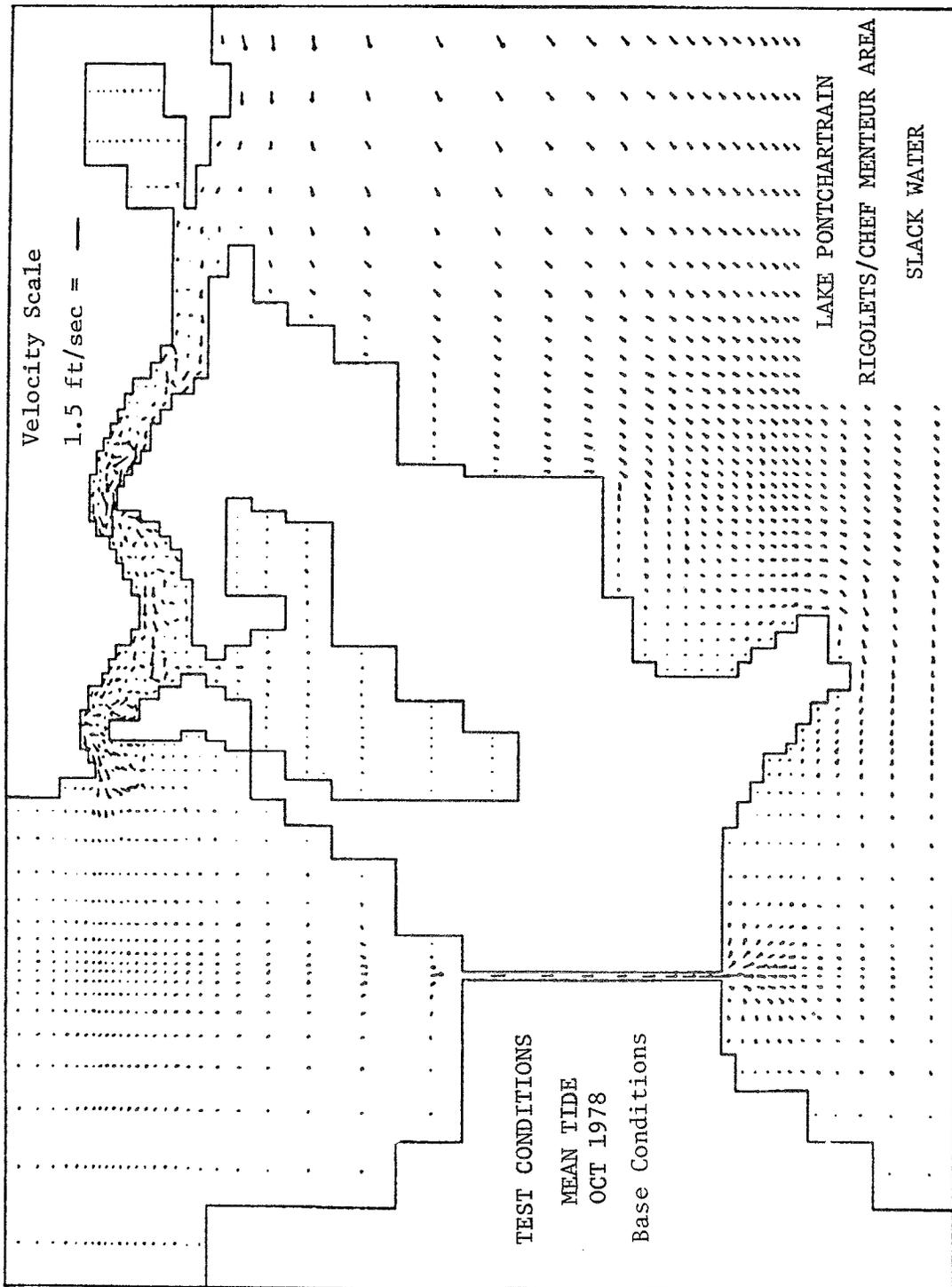


PLATE 18



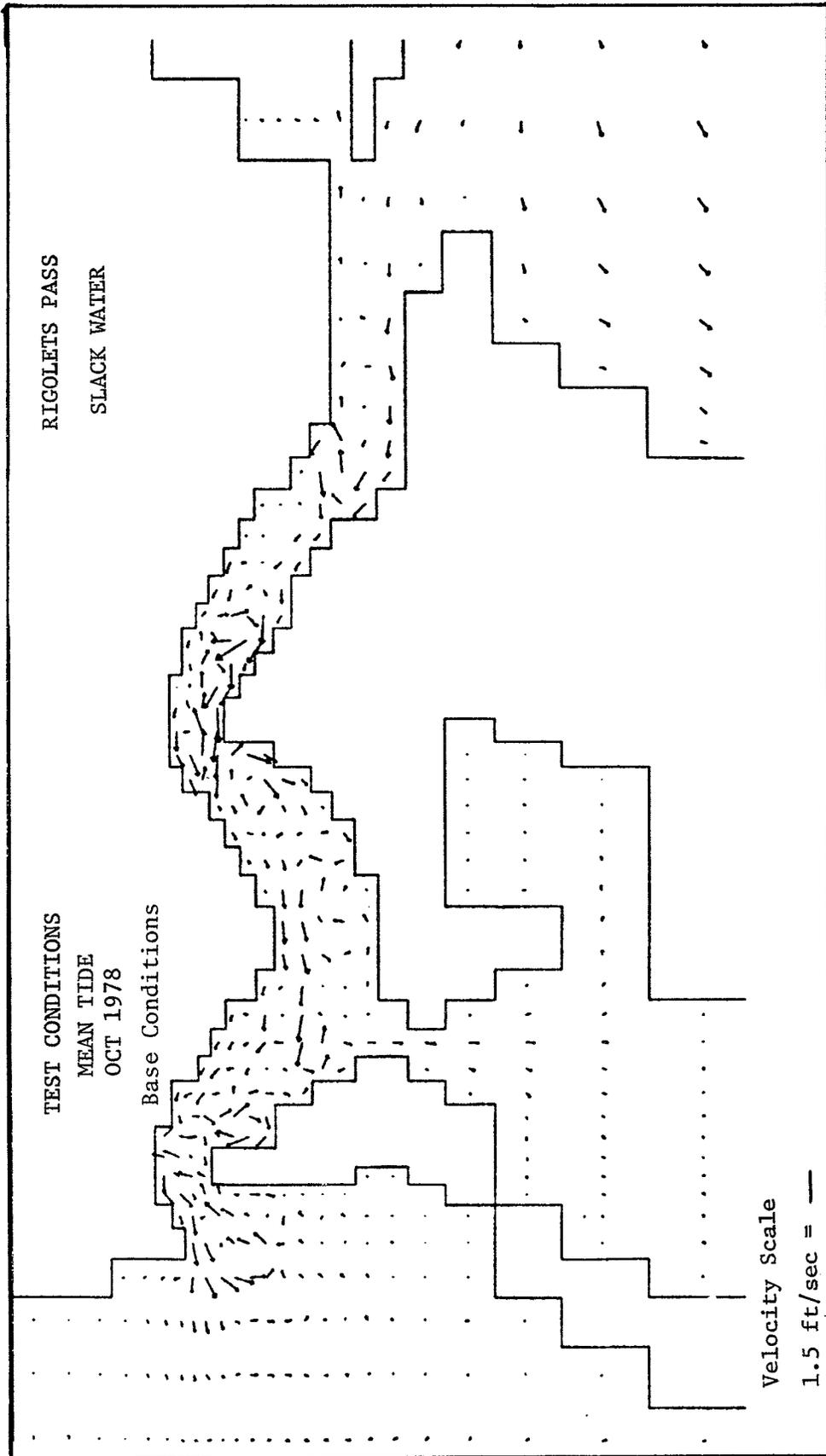


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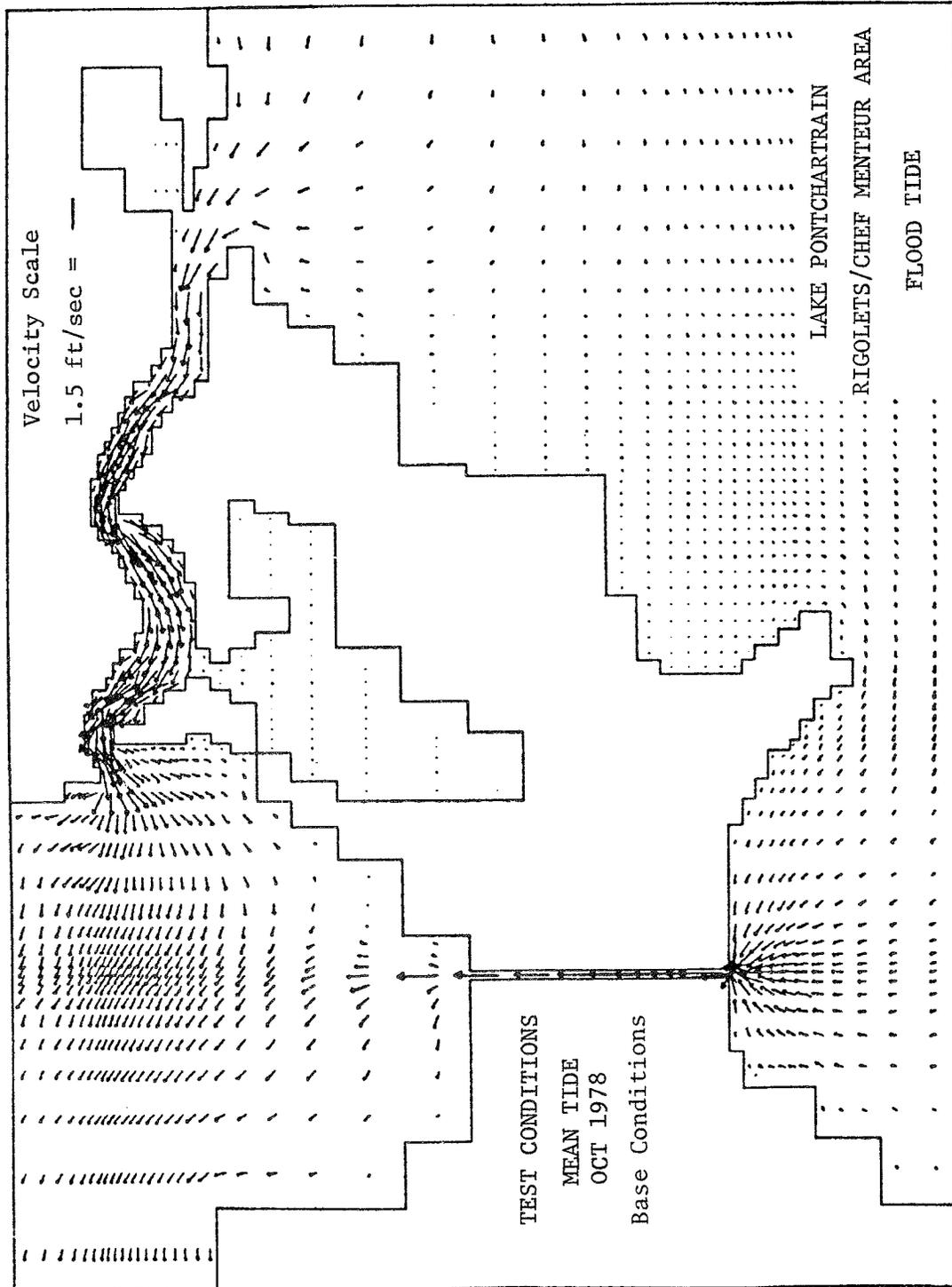


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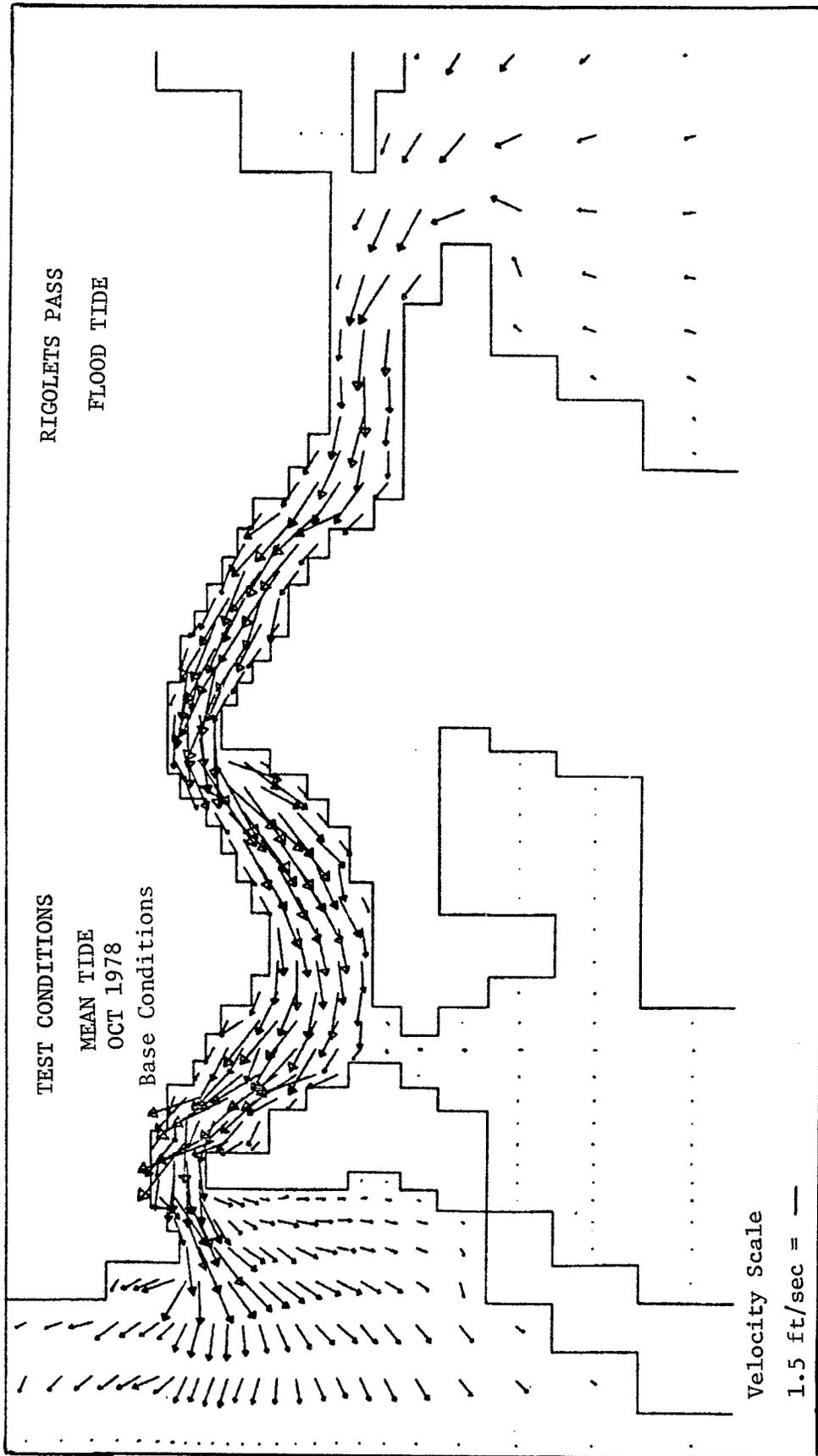
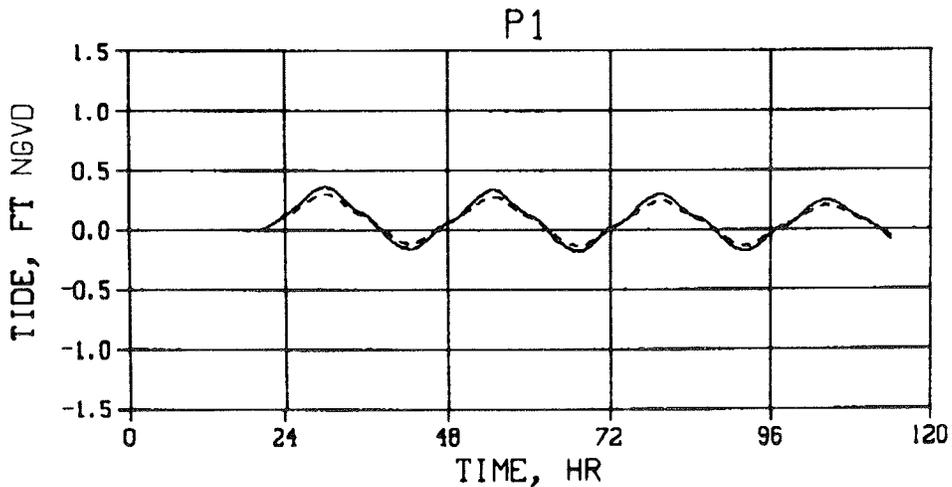
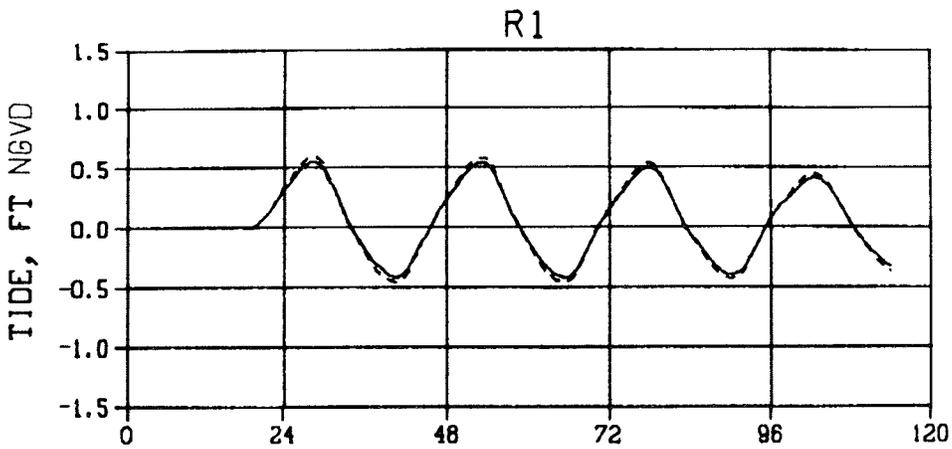
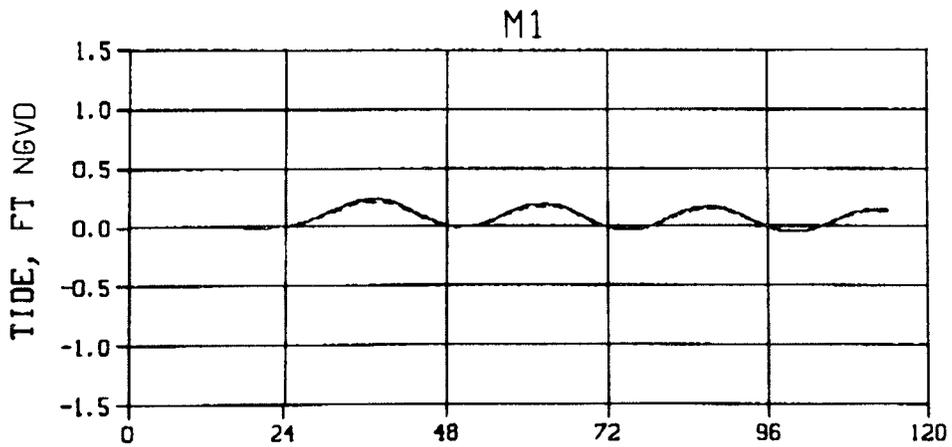


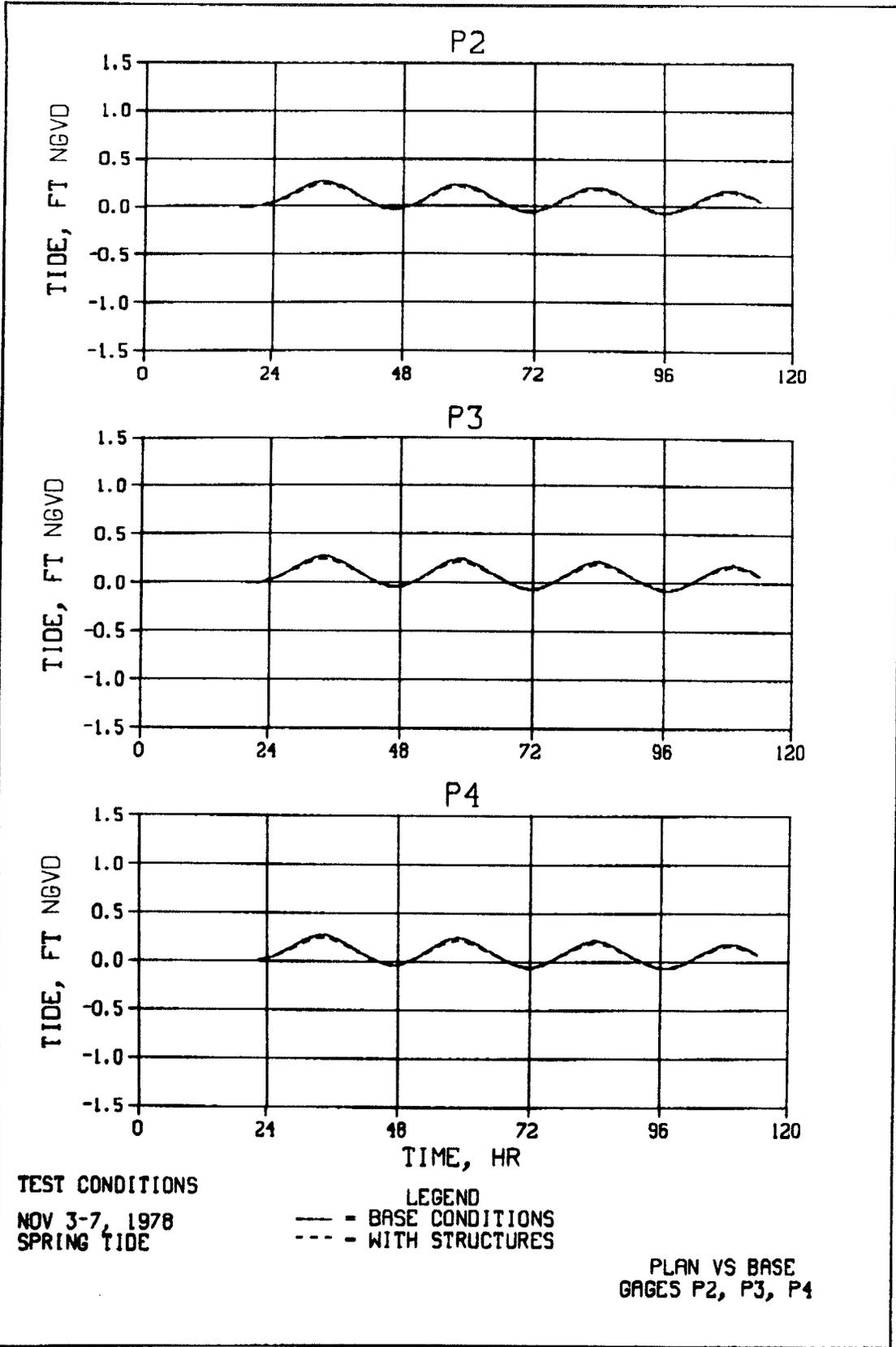
PLATE 22

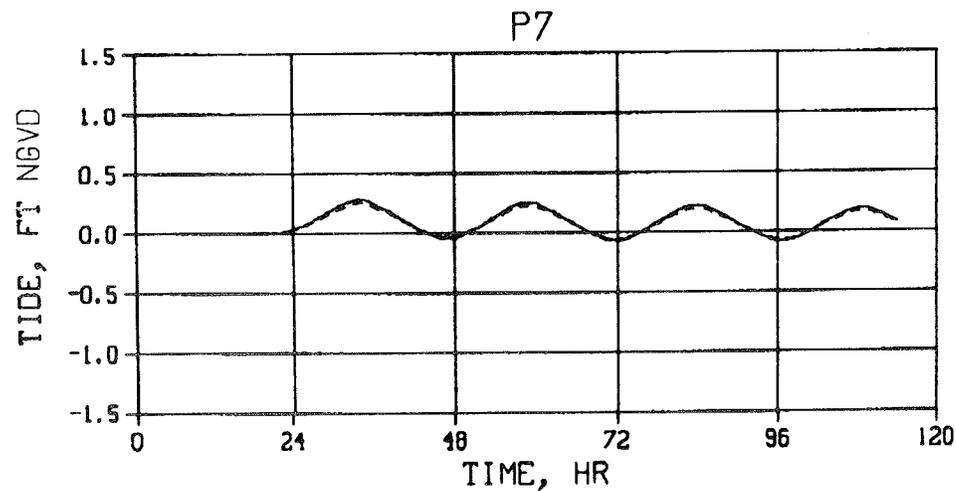
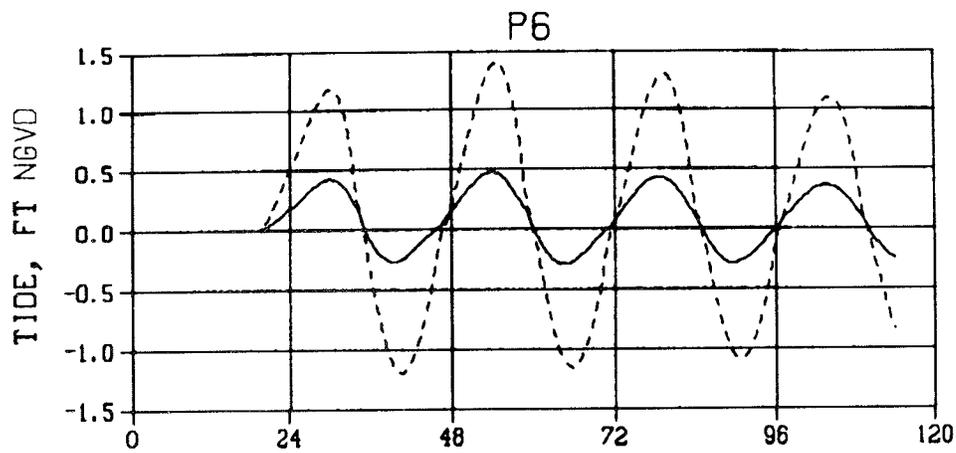
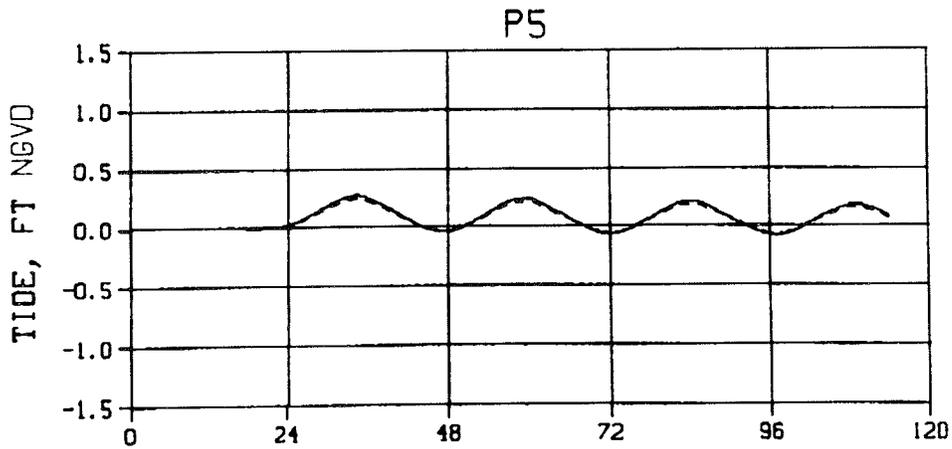


TEST CONDITIONS
 NOV 3-7, 1978
 SPRING TIDE

LEGEND
 — = BASE CONDITIONS
 - - - = WITH STRUCTURES

PLAN VS BASE
 GAGES M1, R1, P1





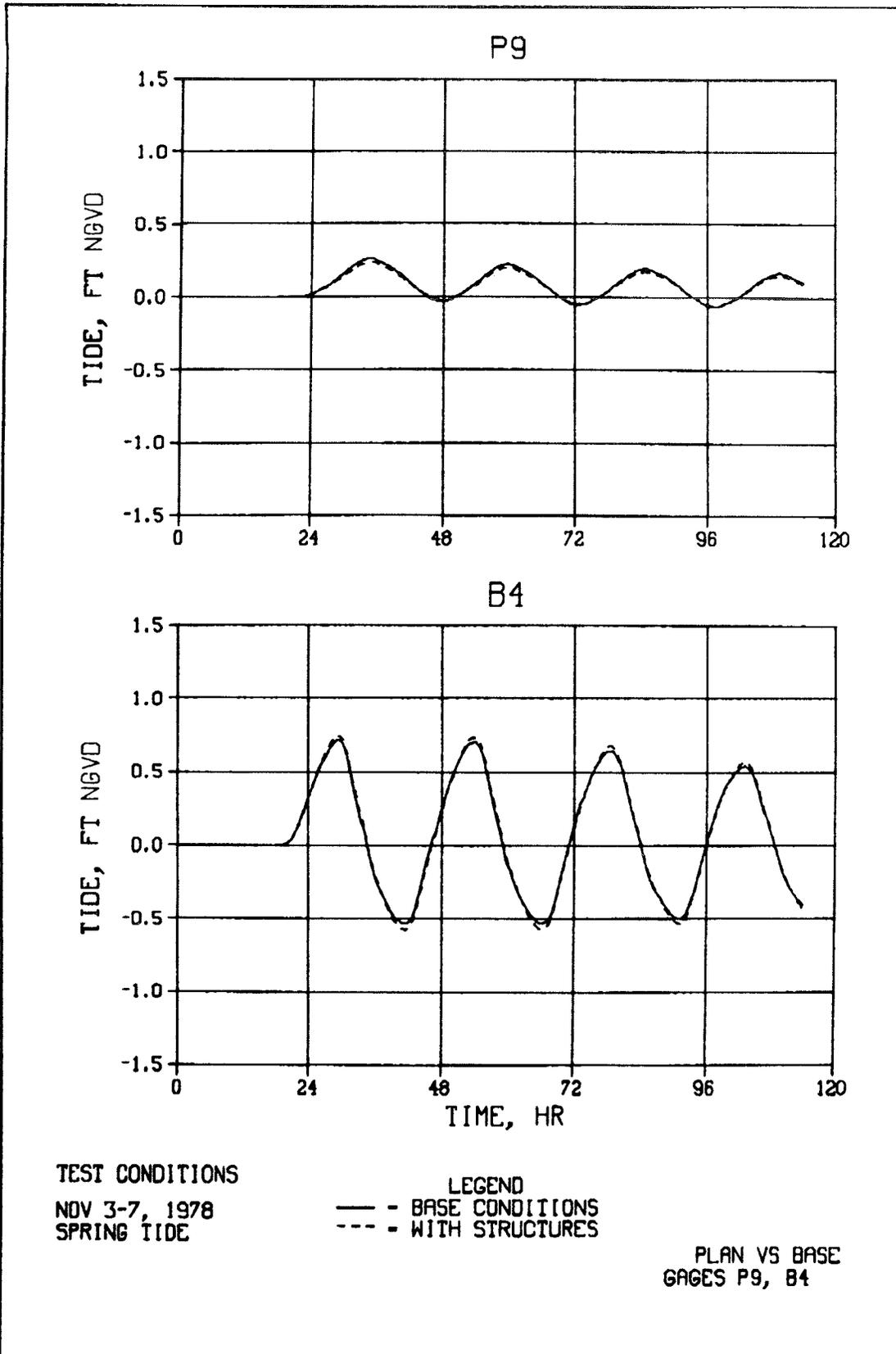
TEST CONDITIONS

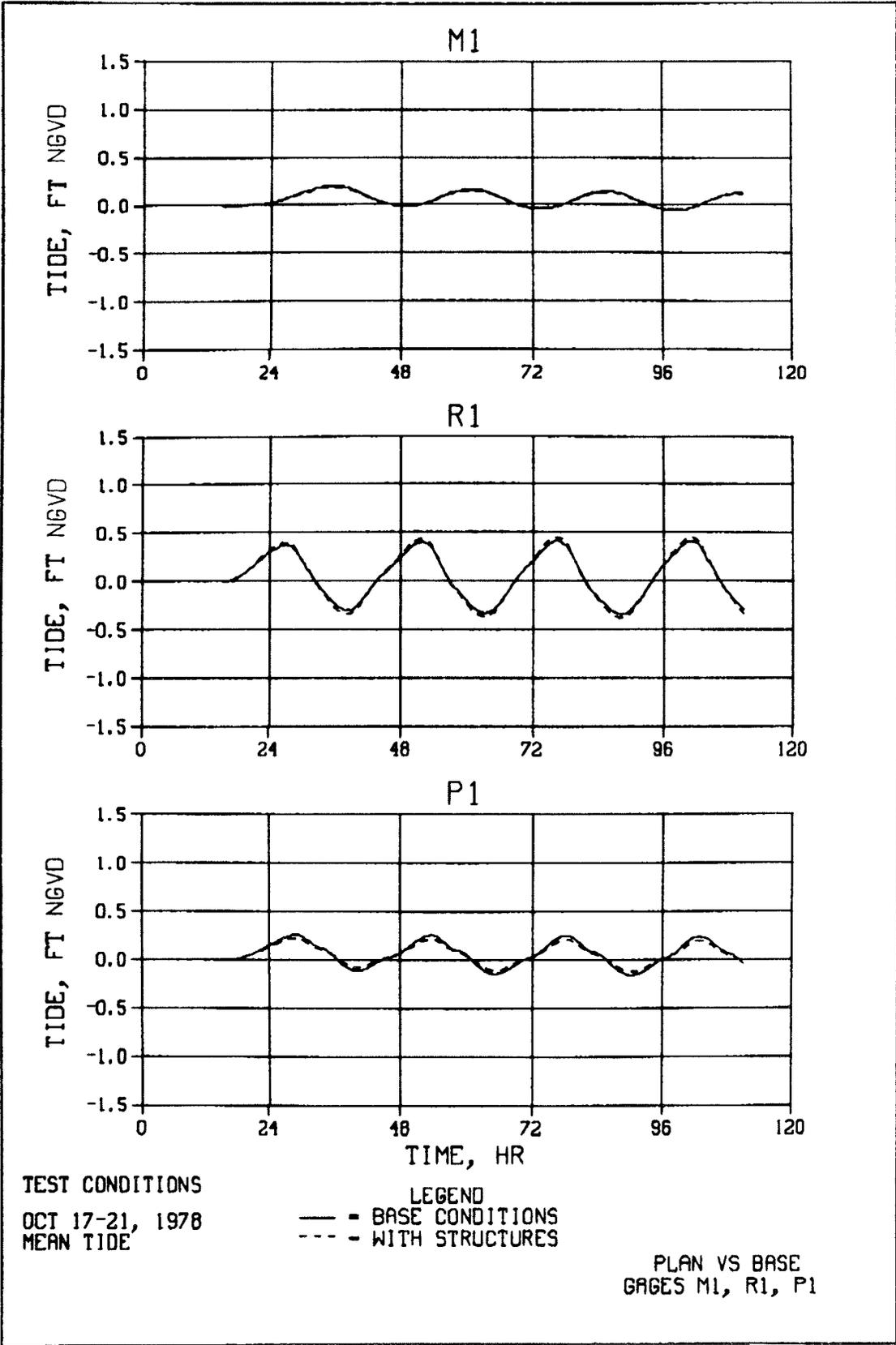
NOV 3-7, 1978
 SPRING TIDE

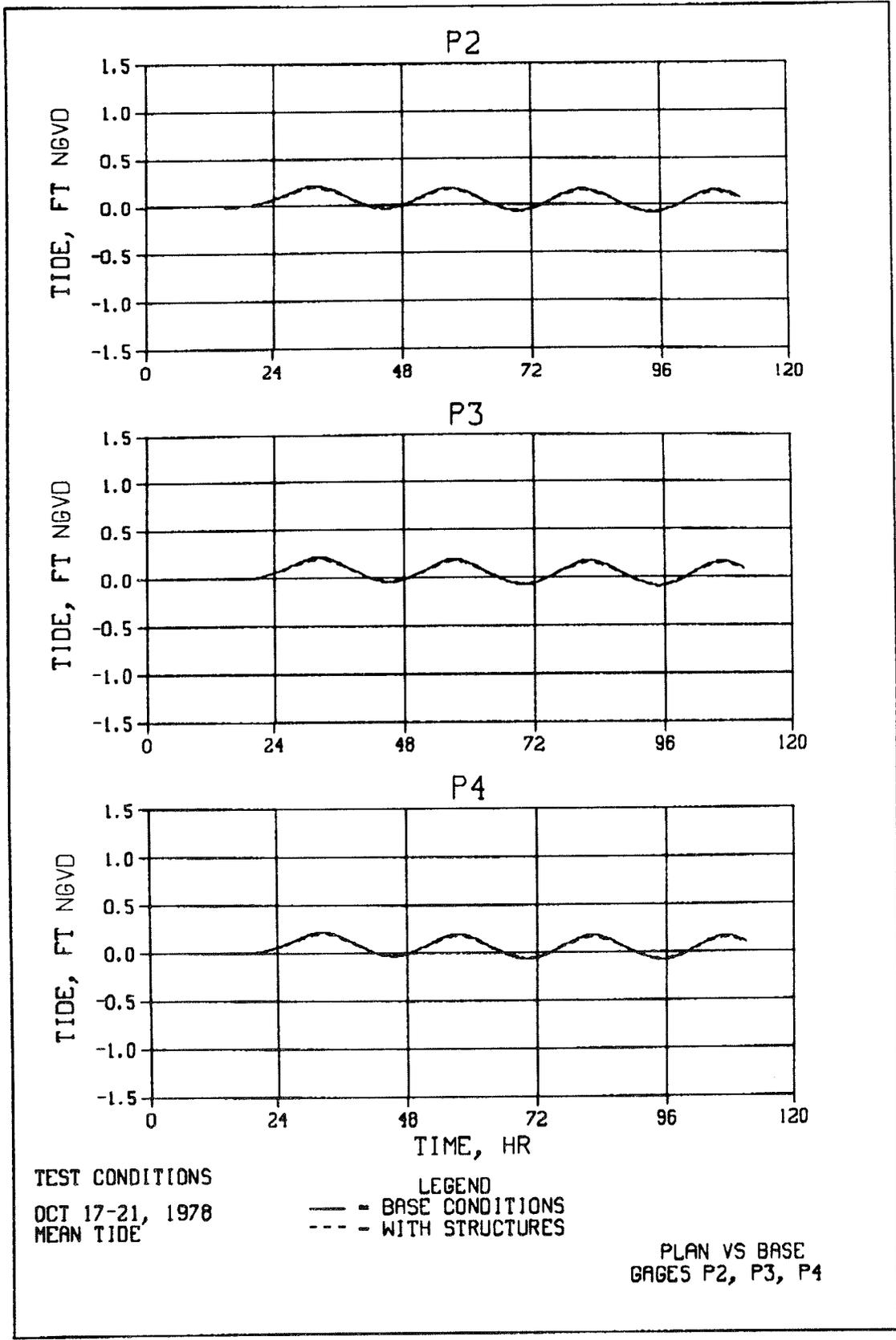
LEGEND

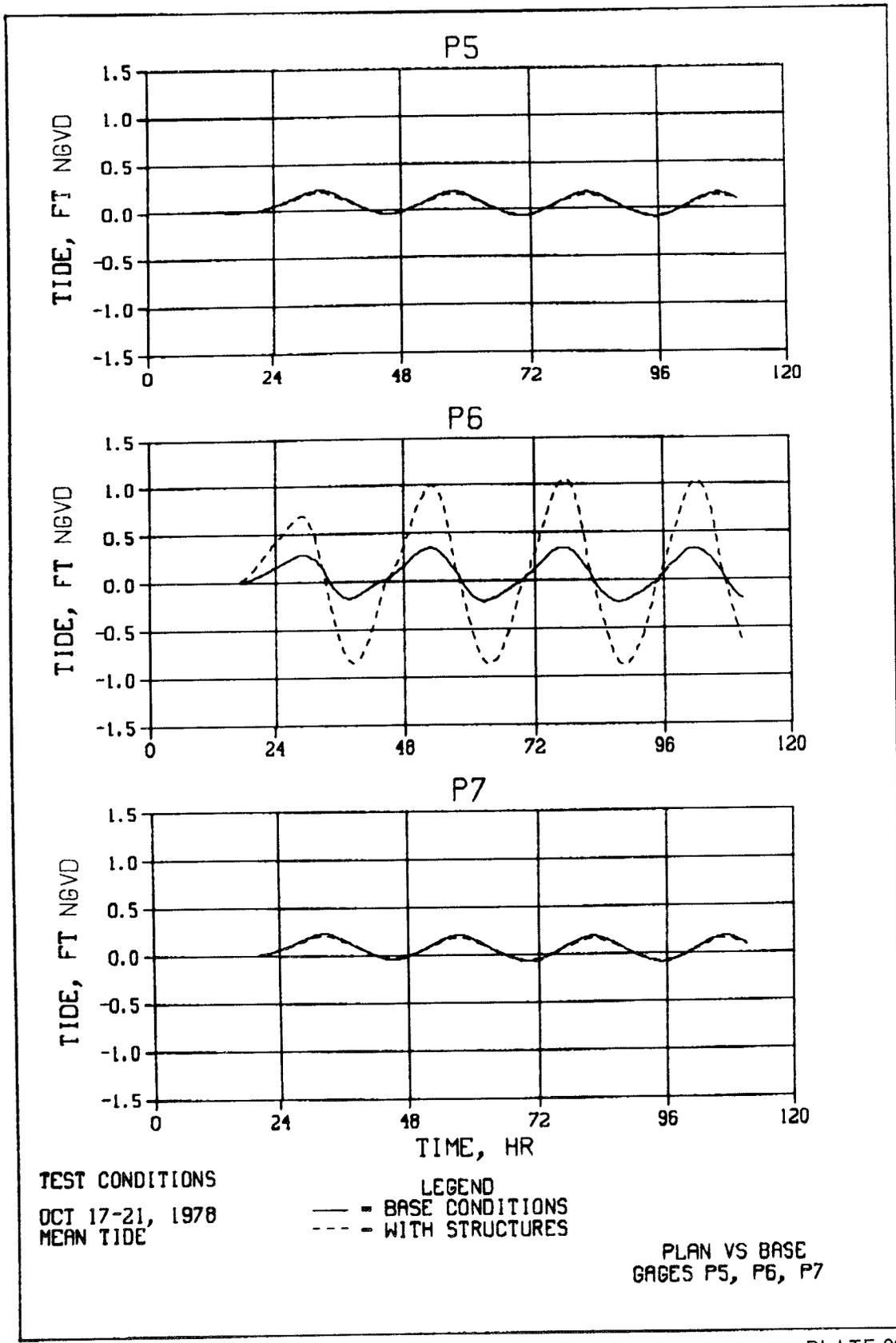
— = BASE CONDITIONS
 - - - = WITH STRUCTURES

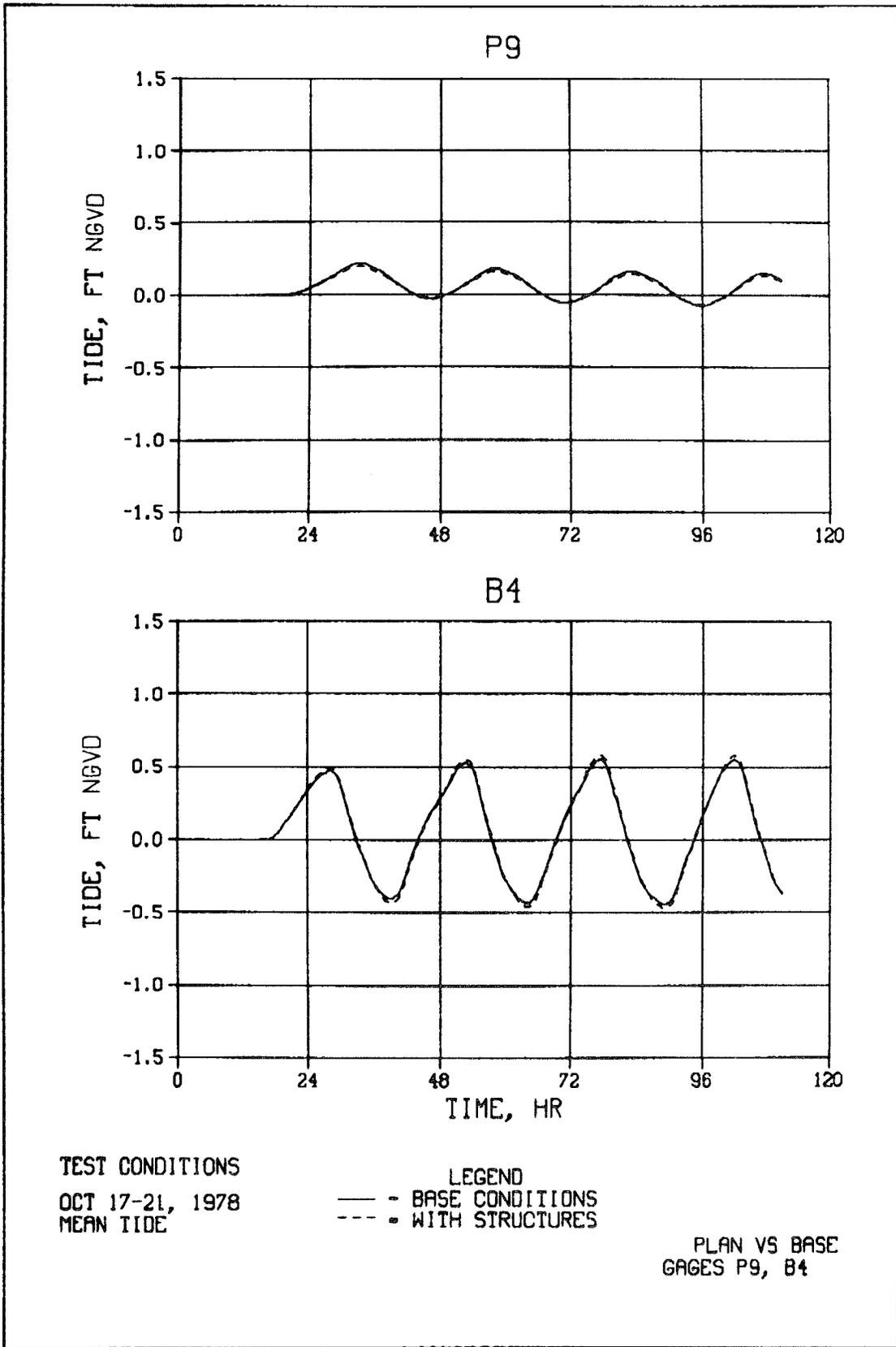
PLAN VS BASE
 GAGES P5, P6, P7

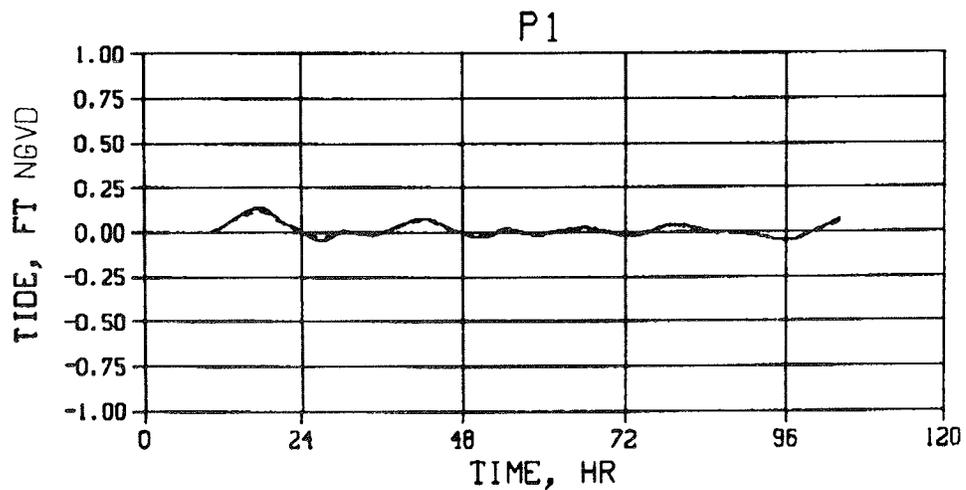
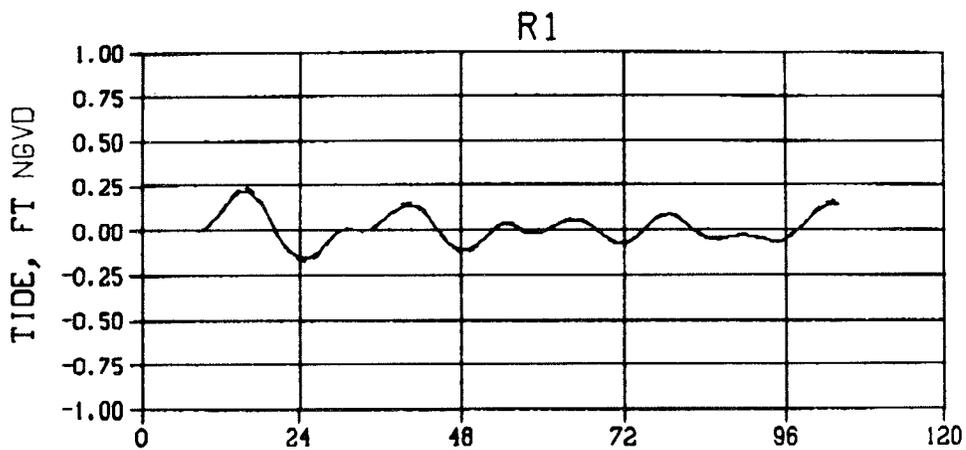
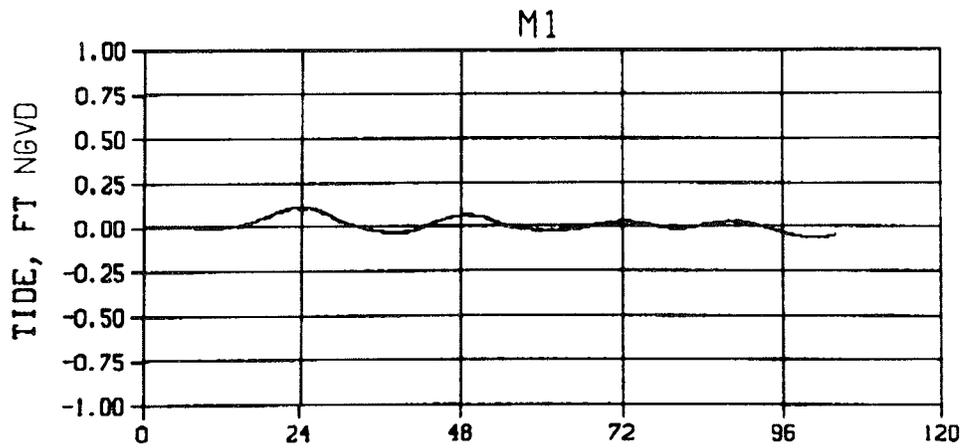








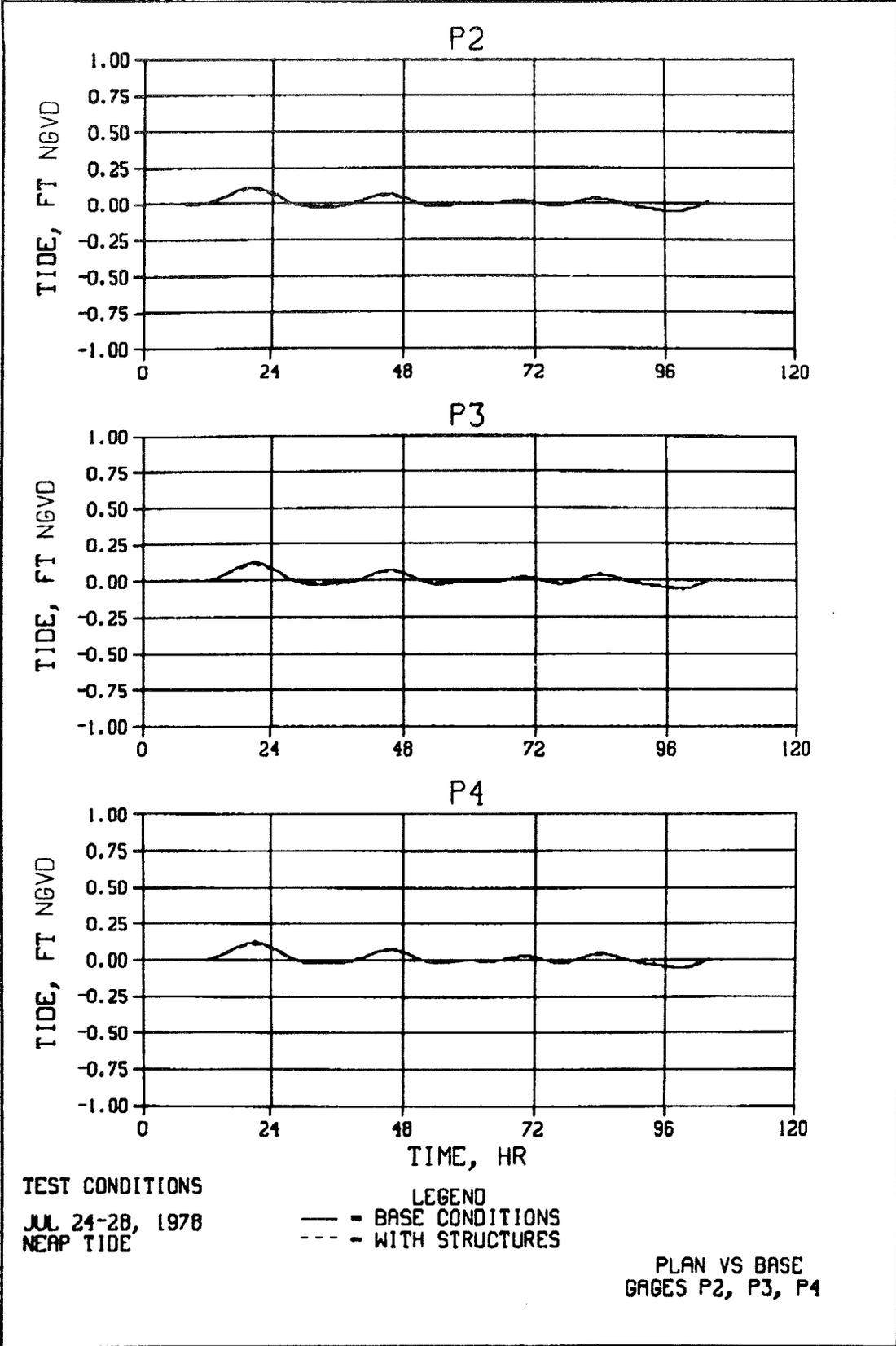


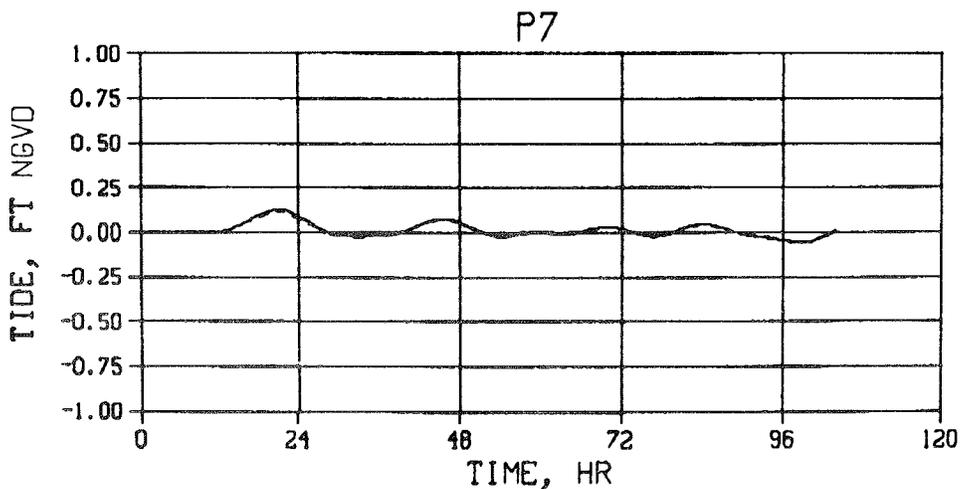
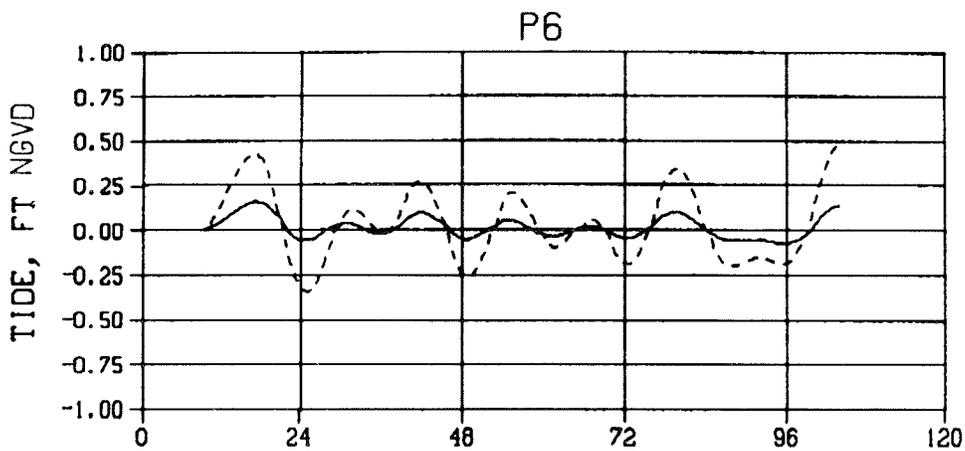
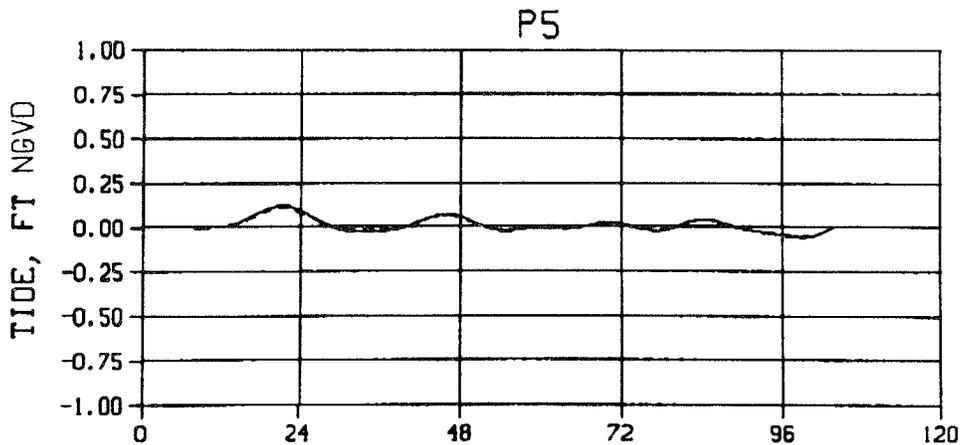


TEST CONDITIONS
 JUL 24-28, 1978
 NEAP TIDE

LEGEND
 --- = BASE CONDITIONS
 - - - = WITH STRUCTURES

PLAN VS BASE
 GAGES M1, R1, P1

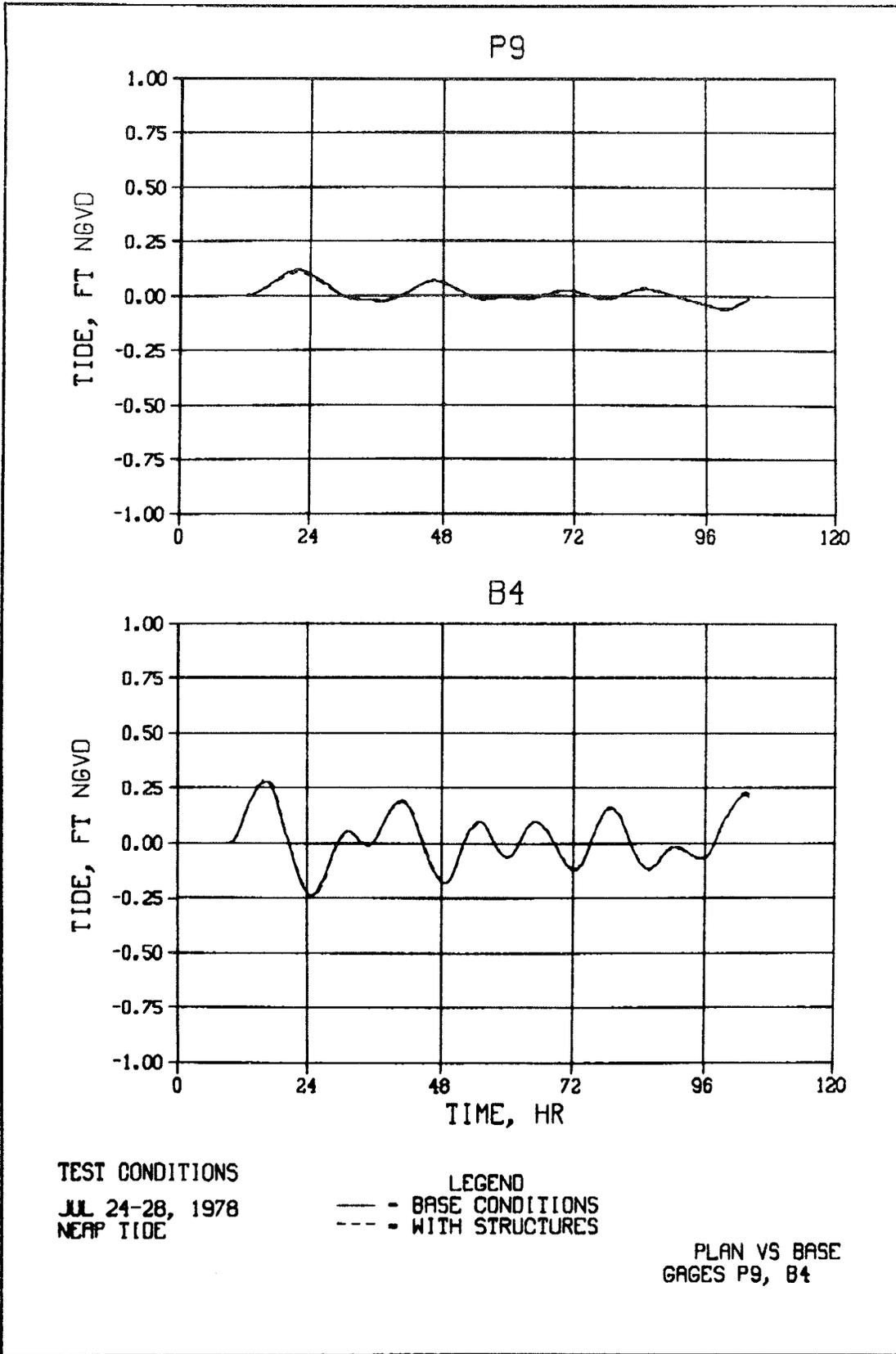




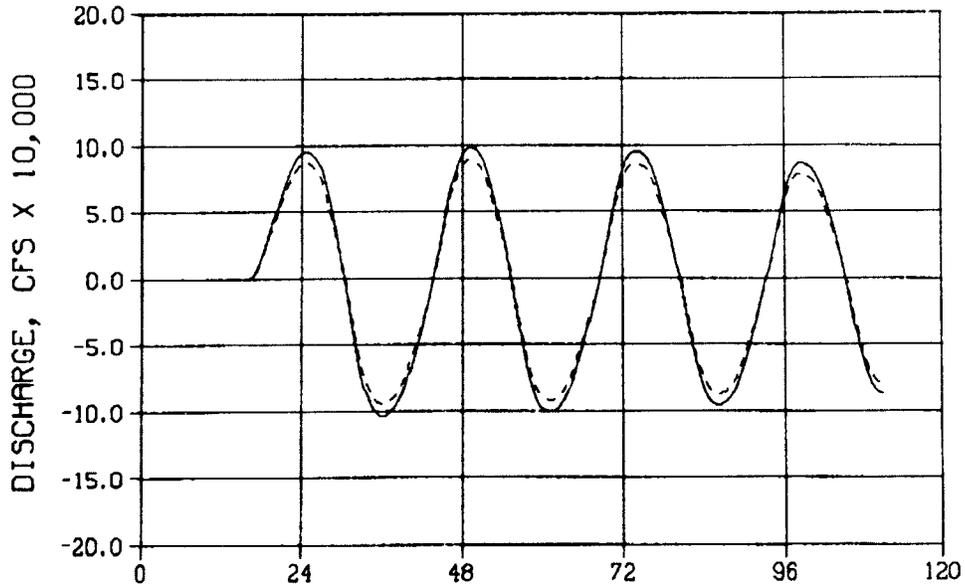
TEST CONDITIONS
 JUL 24-28, 1978
 NEAP TIDE

LEGEND
 — = BASE CONDITIONS
 --- = WITH STRUCTURES

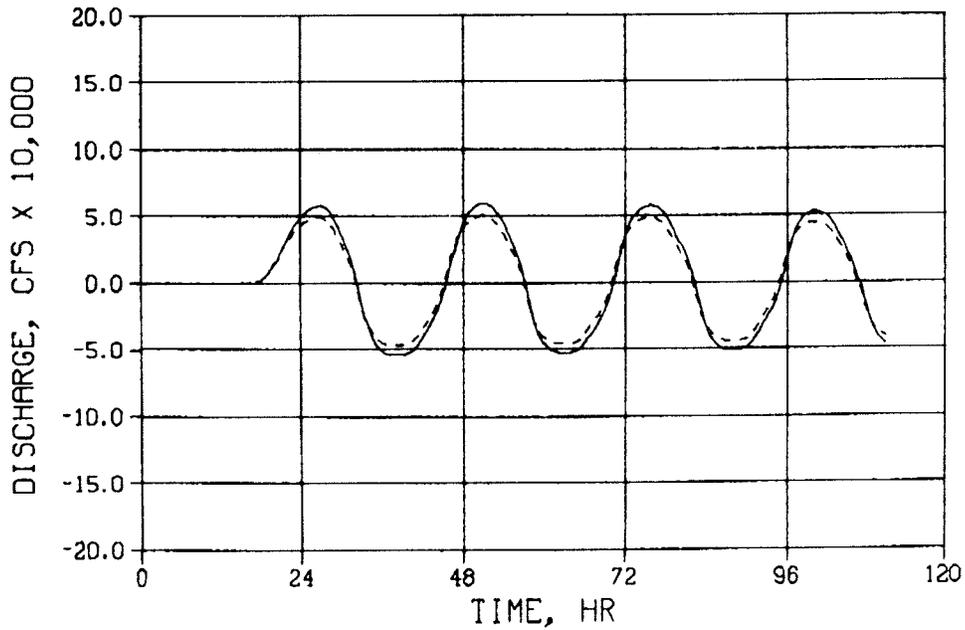
PLAN VS BASE
 GAGES P5, P6, P7



THE RIGOLETS



CHEF MENTEUR

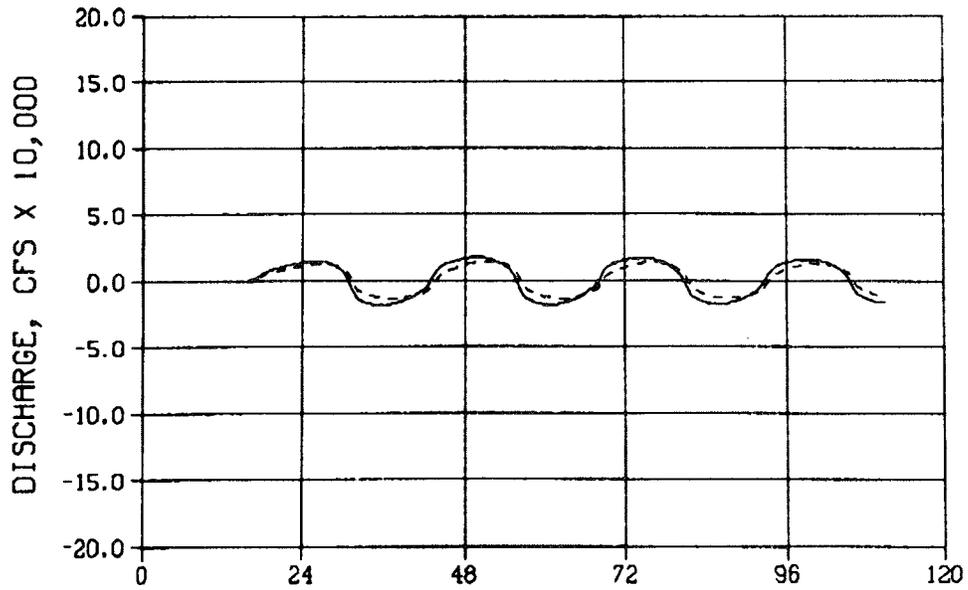


TEST CONDITIONS
NOV 3-7, 1978
SPRING TIDE

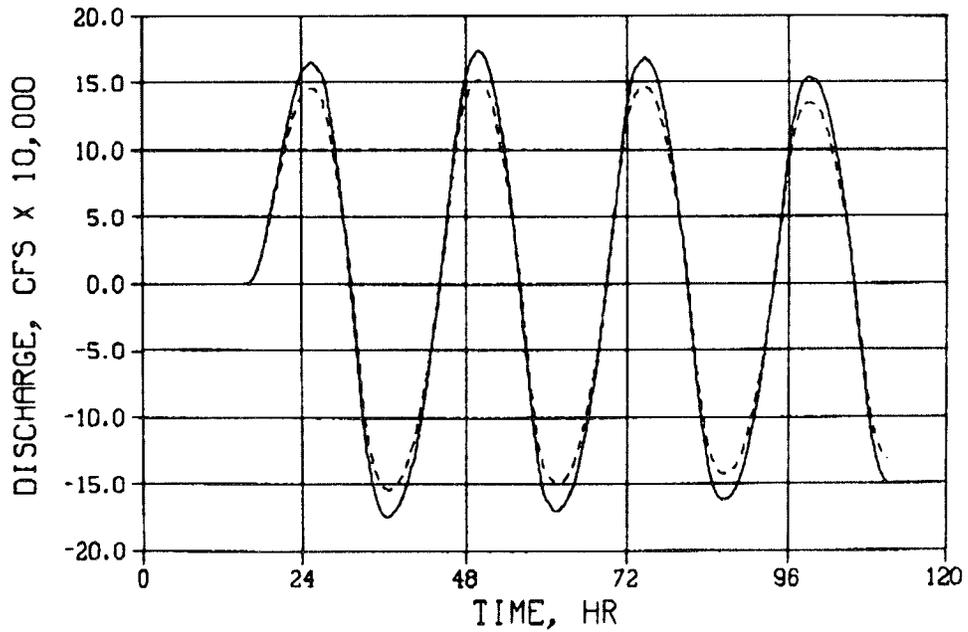
LEGEND
— - BASE CONDITIONS
- - - WITH STRUCTURES

PLAN VS BASE
ENTRANCE PASSES

SEABROOK CANAL



LAKE PONTCHARTRAIN



TEST CONDITIONS

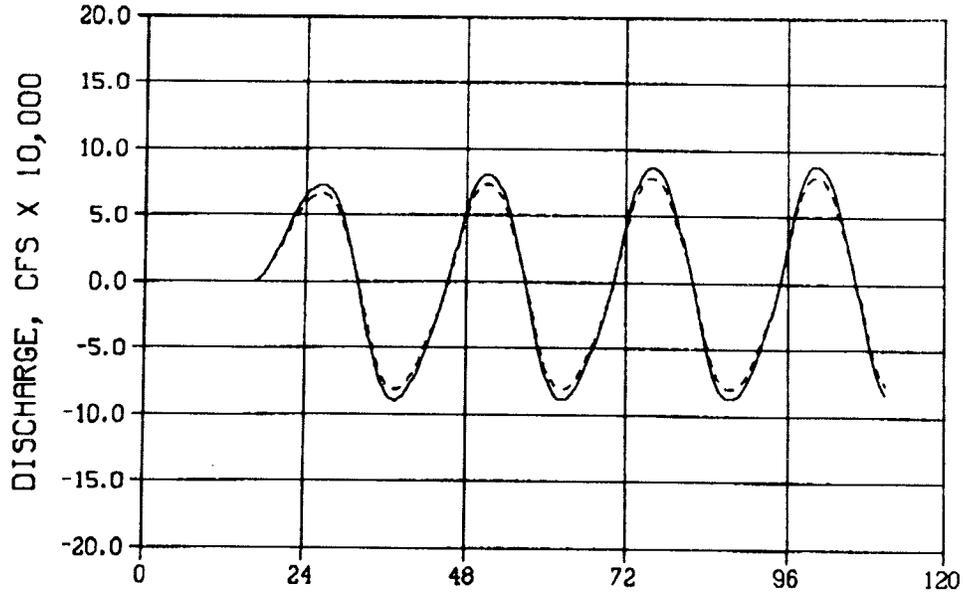
NOV 3-7, 1978
SPRING TIDE

LEGEND

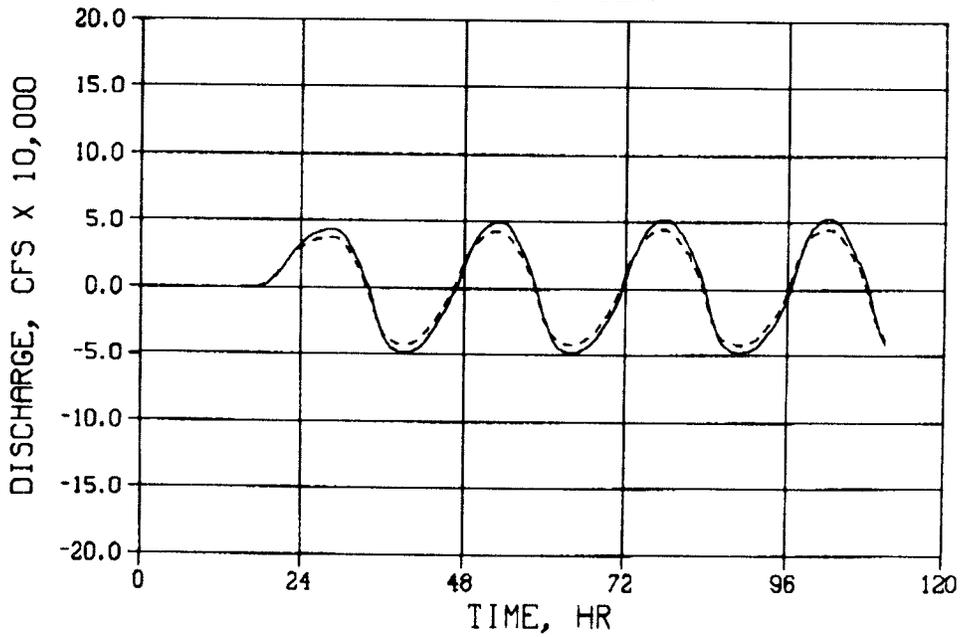
— - BASE CONDITIONS
- - - ■ WITH STRUCTURES

PLAN VS BASE
ENTRANCE PASSES

THE RIGOLETS



CHEF MENTEUR

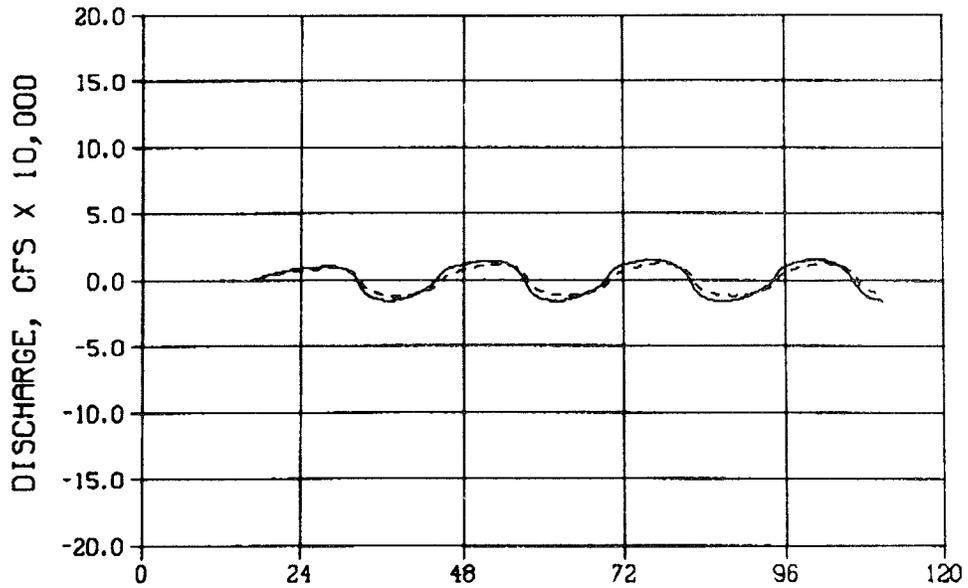


TEST CONDITIONS
OCT 17-21, 1978
MEAN TIDE

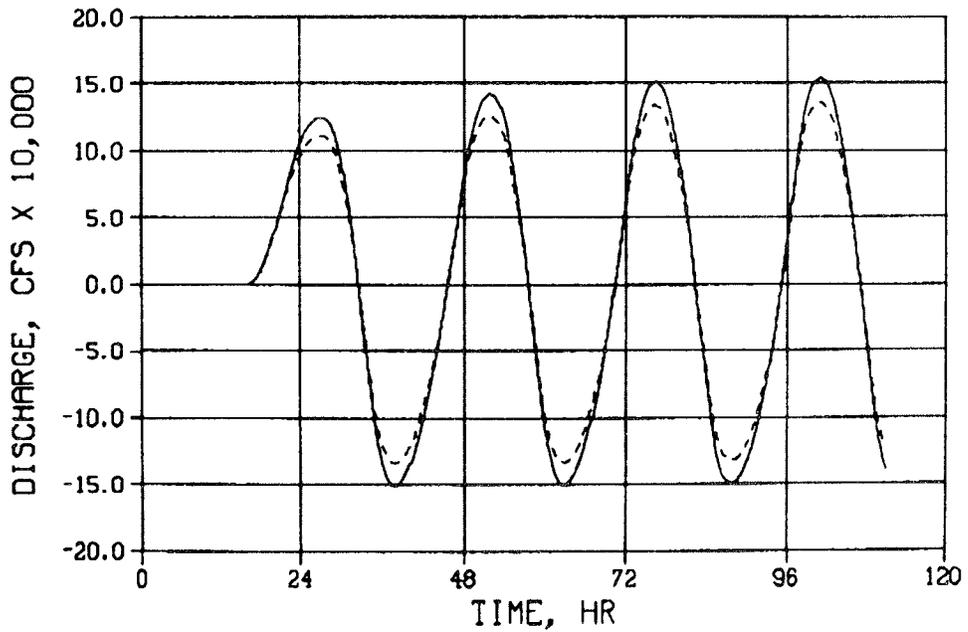
LEGEND
— - BASE CONDITIONS
--- - WITH STRUCTURES

PLAN VS BASE
ENTRANCE PASSES

SEABROOK CANAL



LAKE PONTCHARTRAIN

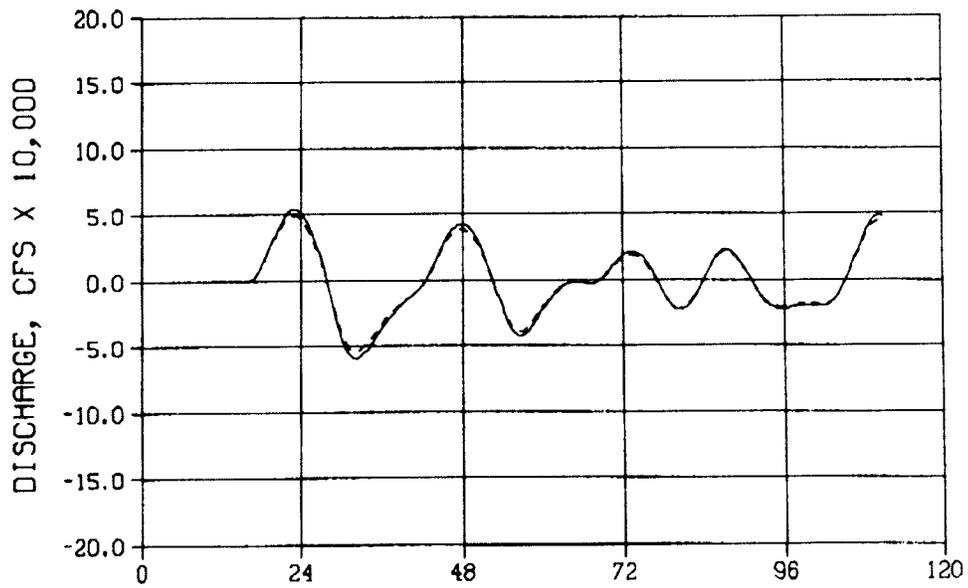


TEST CONDITIONS
OCT 17-21, 1978
MEAN TIDE

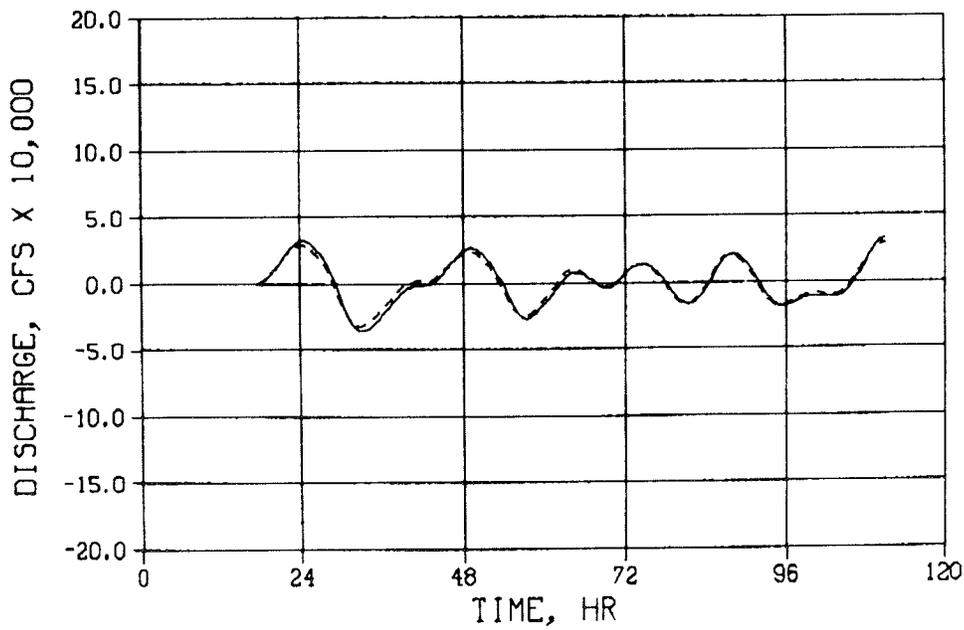
LEGEND
— - BASE CONDITIONS
- - - WITH STRUCTURES

PLAN VS BASE
ENTRANCE PASSES

THE RIGOLETS



CHEF MENTEUR

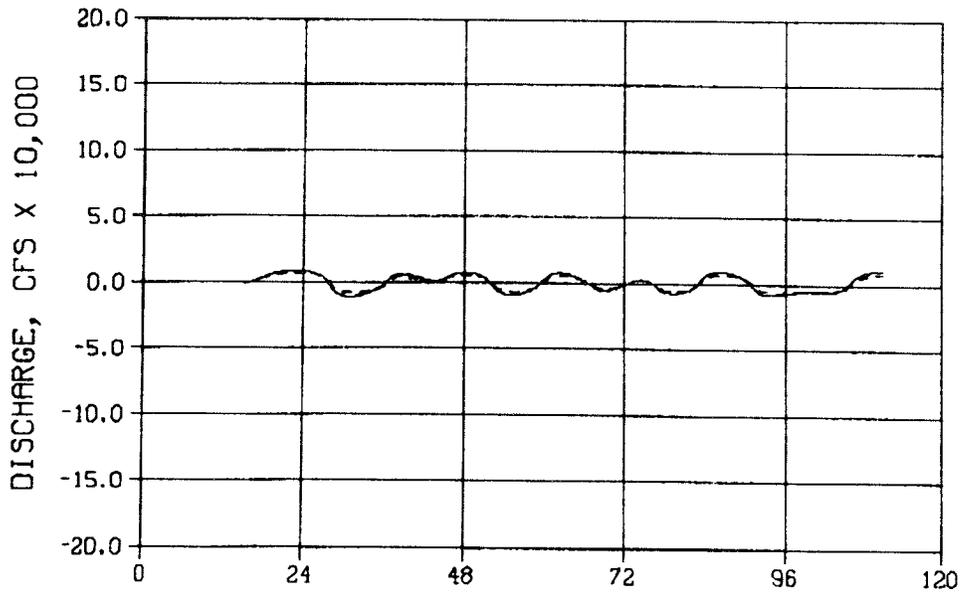


TEST CONDITIONS
JUL 24-28, 1979
NEAP TIDE

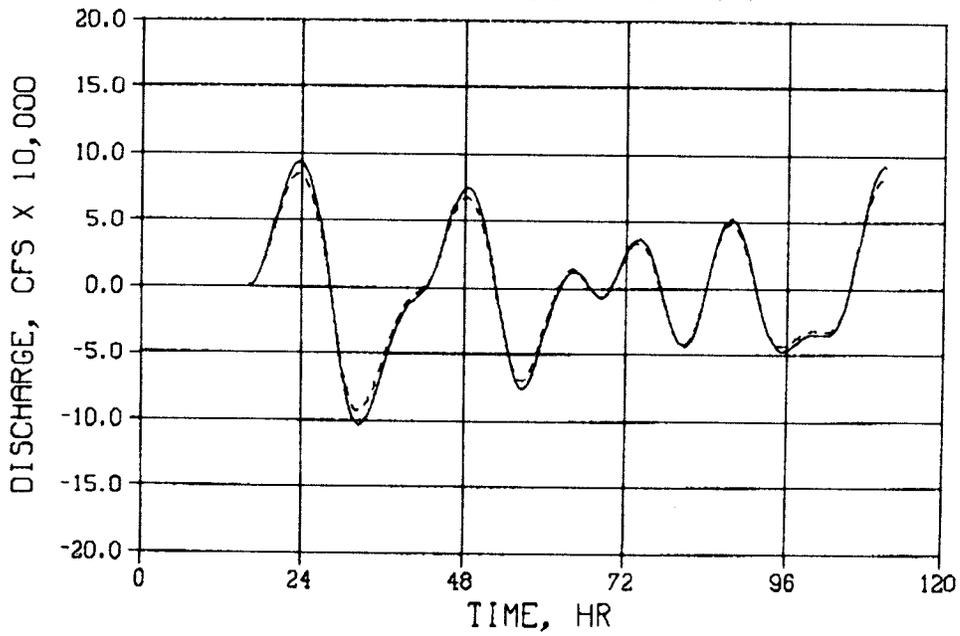
LEGEND
—— - BASE CONDITIONS
- - - - WITH STRUCTURES

PLAN VS BASE
ENTRANCE PASSES

SEABROOK CANAL



LAKE PONTCHARTRAIN



TEST CONDITIONS
JUL 24-28, 1979
NEAP TIDE

LEGEND
— - BASE CONDITIONS
- - - WITH STRUCTURES

PLAN VS BASE
ENTRANCE PASSES

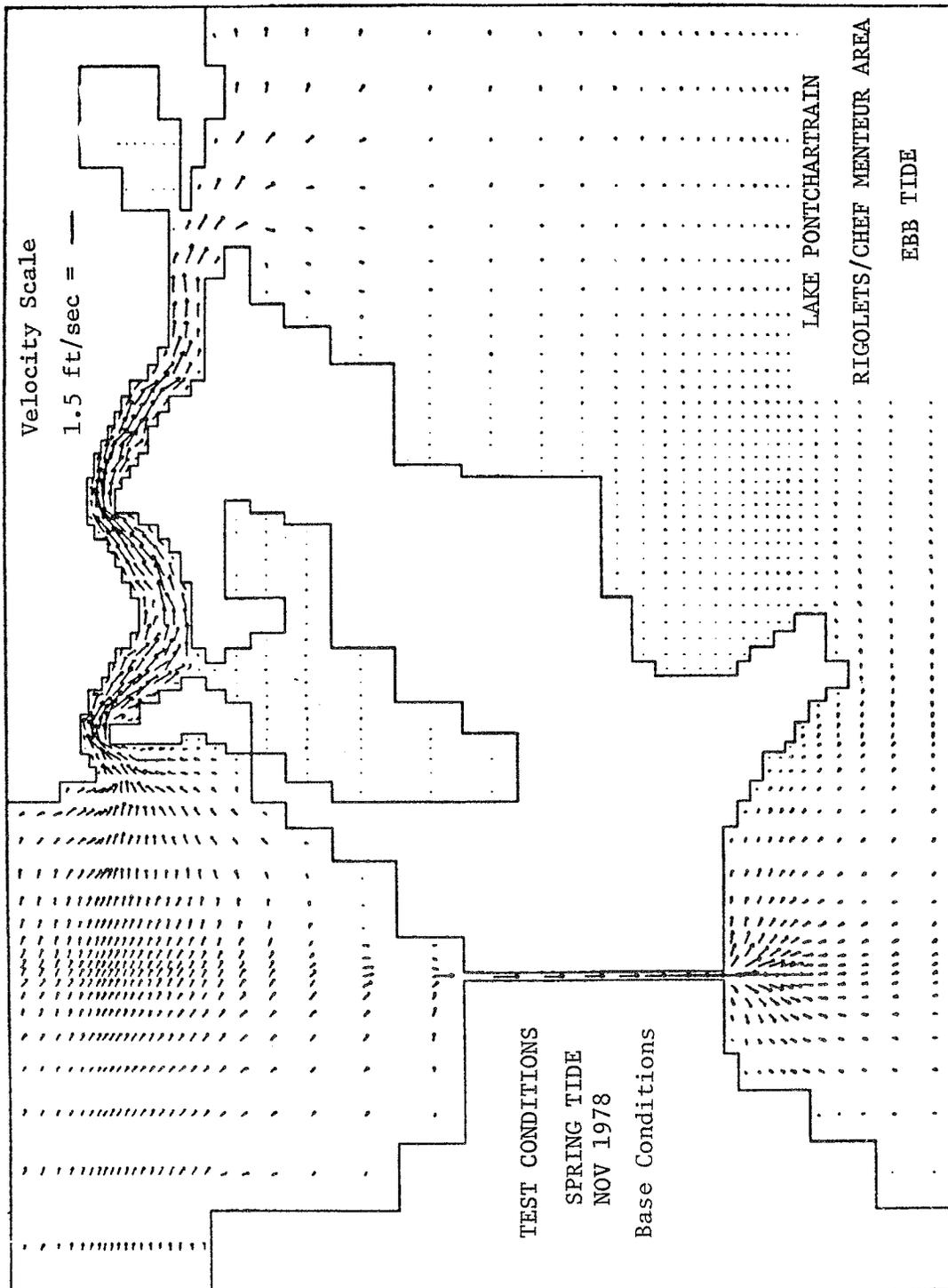


PLATE 41

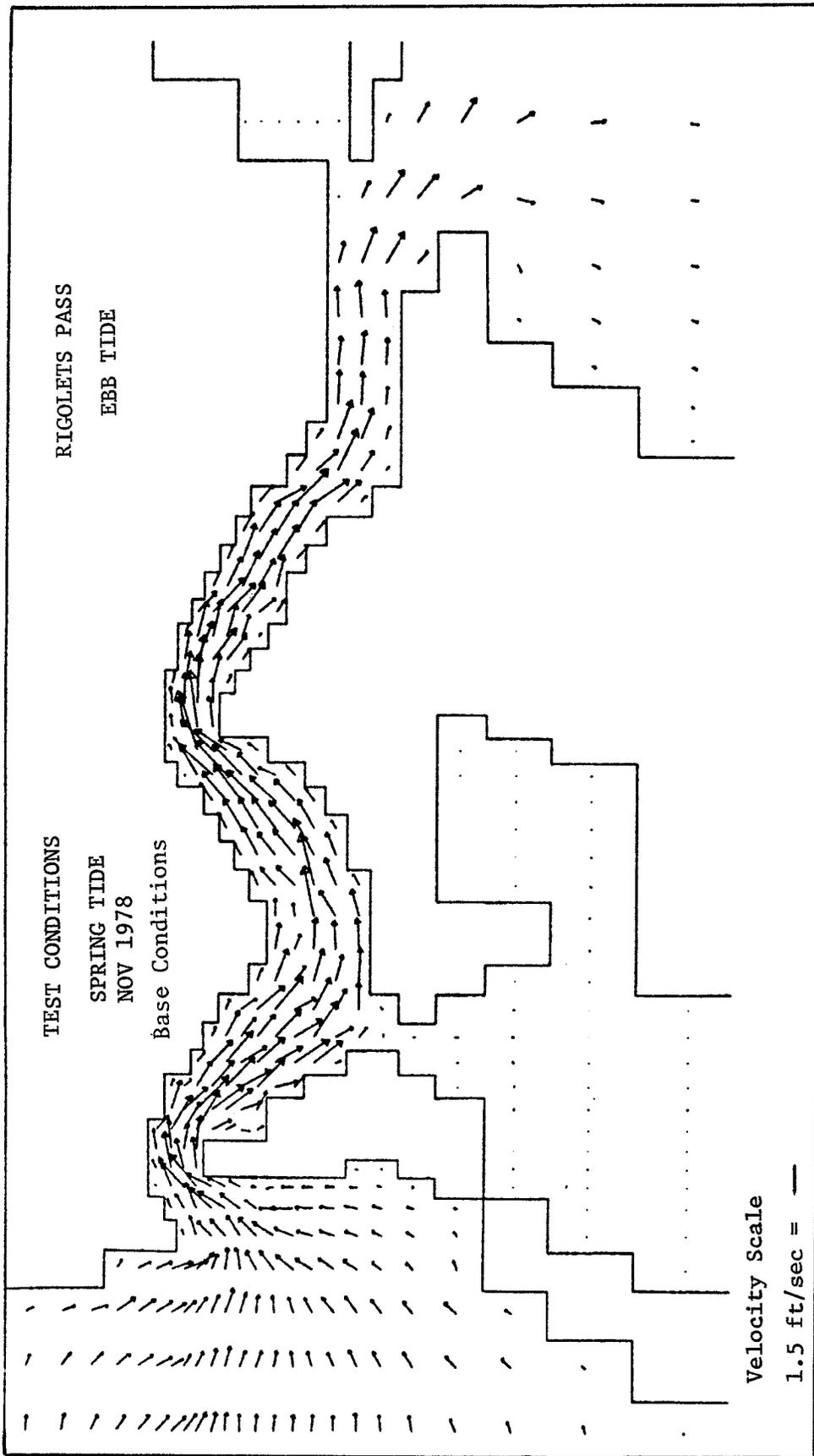
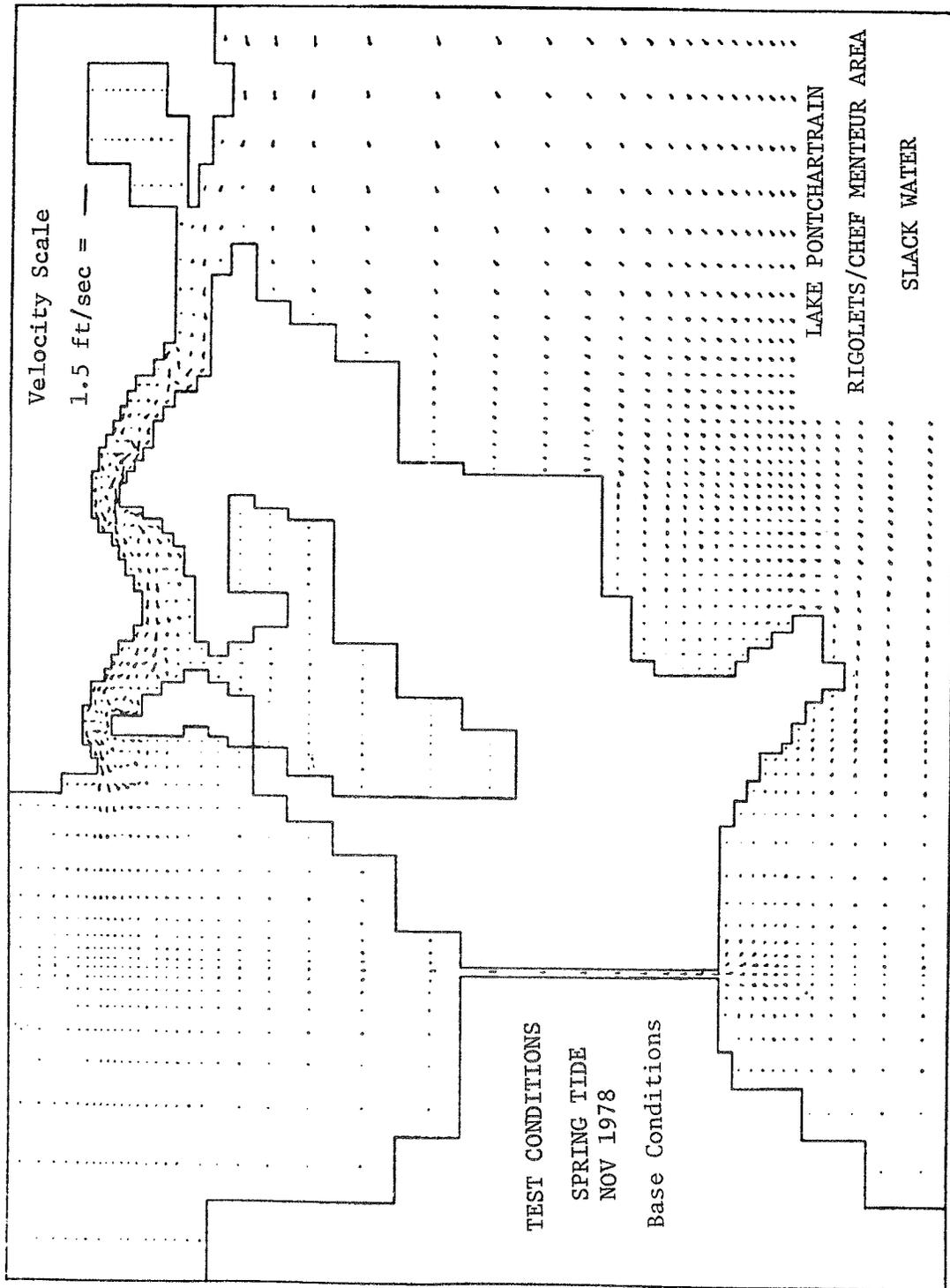


PLATE 42



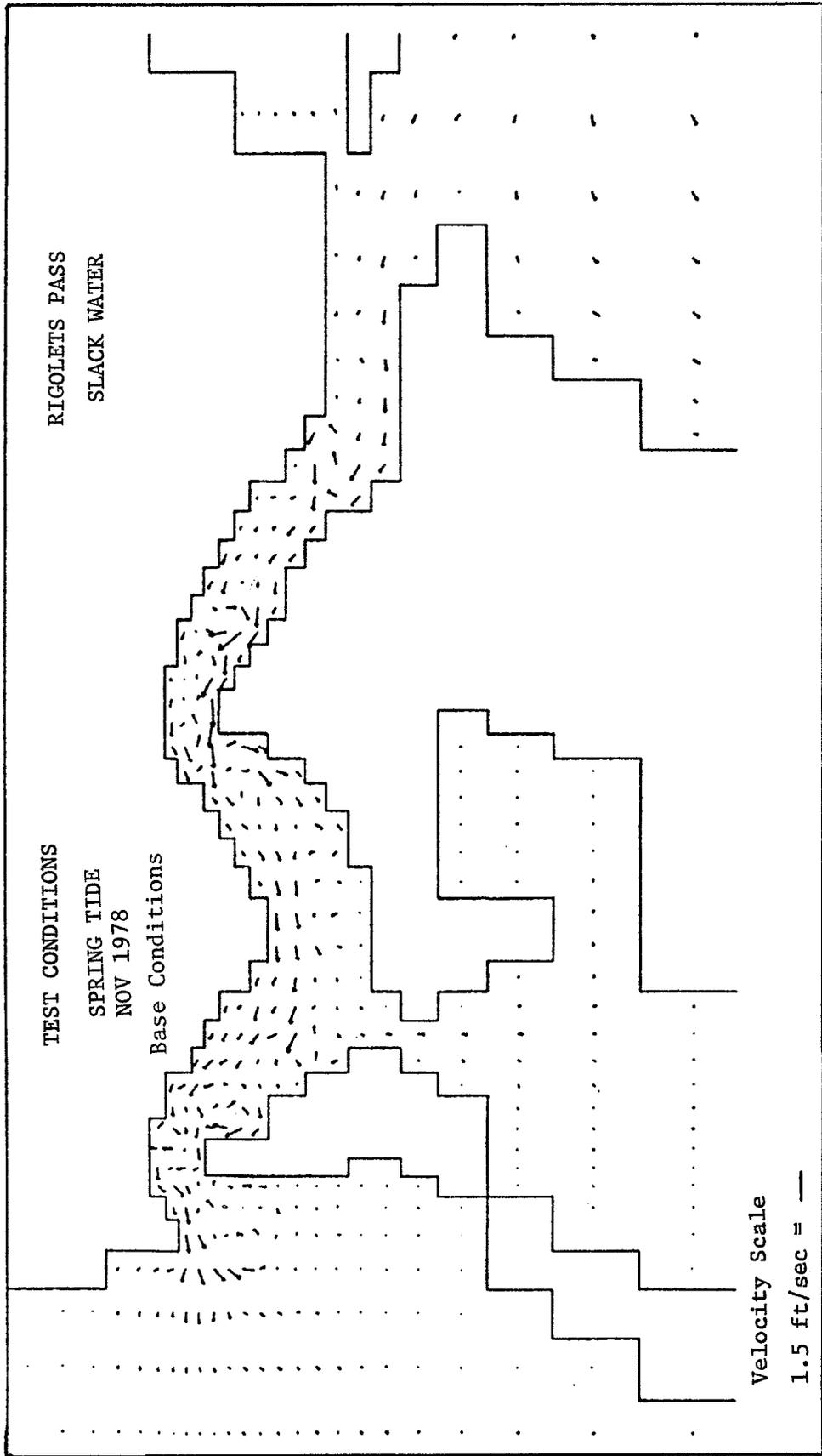
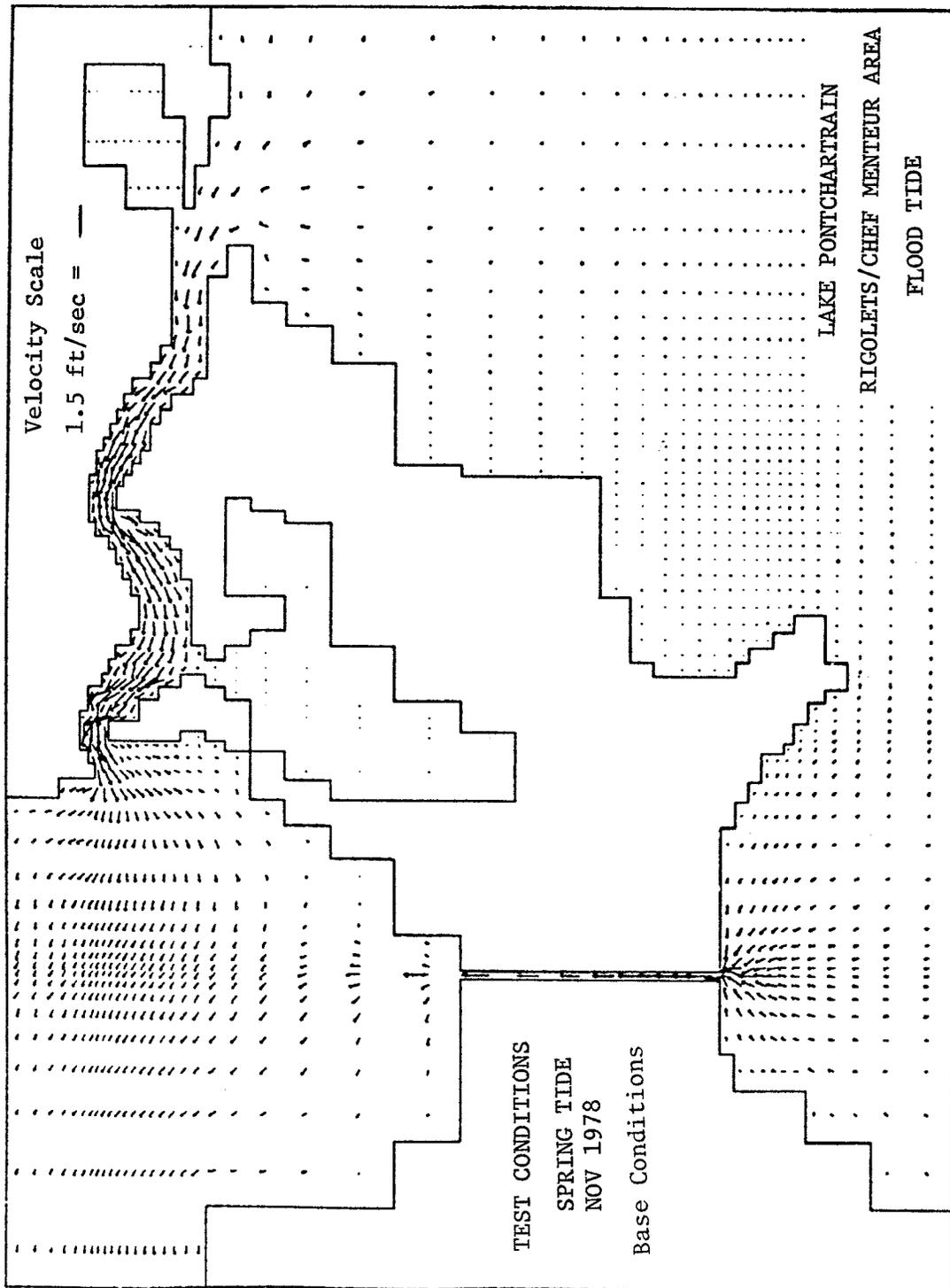


PLATE 44



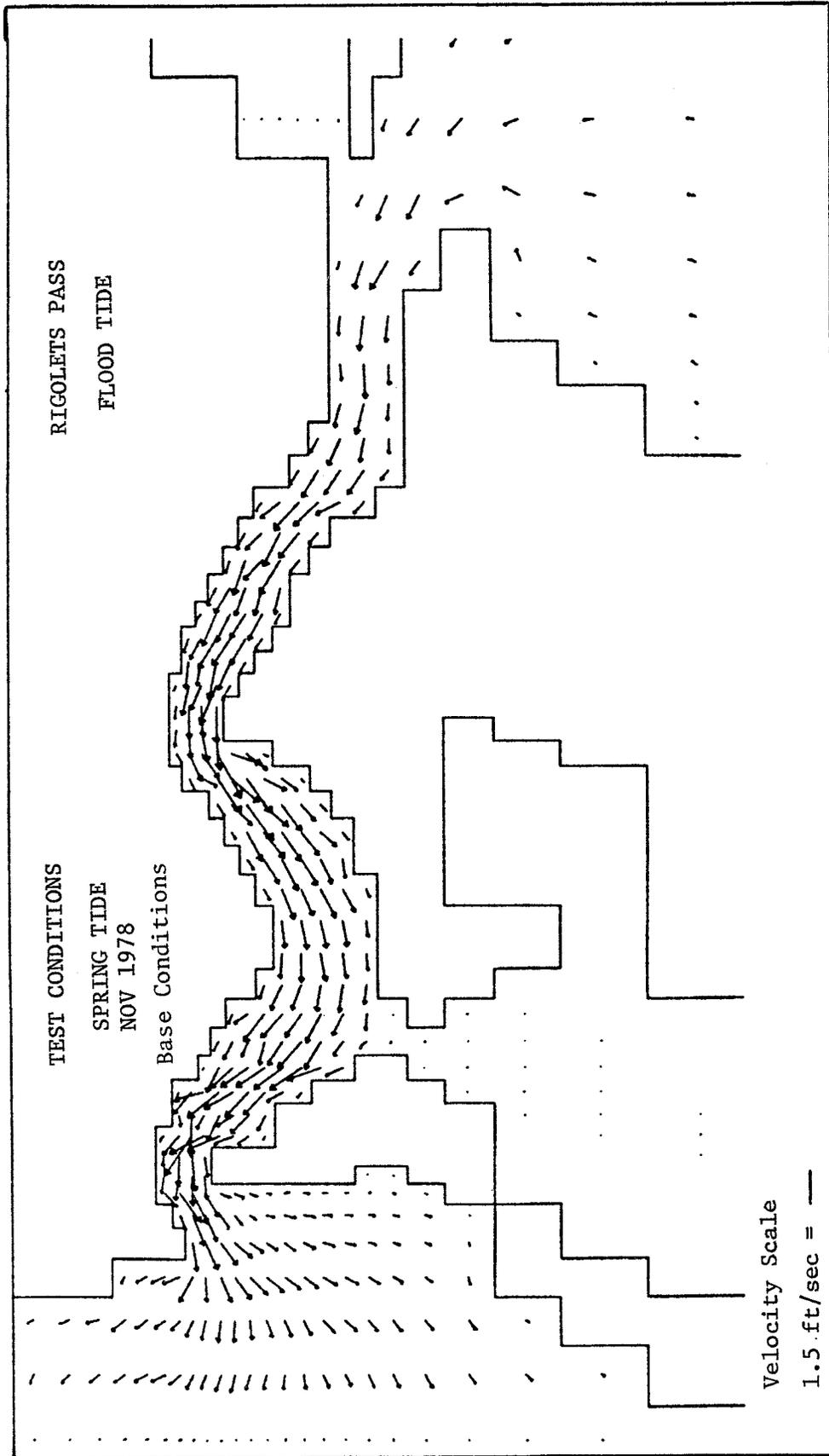
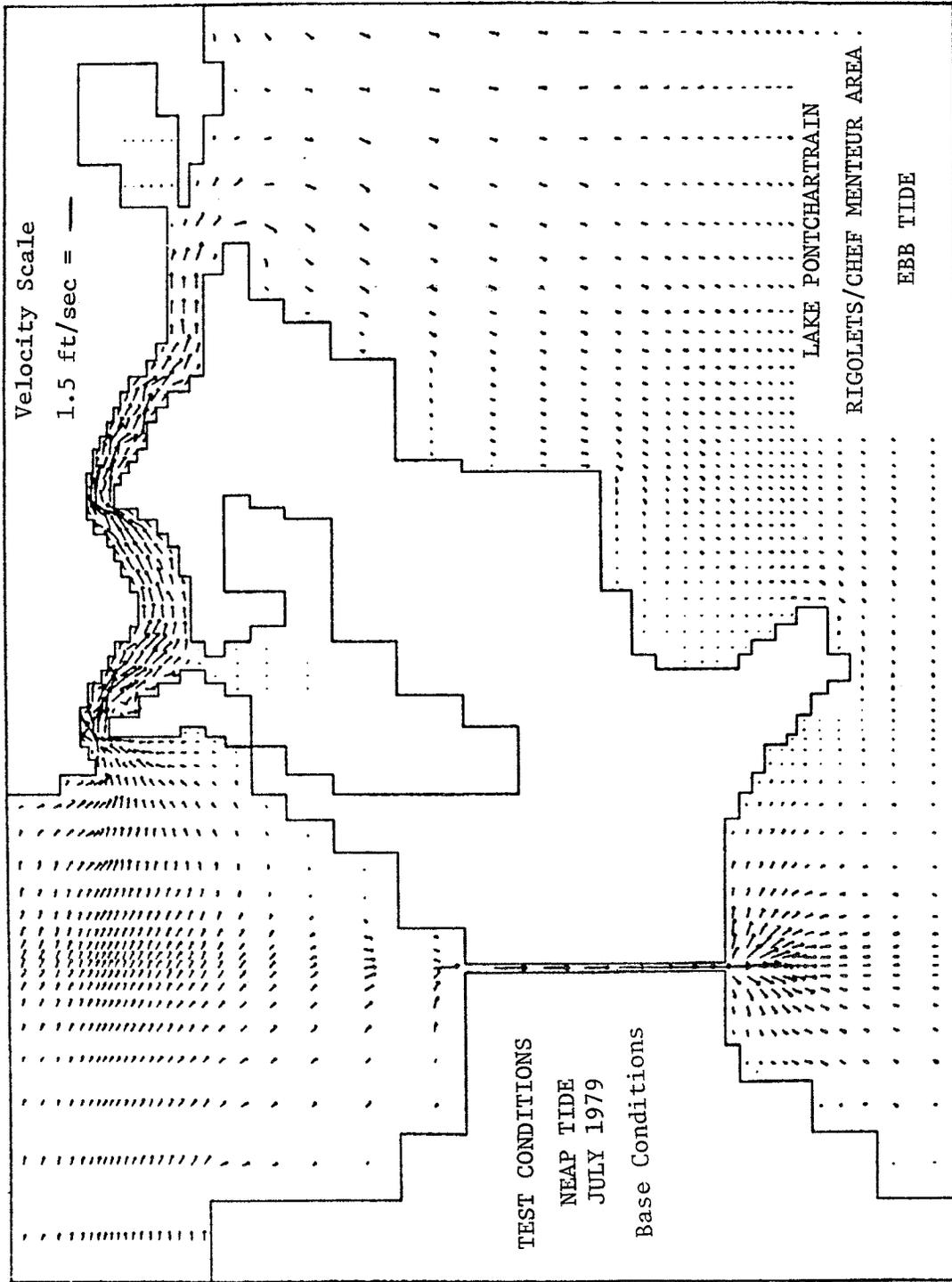
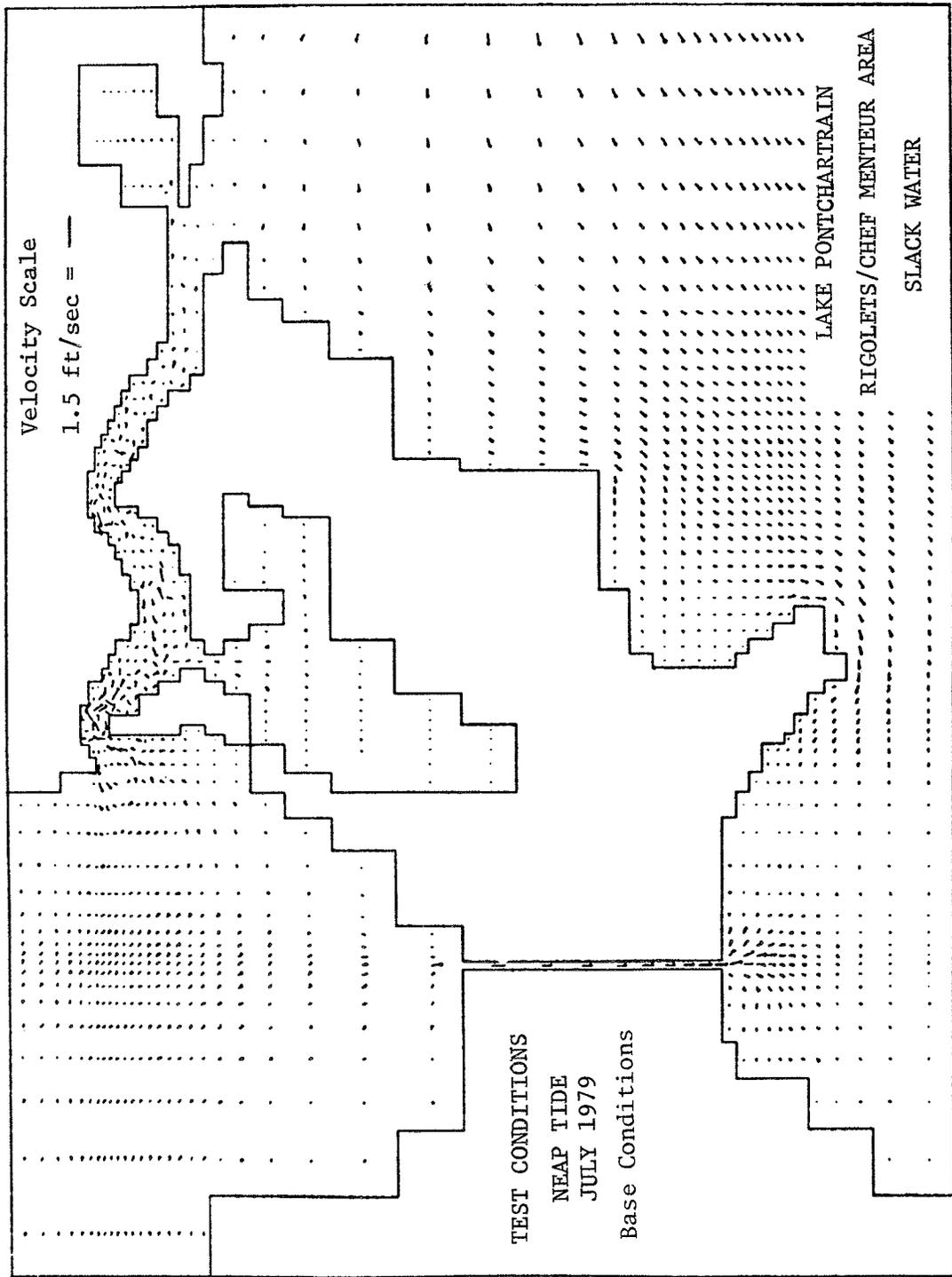


PLATE 46





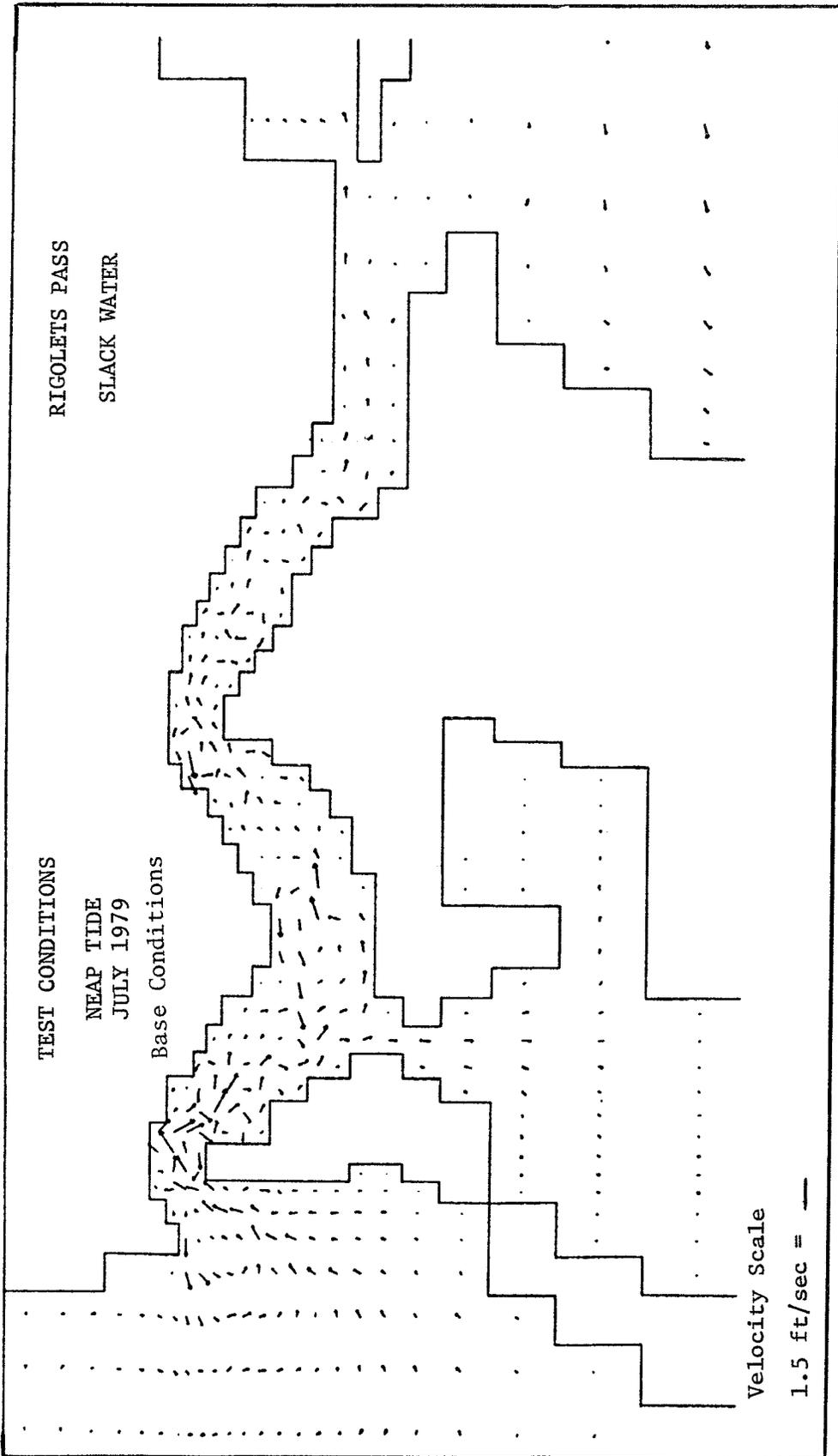


PLATE 50

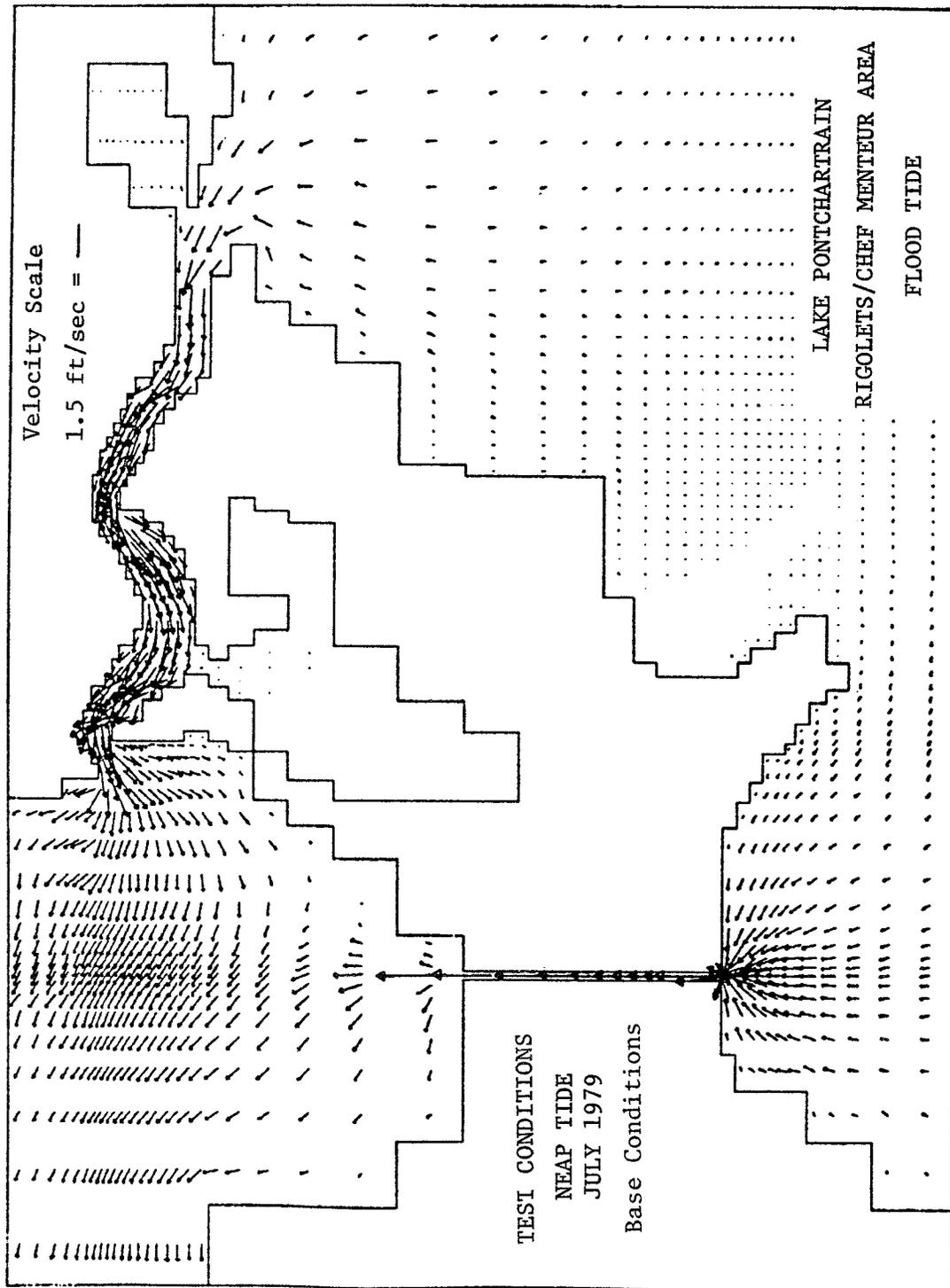


PLATE 51

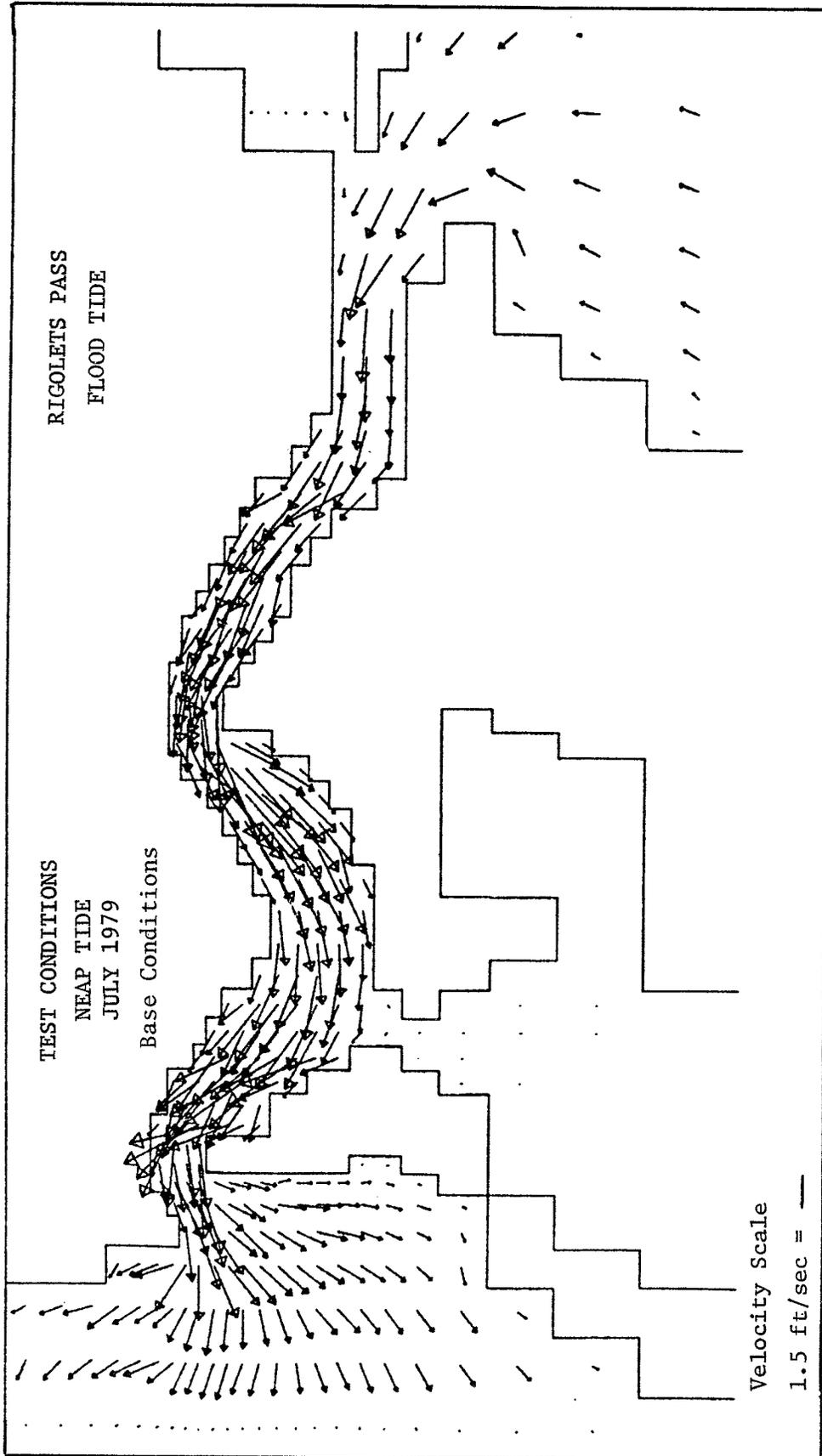
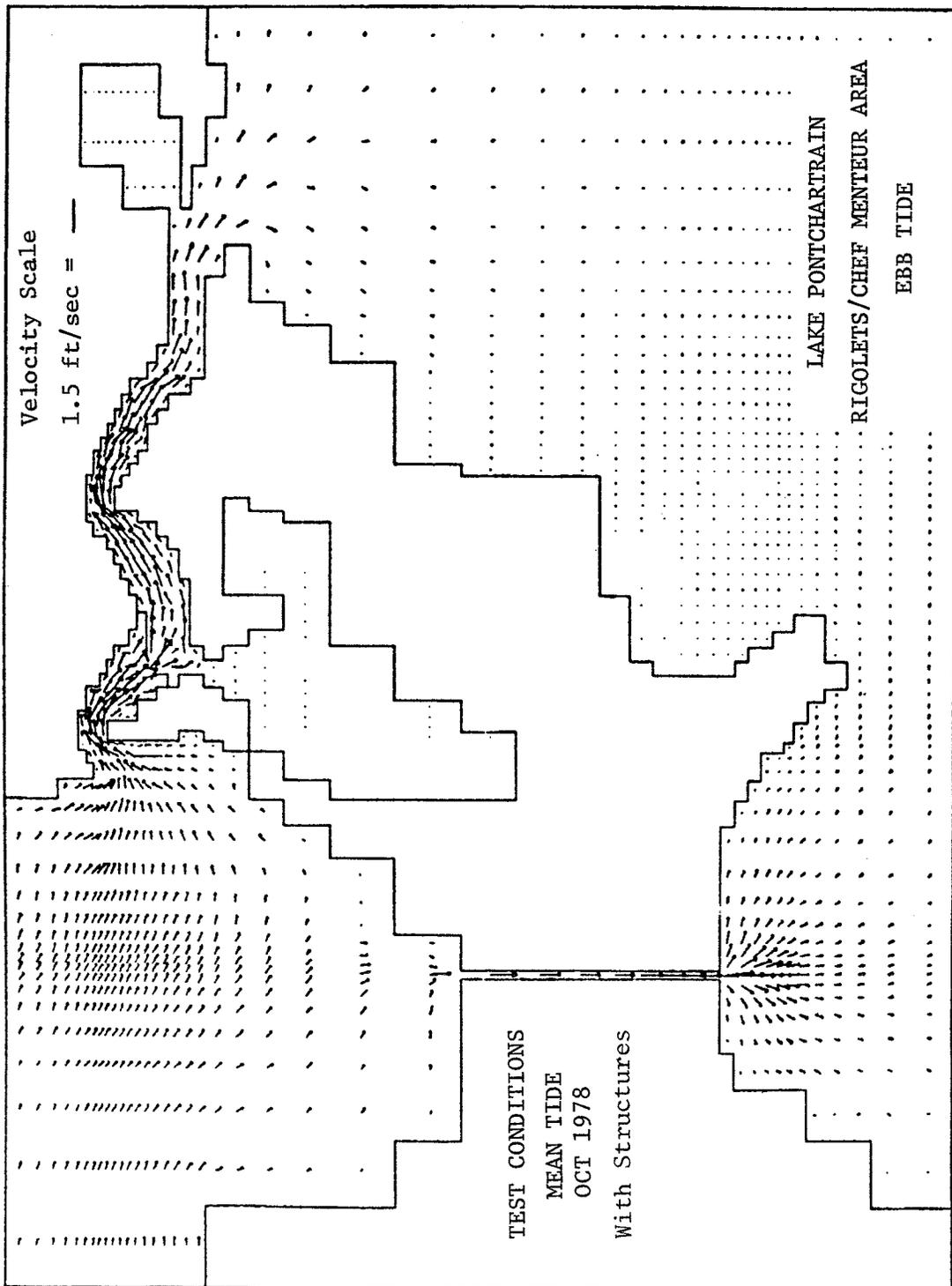


PLATE 52



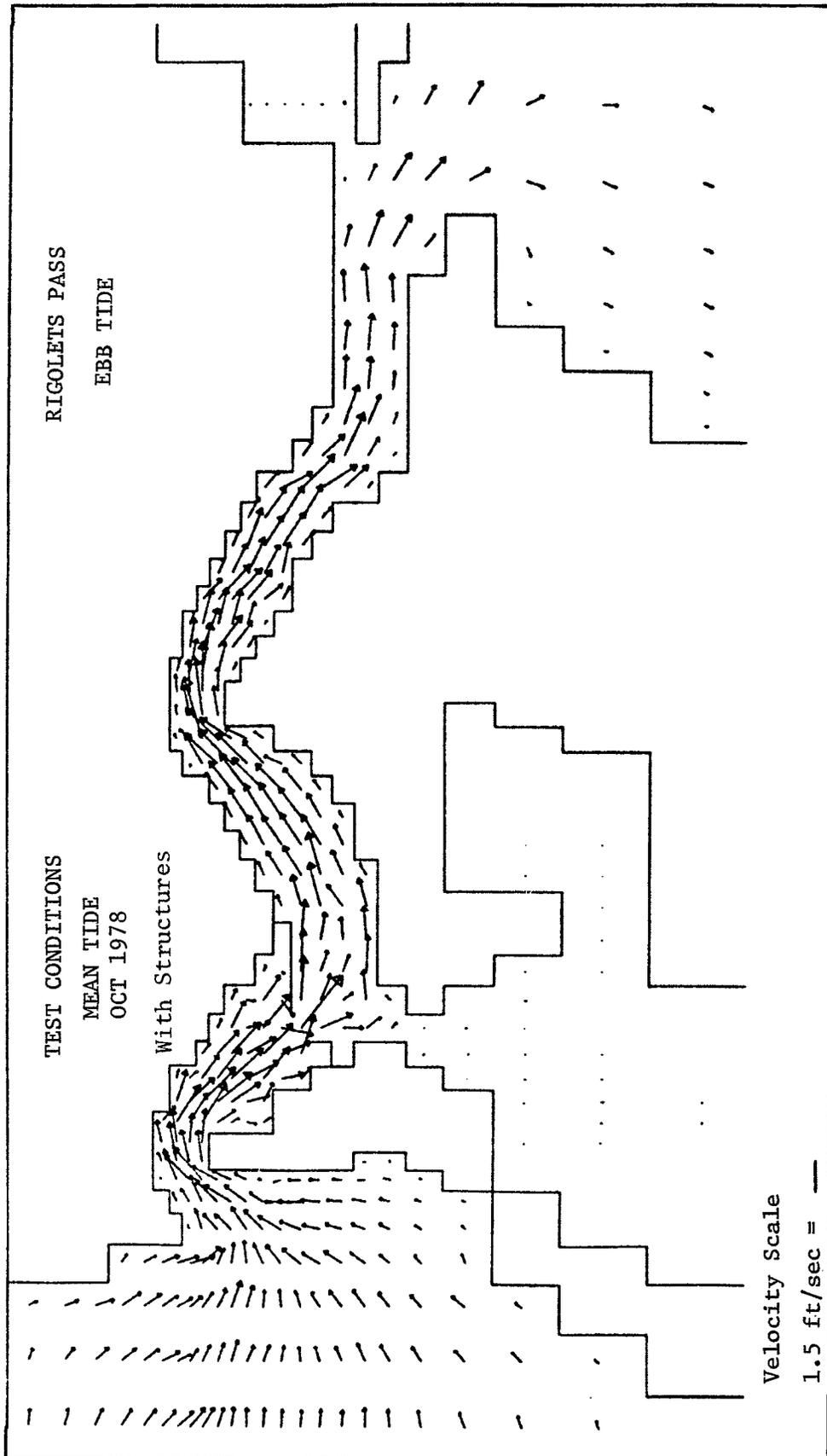
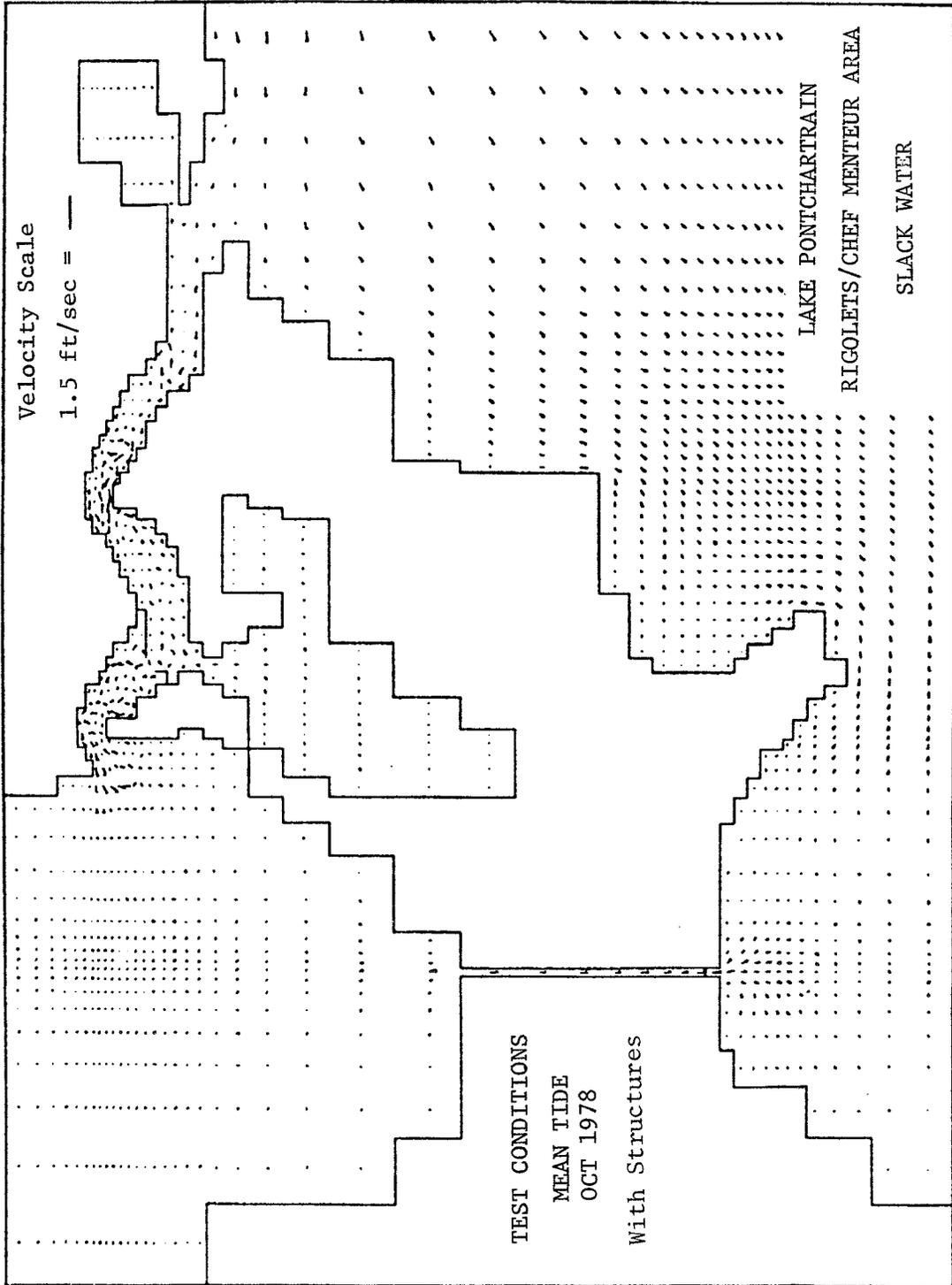


PLATE 54



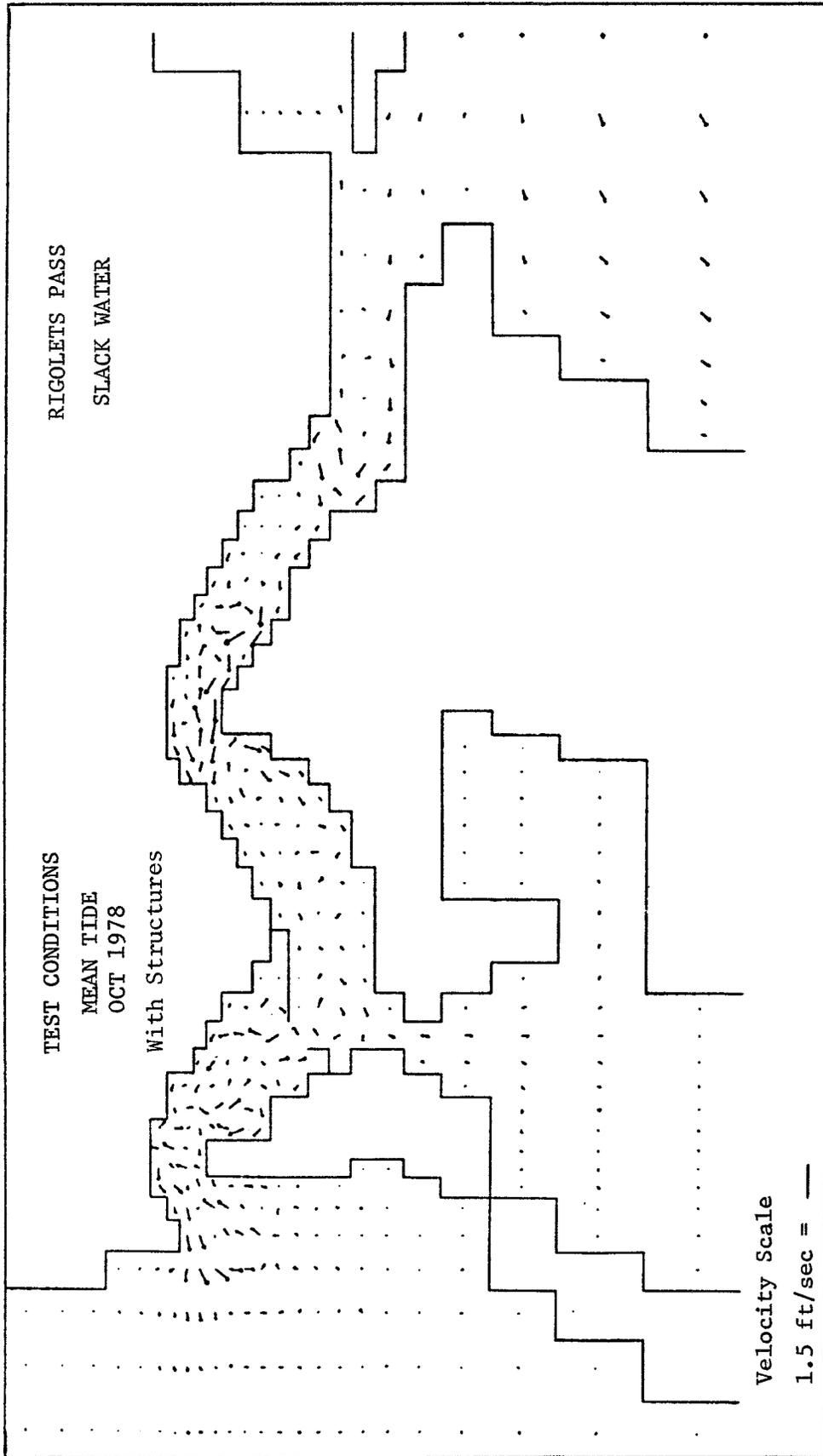


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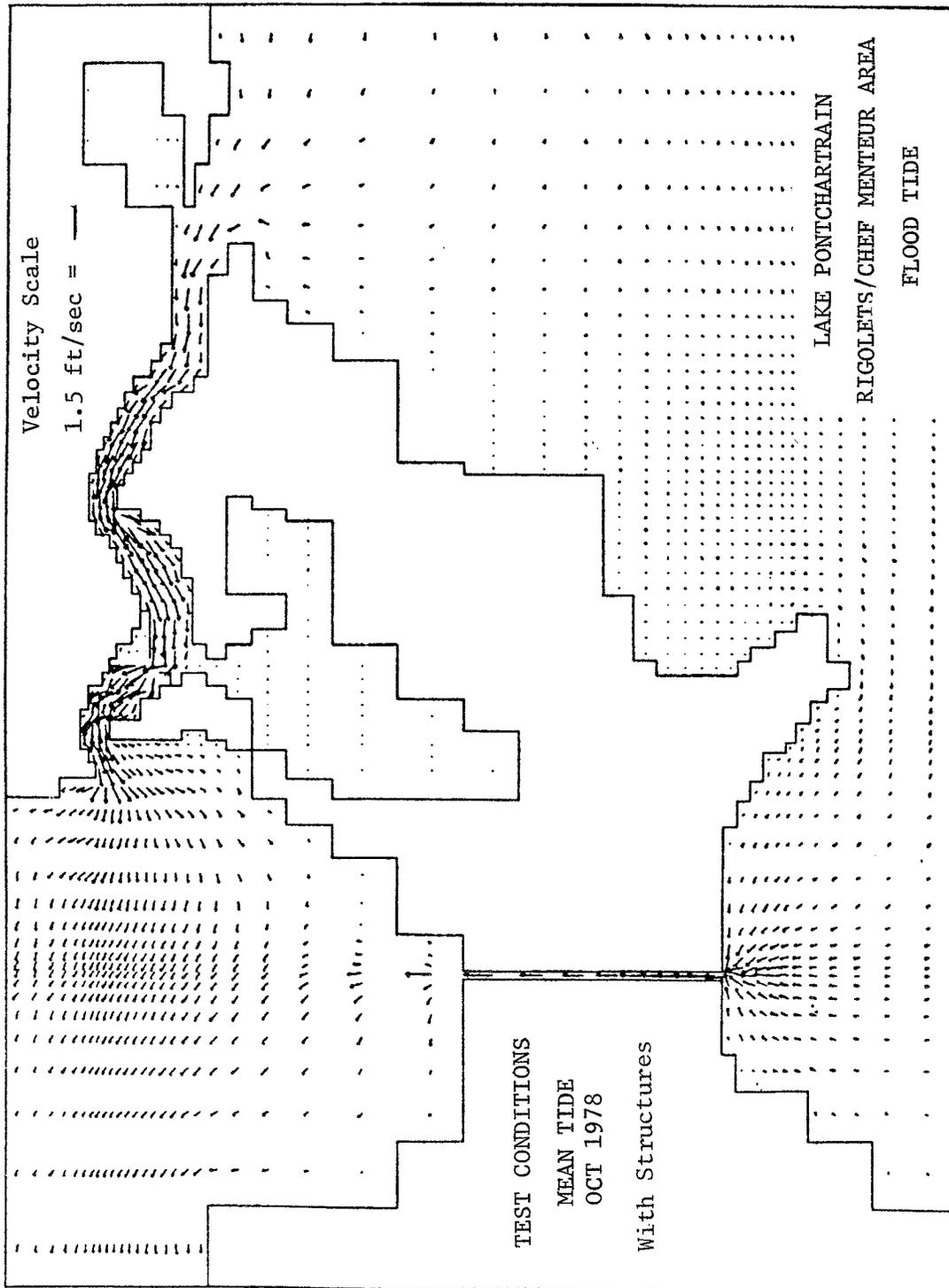


PLATE 57

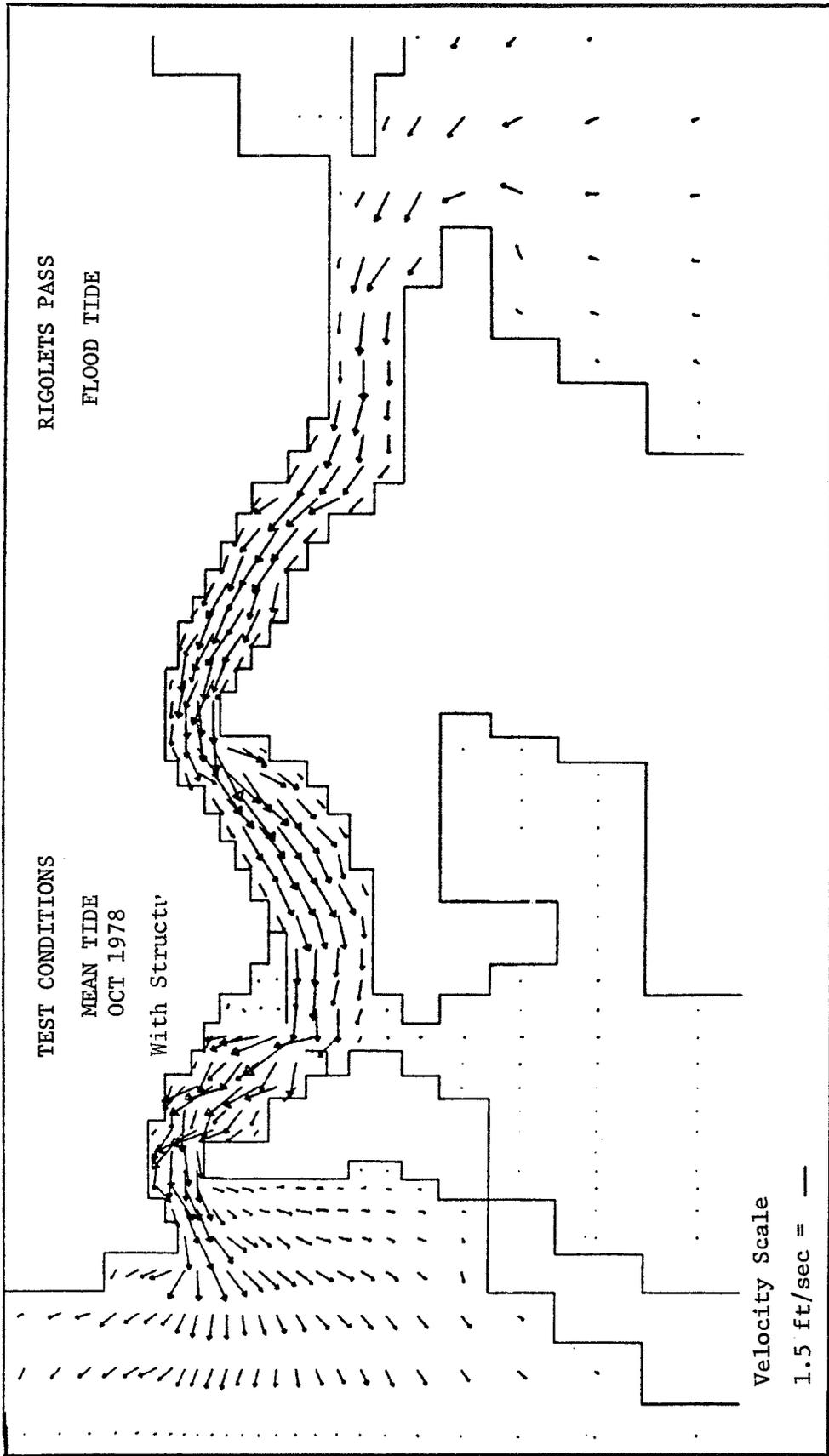
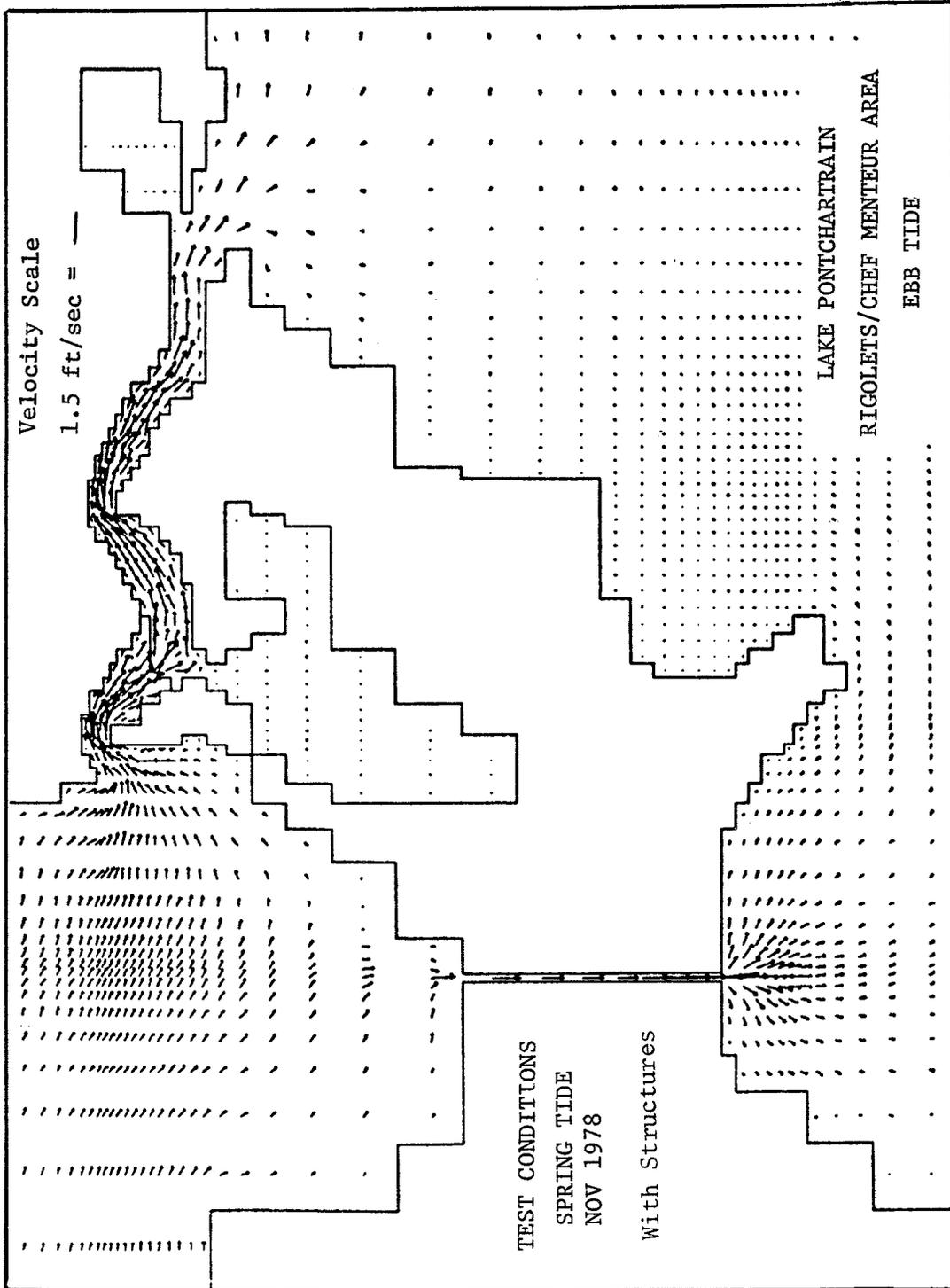


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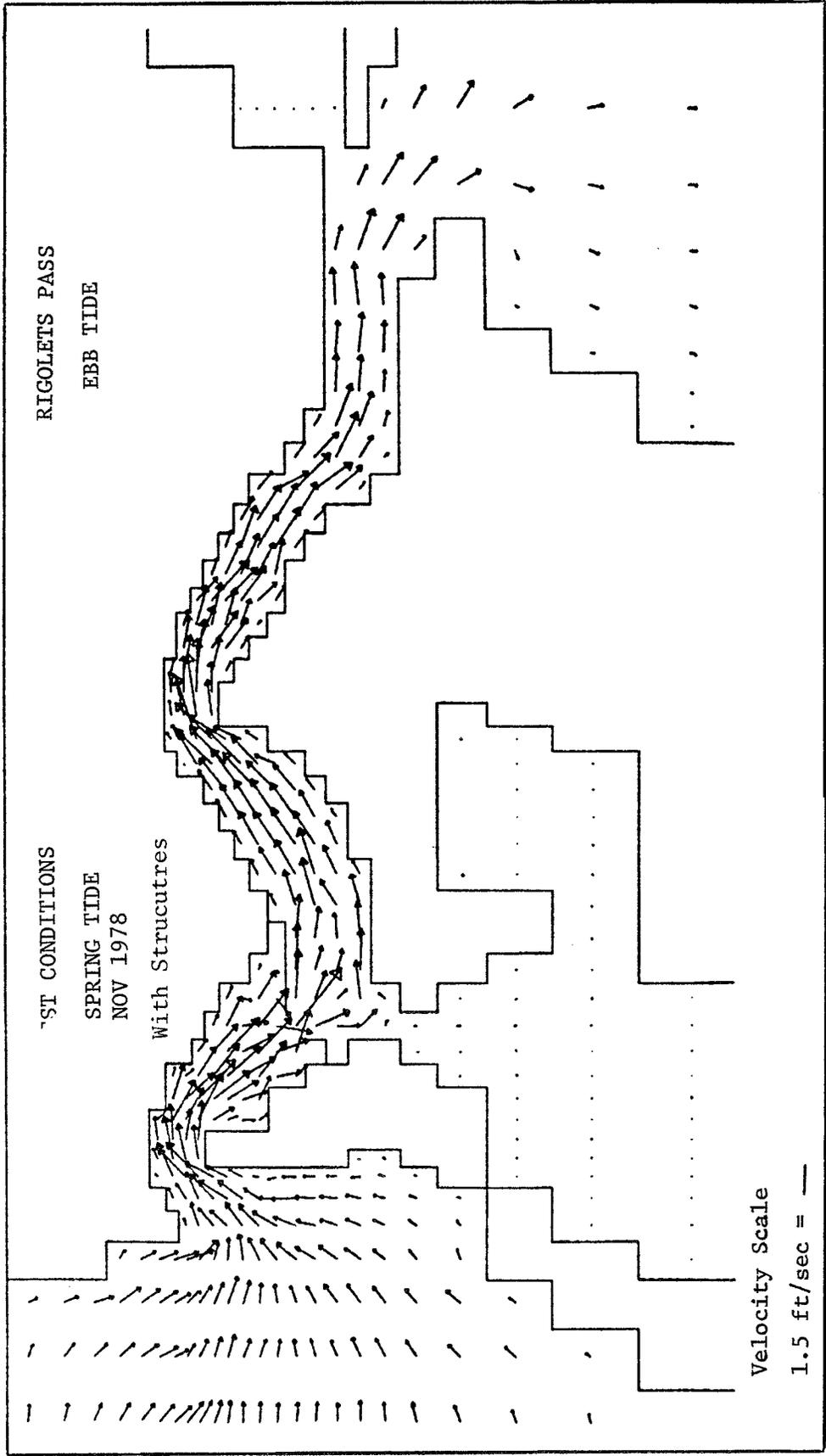


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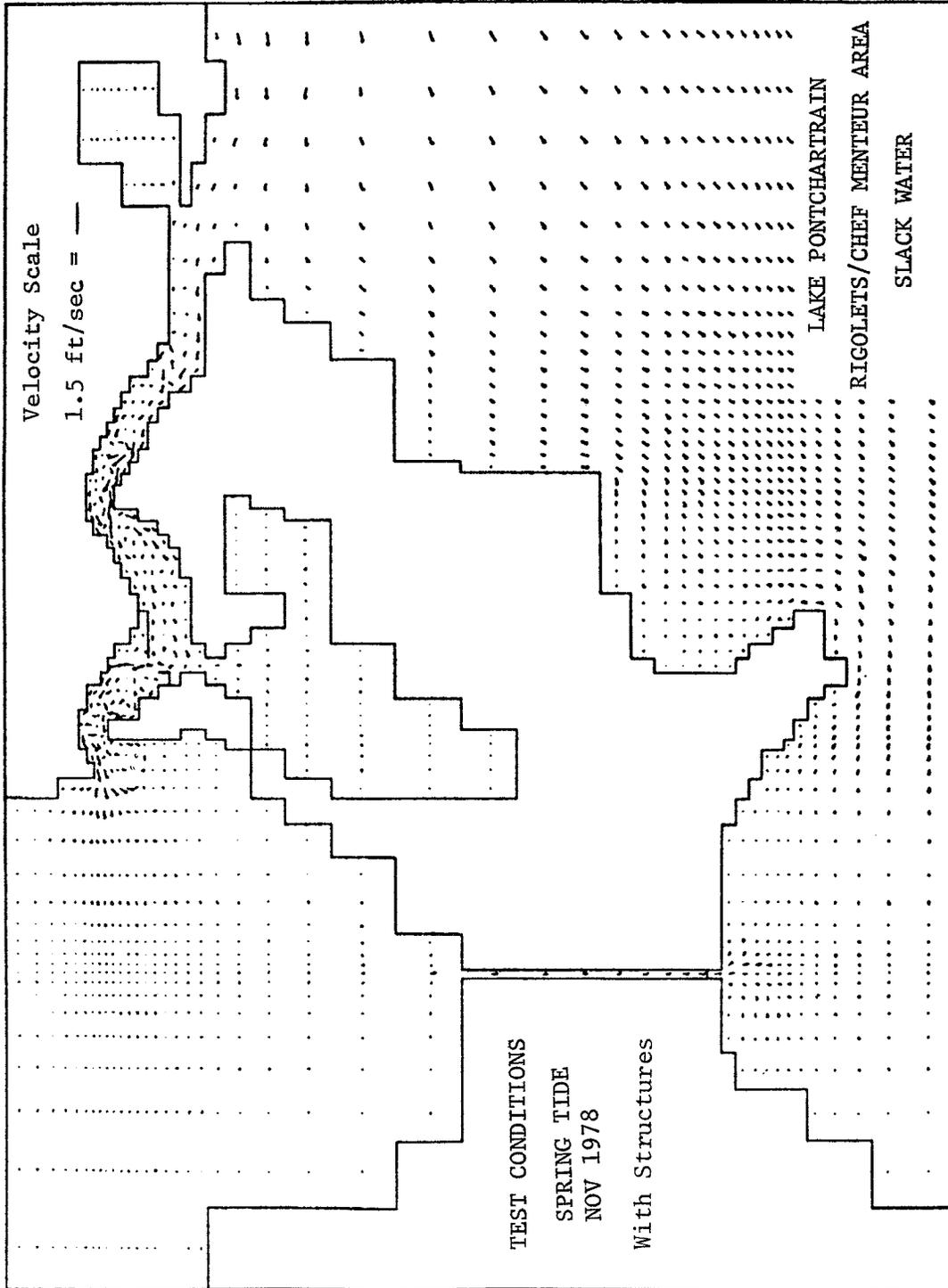


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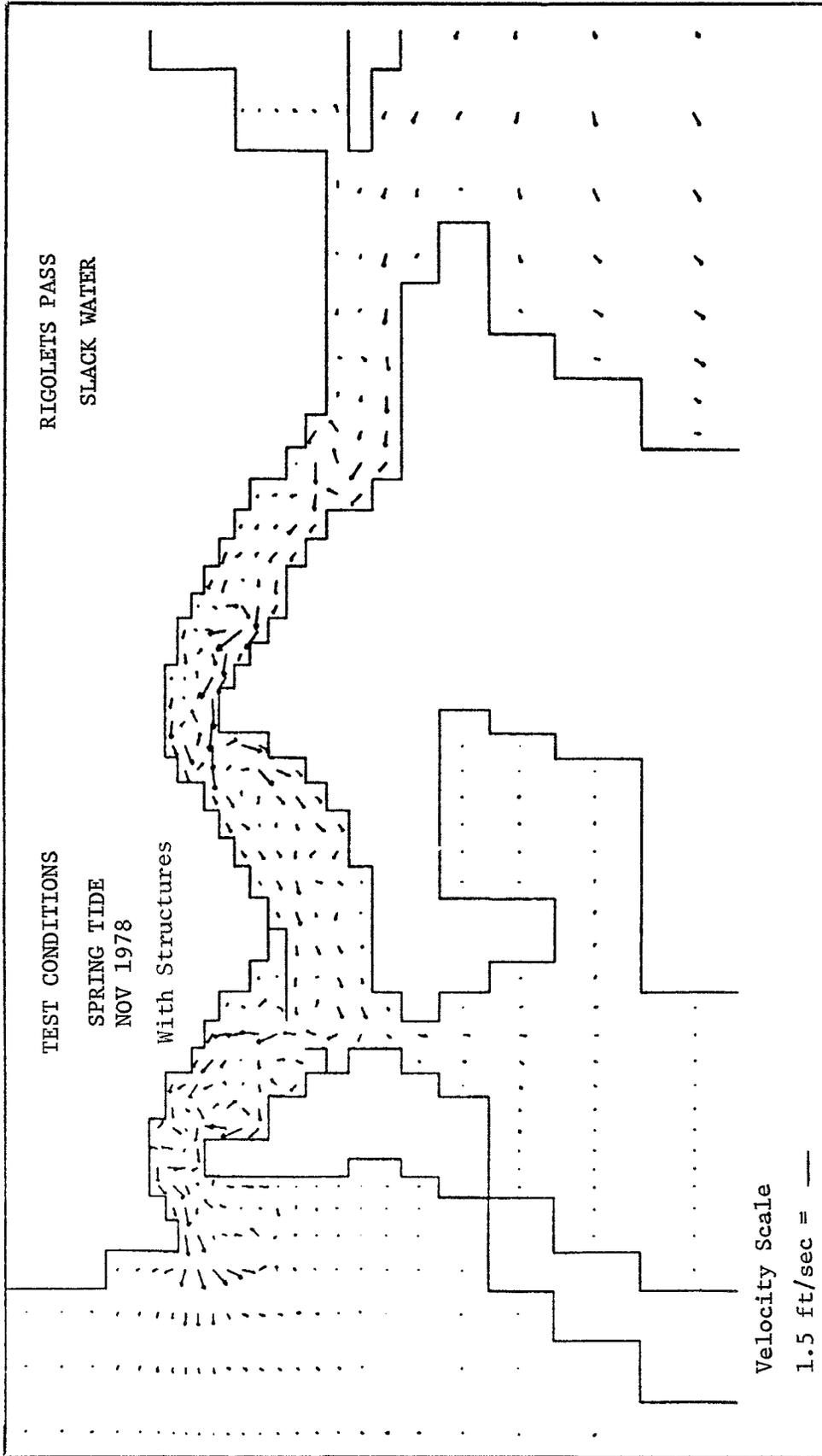
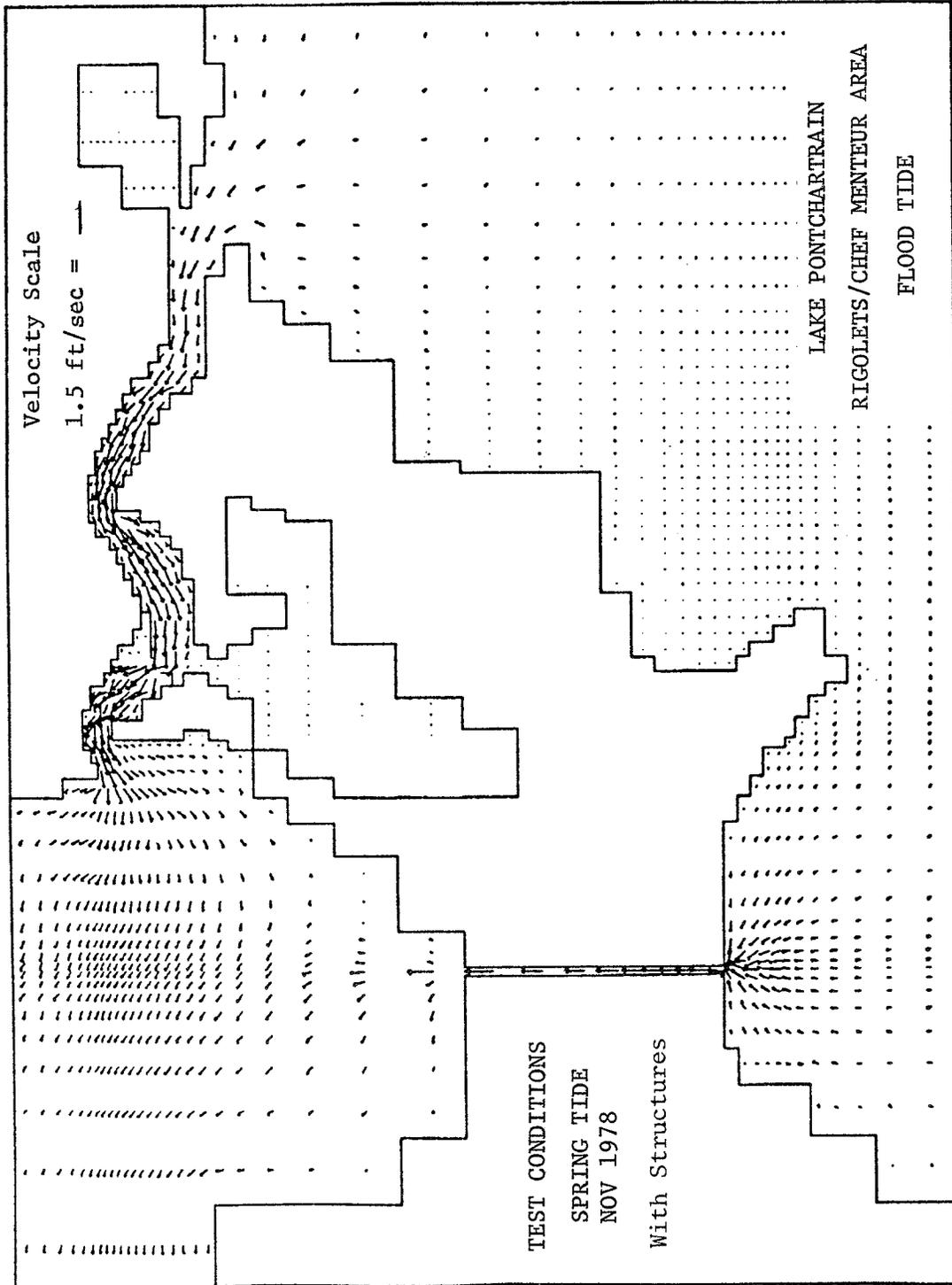


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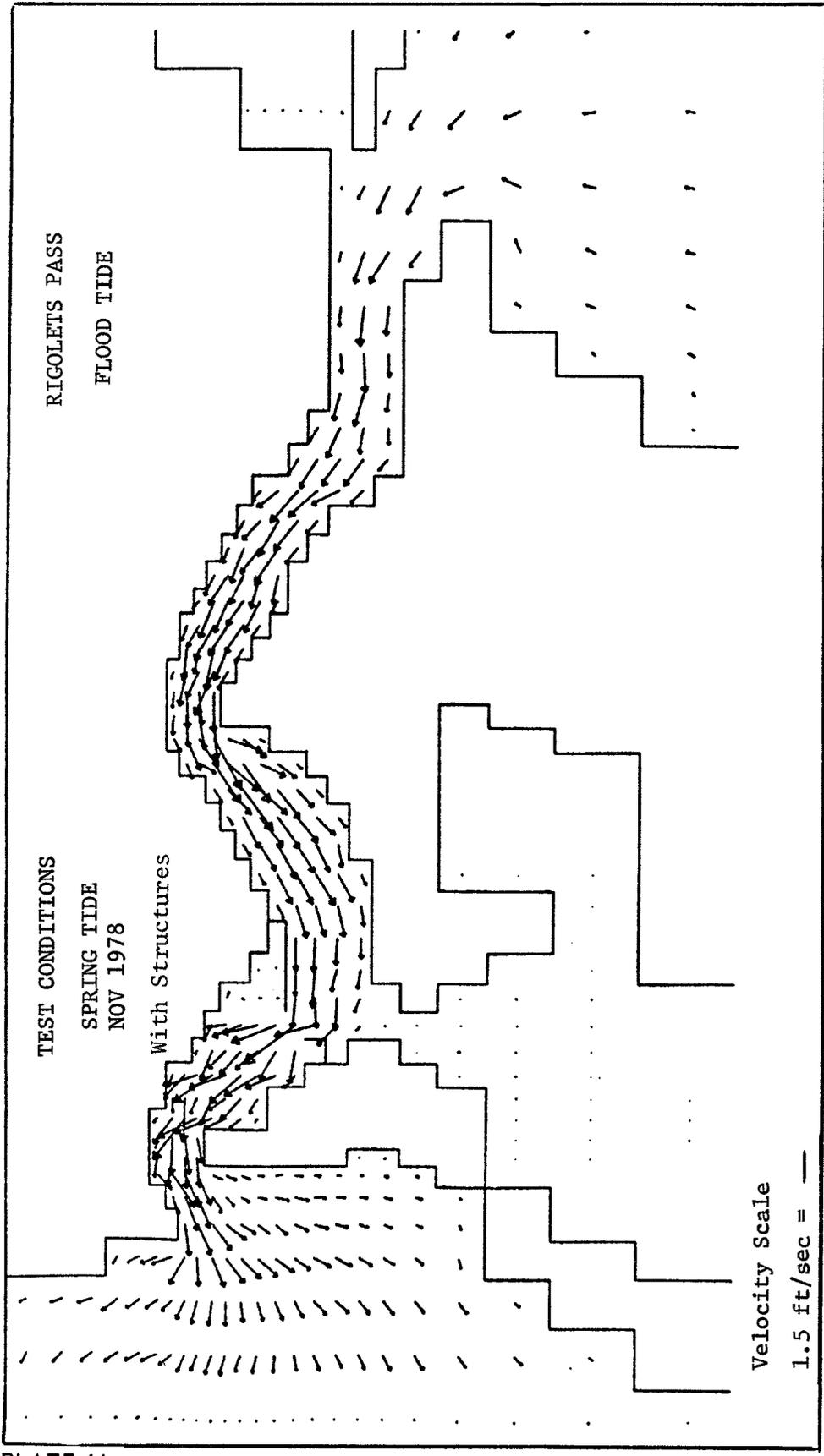


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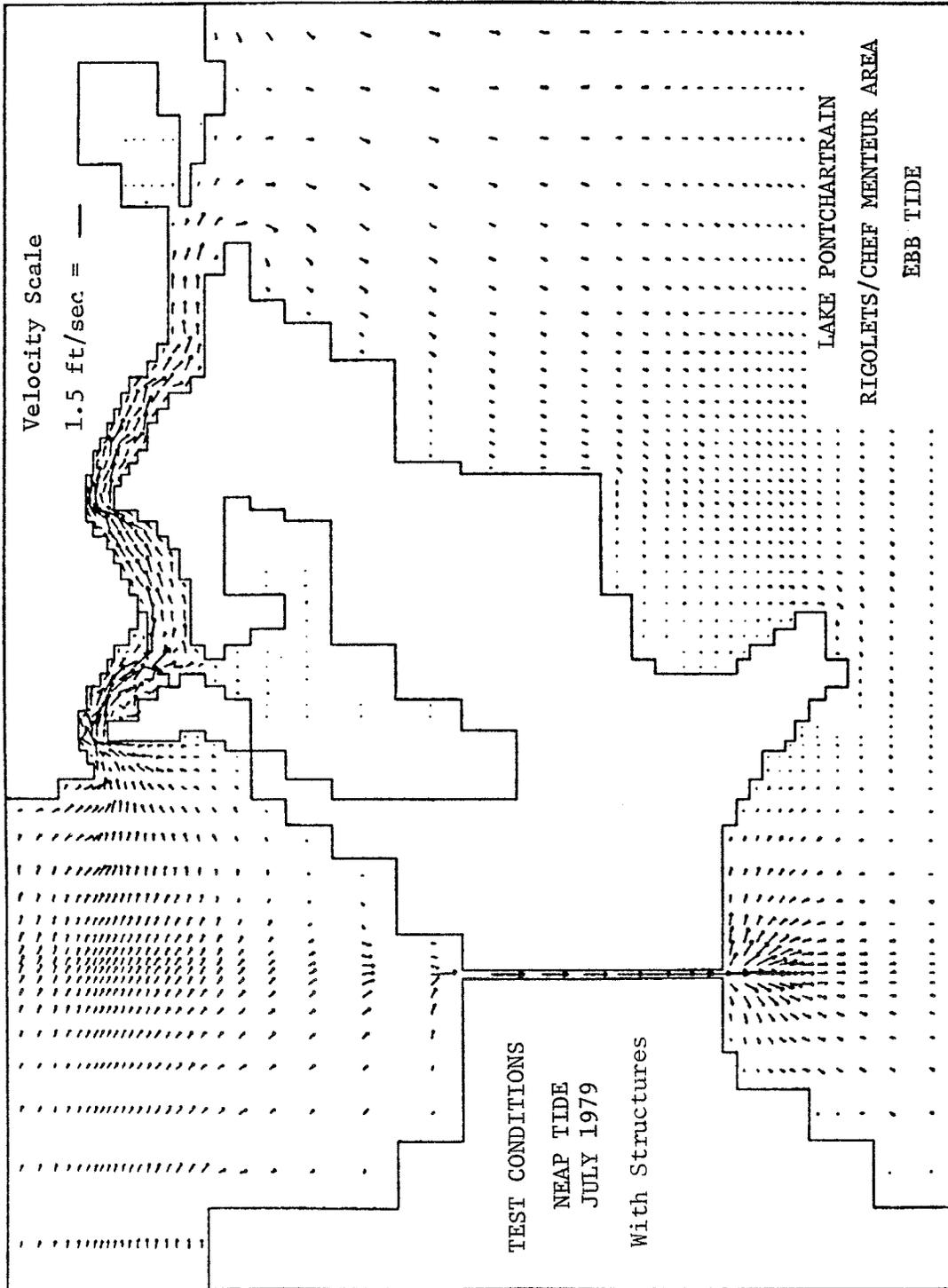


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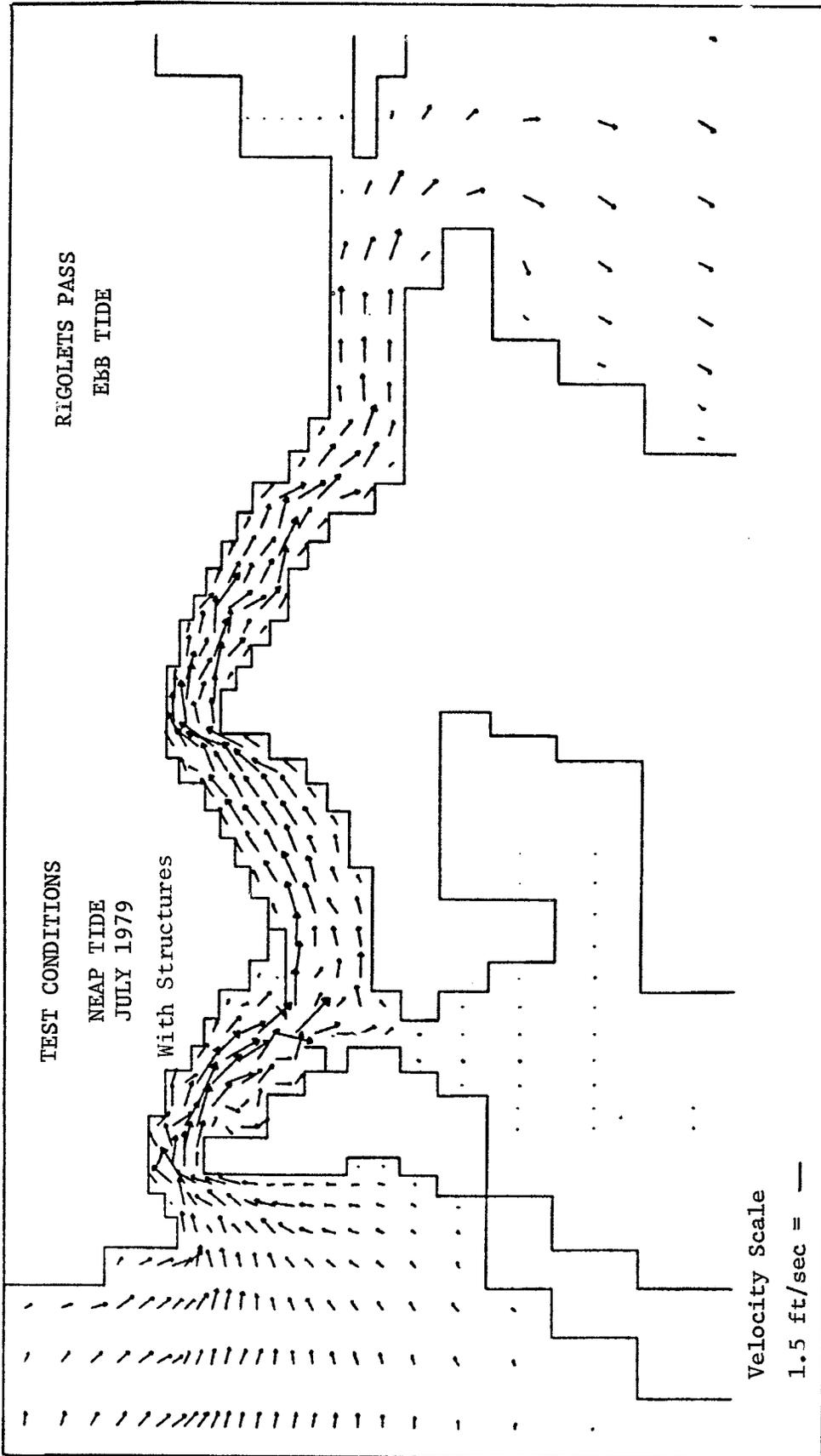
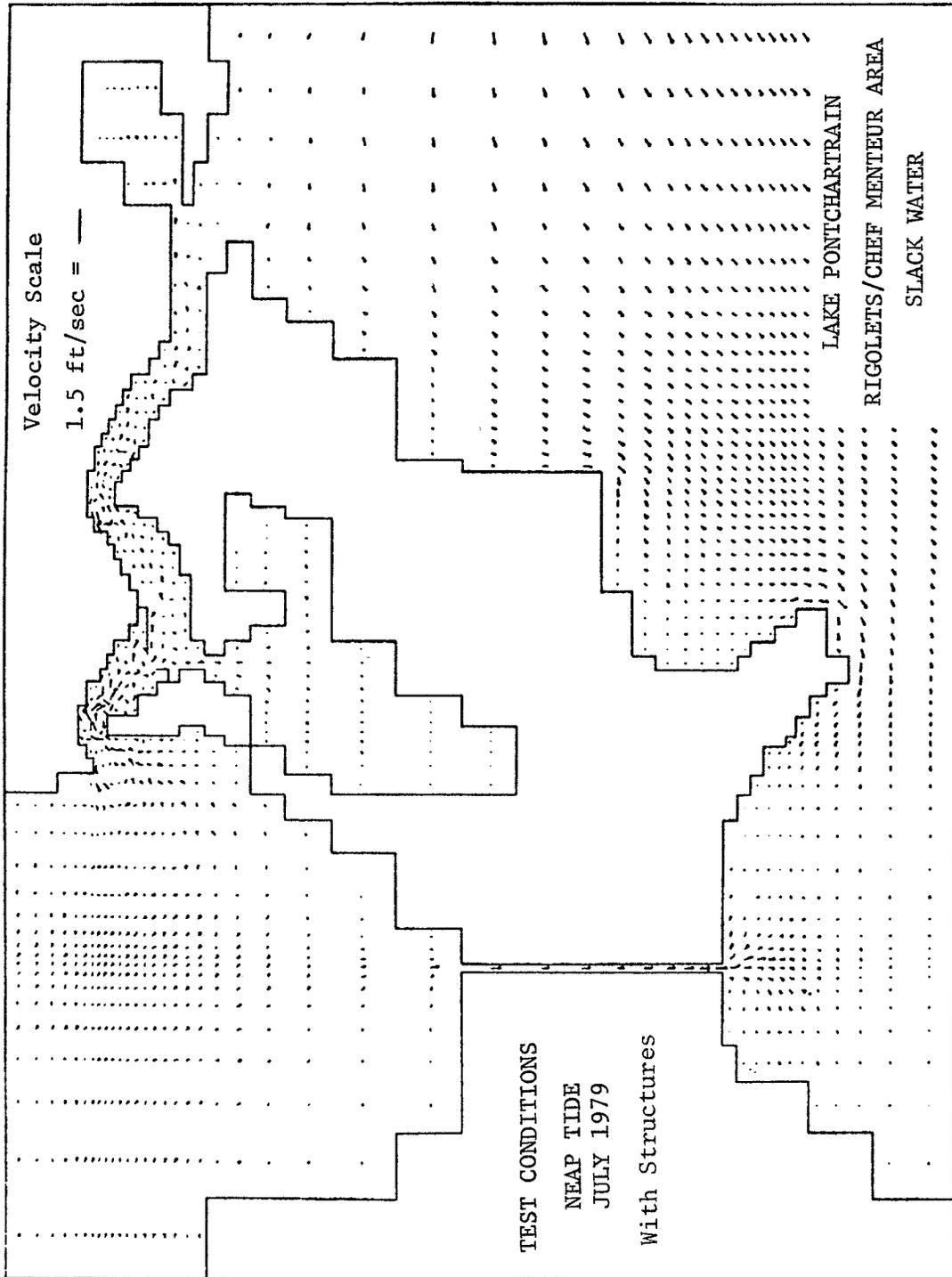


PLATE 66



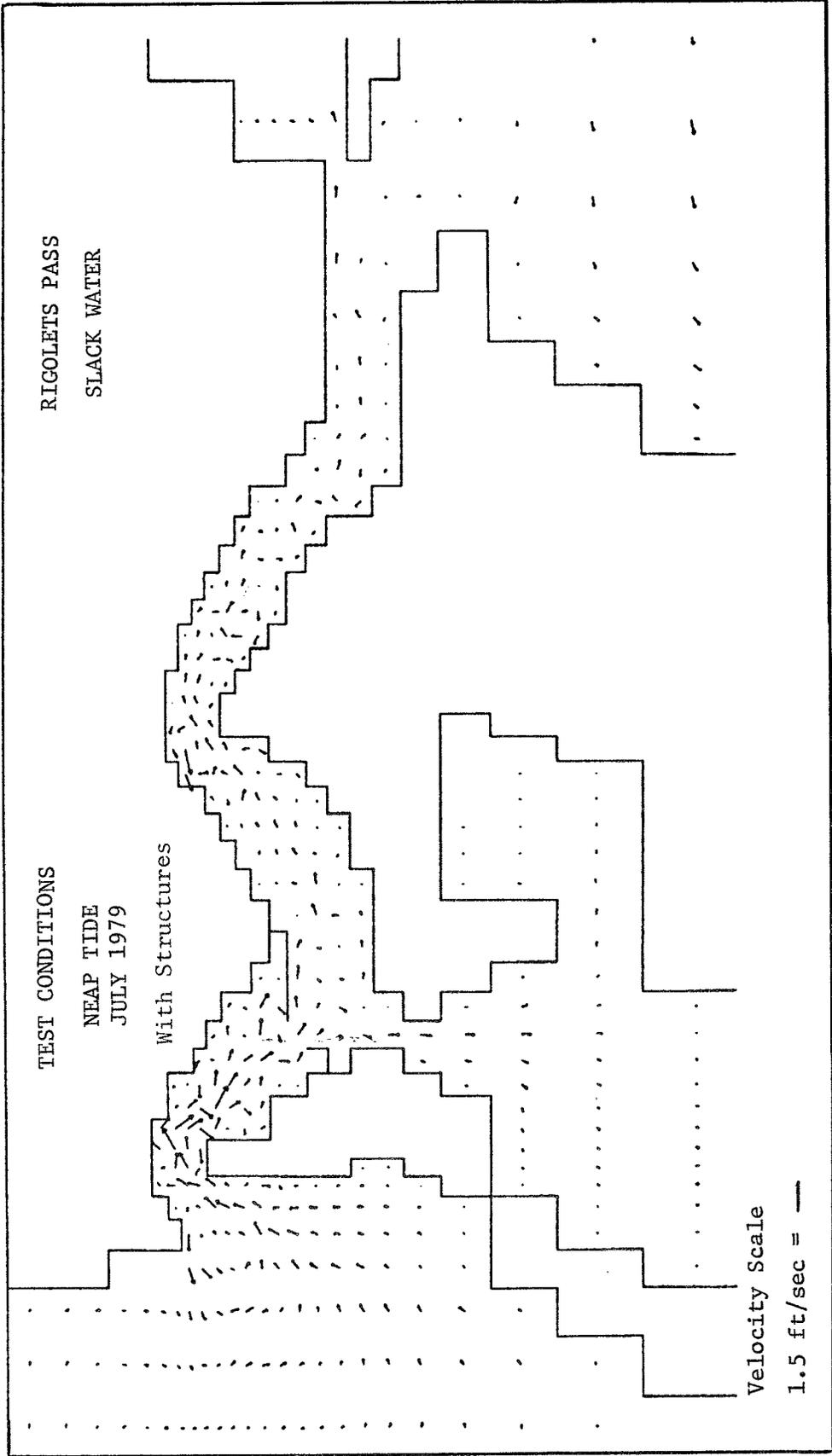


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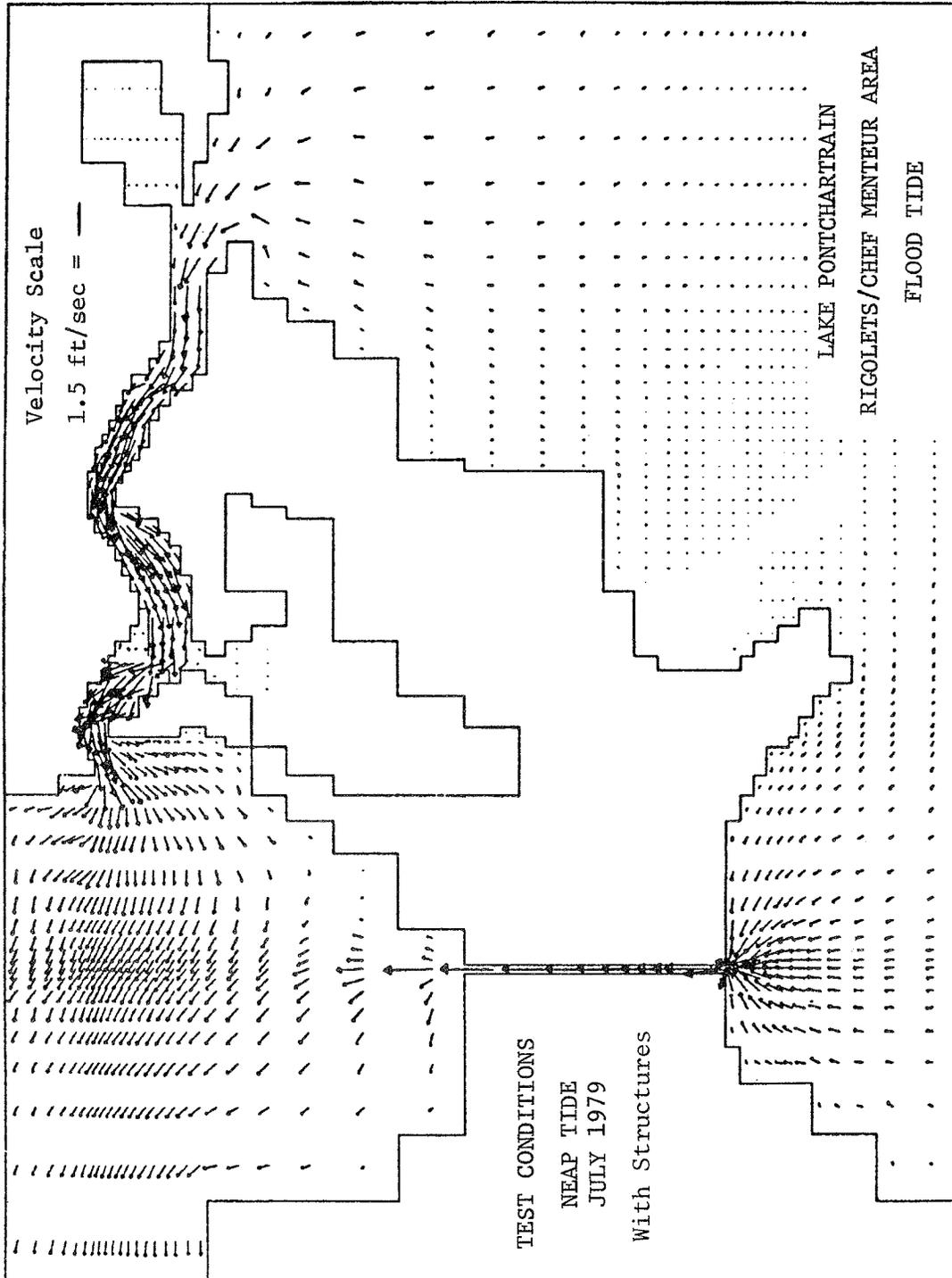
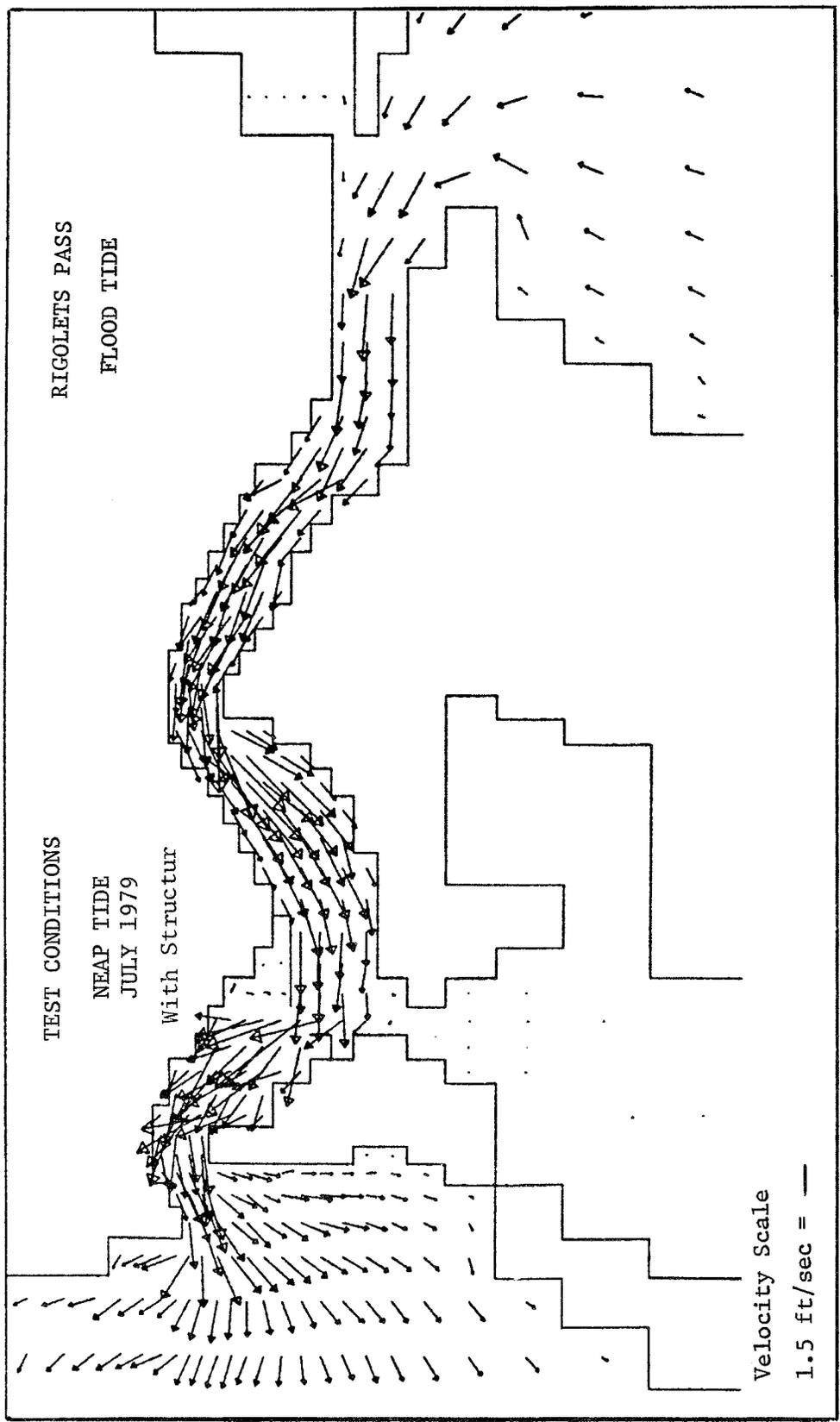


PLATE 69



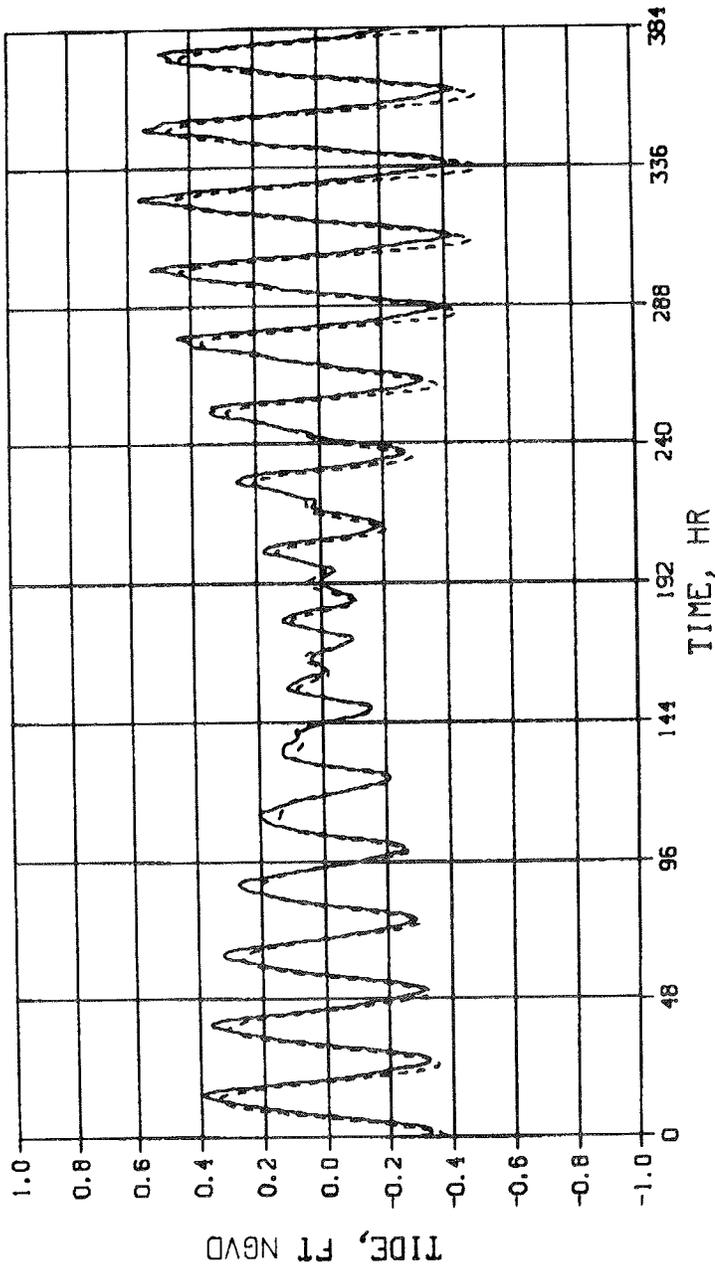
RIGOLETS PASS
FLOOD TIDE

TEST CONDITIONS
NEAP TIDE
JULY 1979
With Structure

Velocity Scale
1.5 ft/sec = —

PLATE 70

GAGE R1



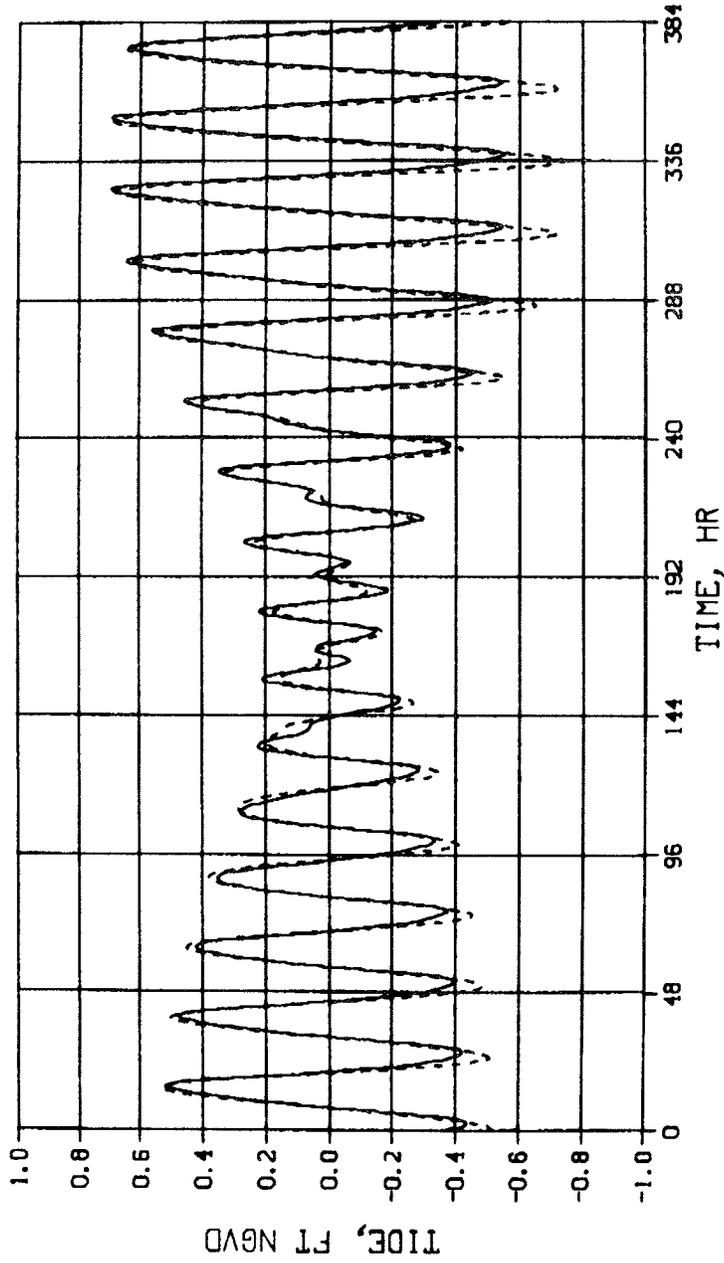
VERIFICATION

TEST CONDITIONS

16 DAY RUN
OCT 21-NOV 6, 1978

LEGEND
— NUMERICAL MODEL
- - - PROTOTYPE DATA

GAGE B4



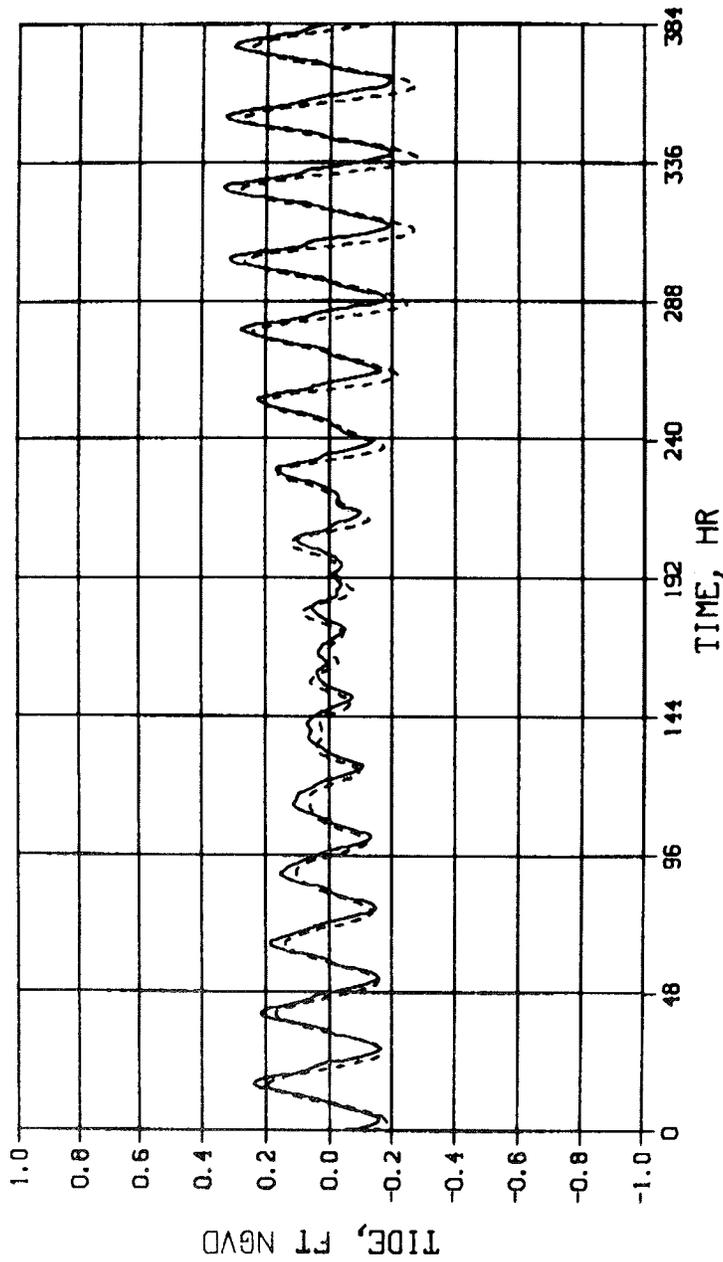
VERIFICATION

TEST CONDITIONS

16 DAY RUN
OCT 21-NOV 6, 1978

LEGEND
- - - - - NUMERICAL MODEL
- - - - - PROTOTYPE DATA

GAGE P1



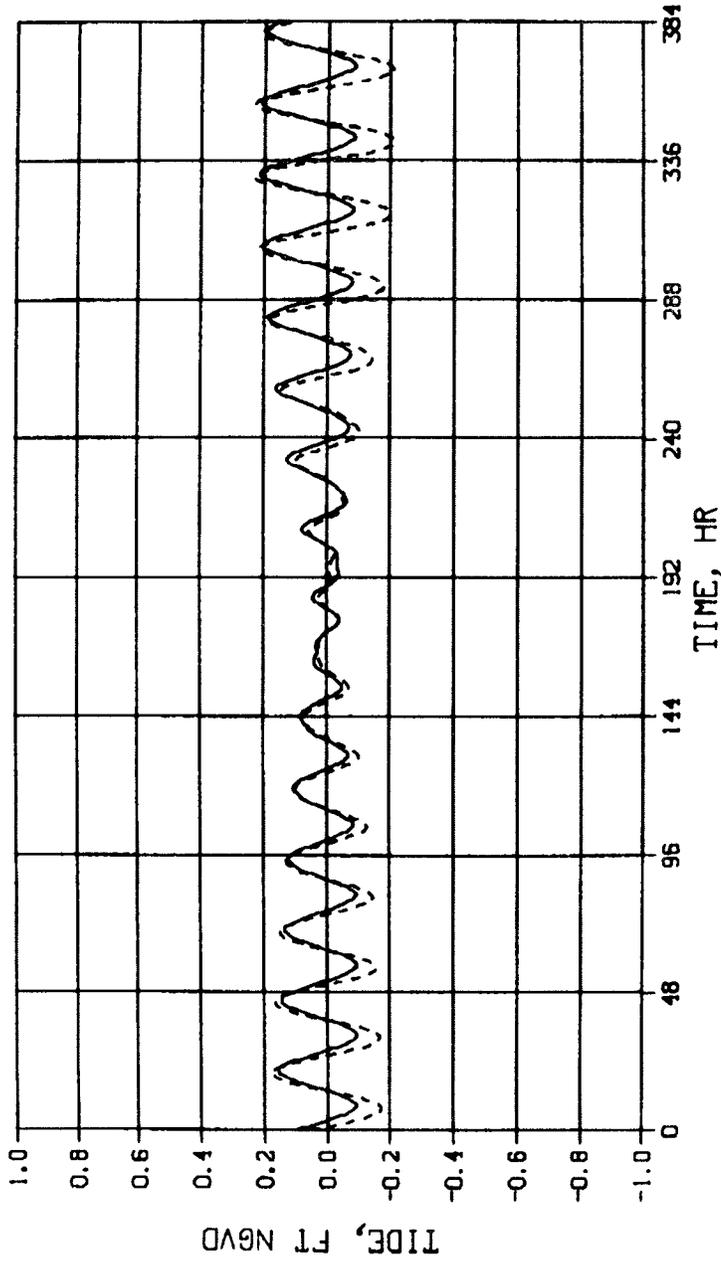
VERIFICATION

TEST CONDITIONS

16 DAY RUN
OCT 21-NOV 6, 1978

LEGEND
- - - - - NUMERICAL MODEL
_____ PROTOTYPE DATA

GAGE P4



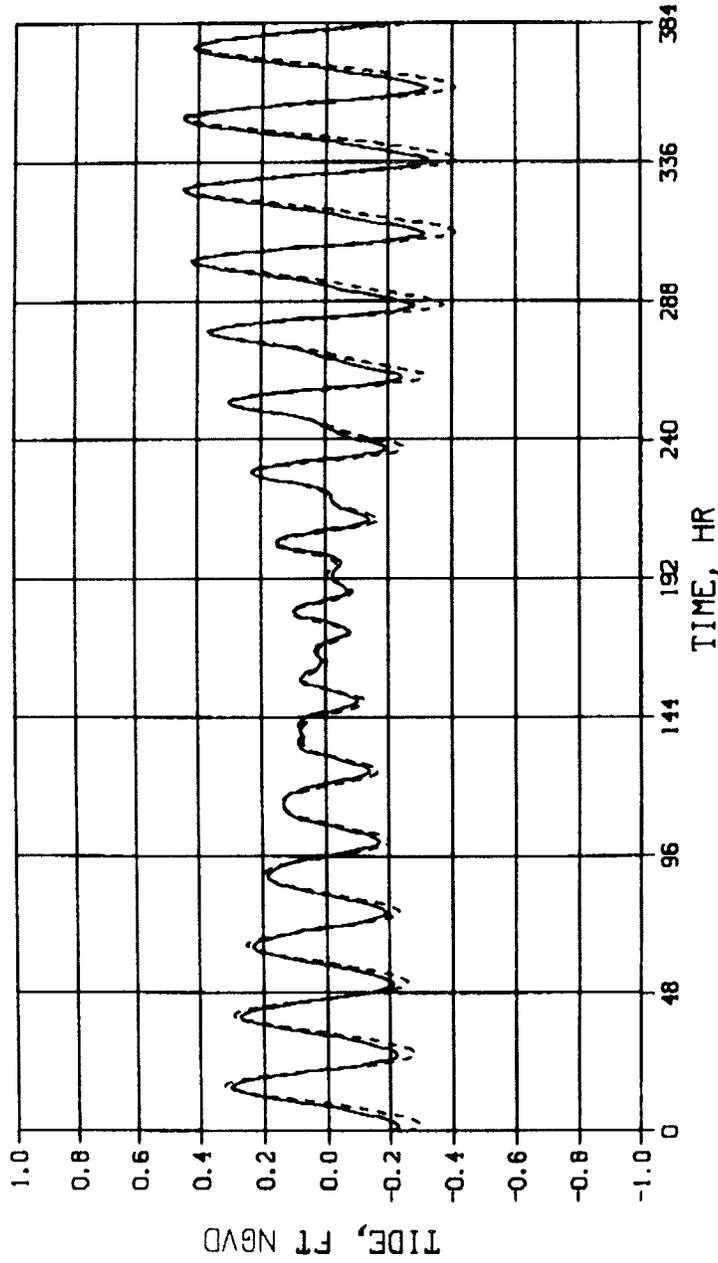
VERIFICATION

TEST CONDITIONS

16 DAY RUN
OCT 21-NOV 6, 1978

LEGEND
- - - - - NUMERICAL MODEL
- - - - - PROTOTYPE DATA

GAGE P6



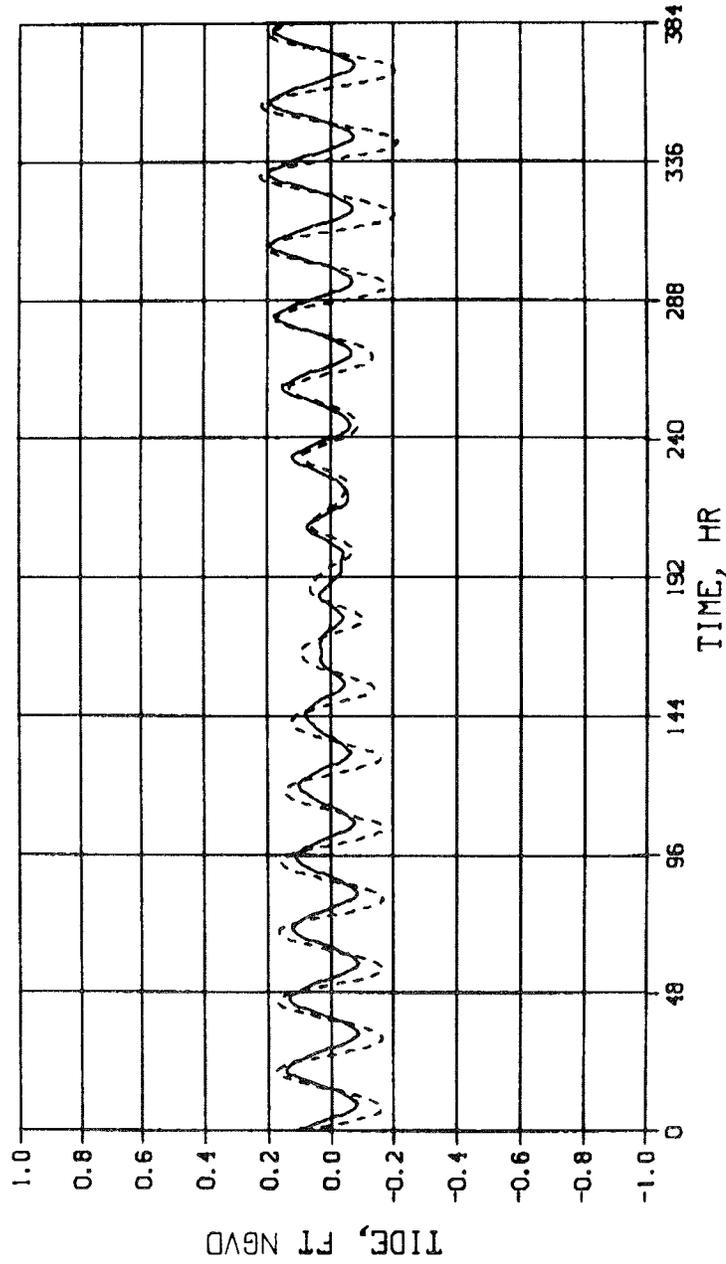
VERIFICATION

TEST CONDITIONS

16 DAY RUN
OCT 21-NOV 6, 1978

LEGEND
- - - - - NUMERICAL MODEL
- - - - - PROTOTYPE DATA

GAGE P9



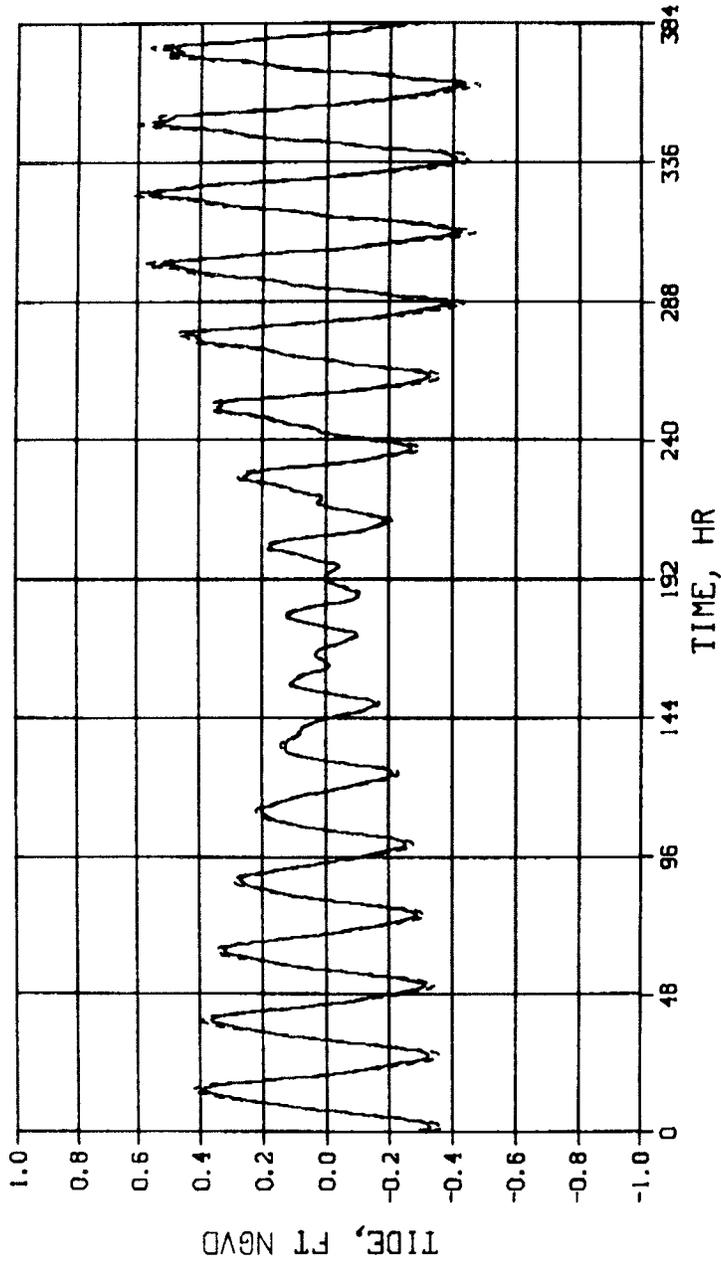
VERIFICATION

TEST CONDITIONS

16 DAY RUN
OCT 21-NOV 6, 1978

LEGEND
— NUMERICAL MODEL
- - - PROTOTYPE DATA

GAGE R1



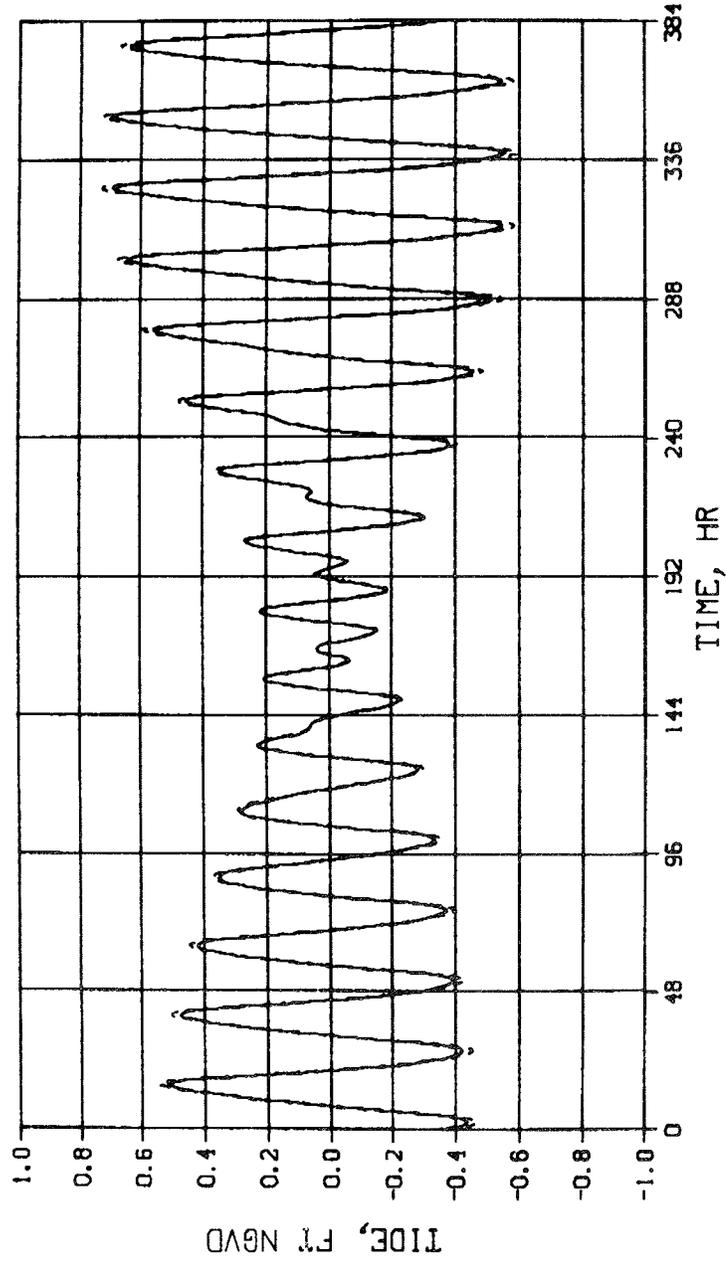
PLAN VS BASE

TEST CONDITIONS

16 DAY RUN
OCT 21-NOV 6, 1978

LEGEND
- - - WITH STRUCTURE
— BASE CONDITIONS

GAGE B4



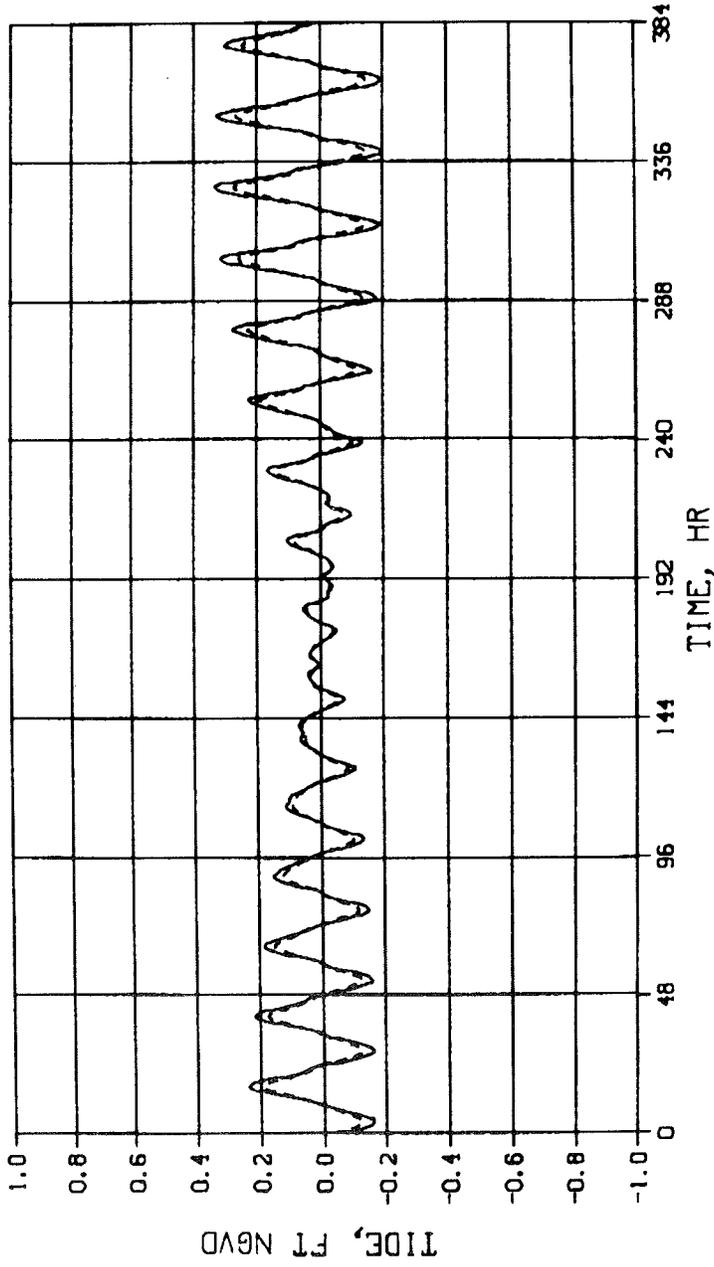
PLAN VS BASE

TEST CONDITIONS

16 DAY RUN
OCT 21-NOV 6, 1978

LEGEND
— - BASE CONDITIONS
- - - - WITH STRUCTURE

GAGE P1

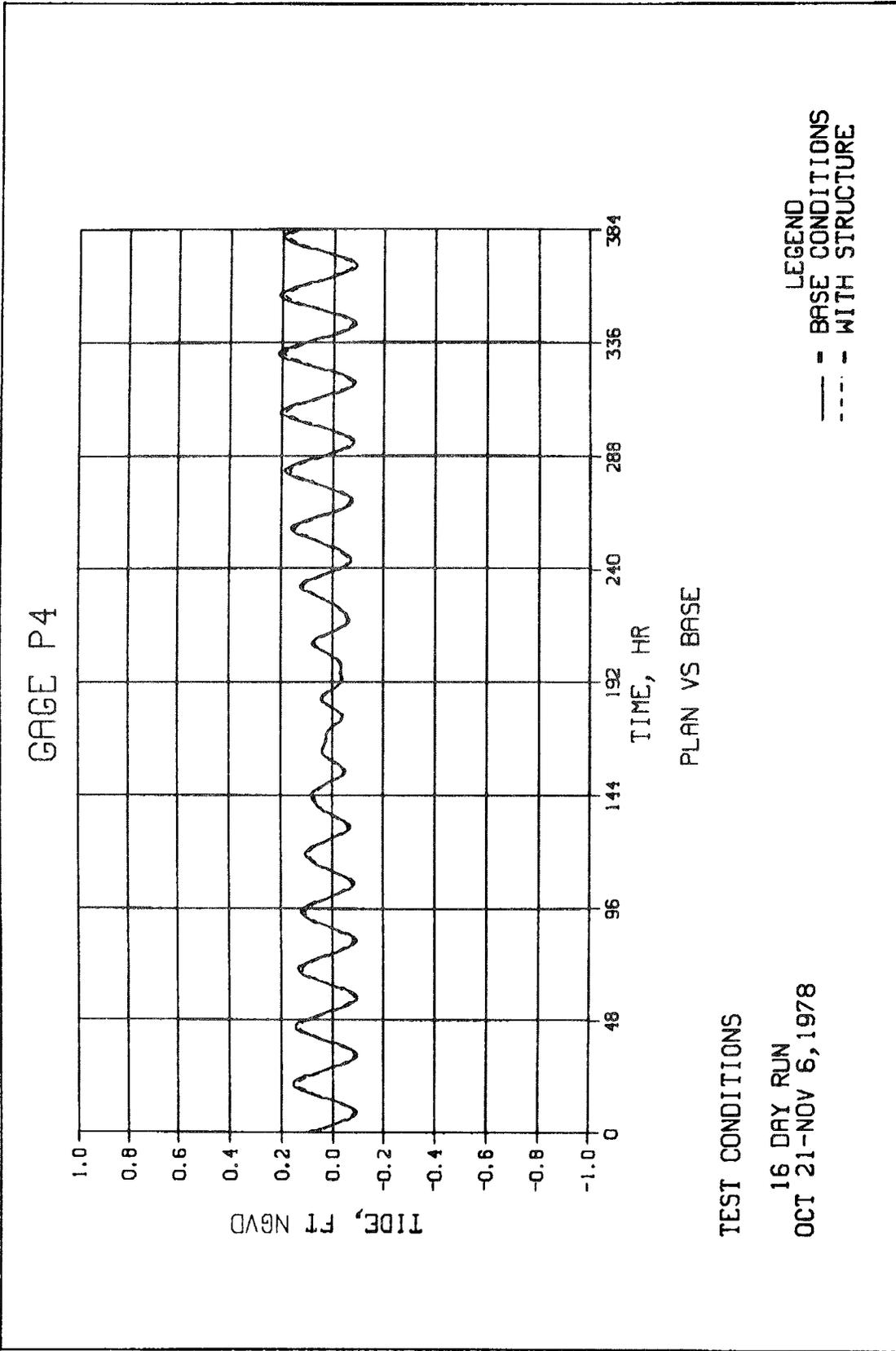


PLAN VS BASE

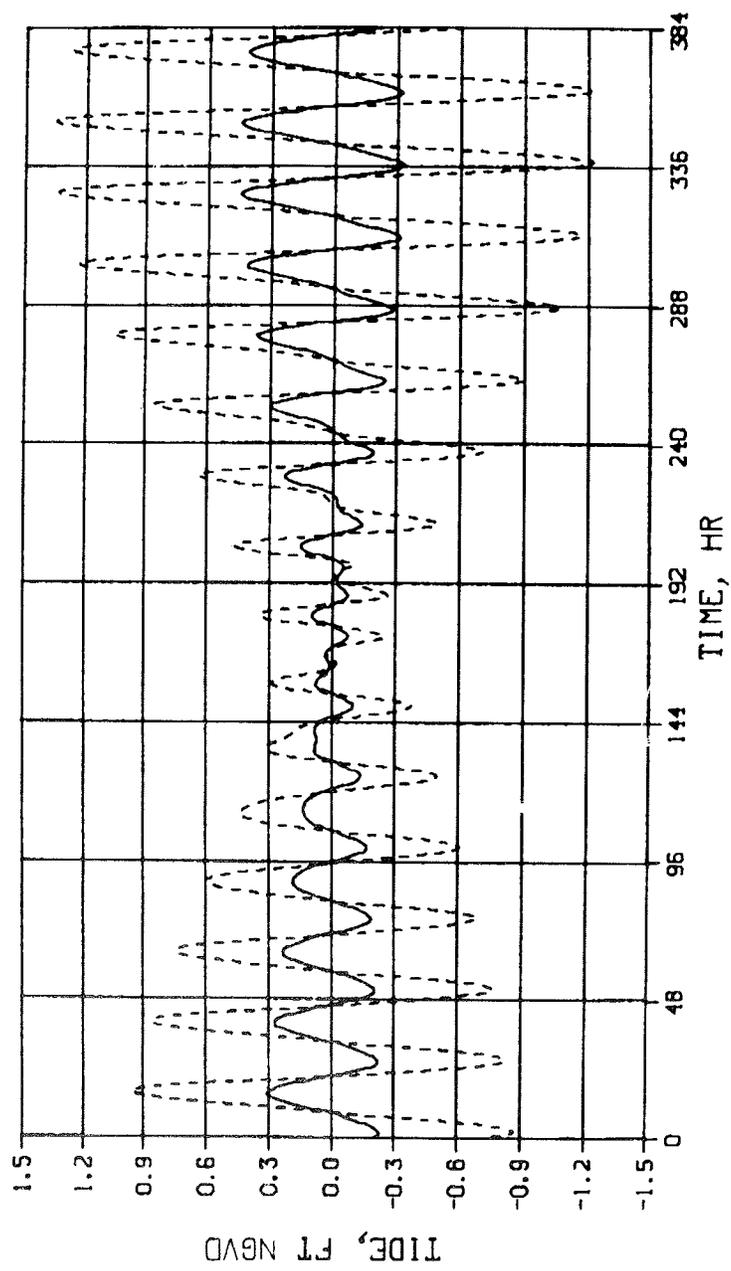
TEST CONDITIONS

16 DAY RUN
OCT 21-NOV 6, 1978

LEGEND
- - - BASE CONDITIONS
- - - WITH STRUCTURE



GAGE P6



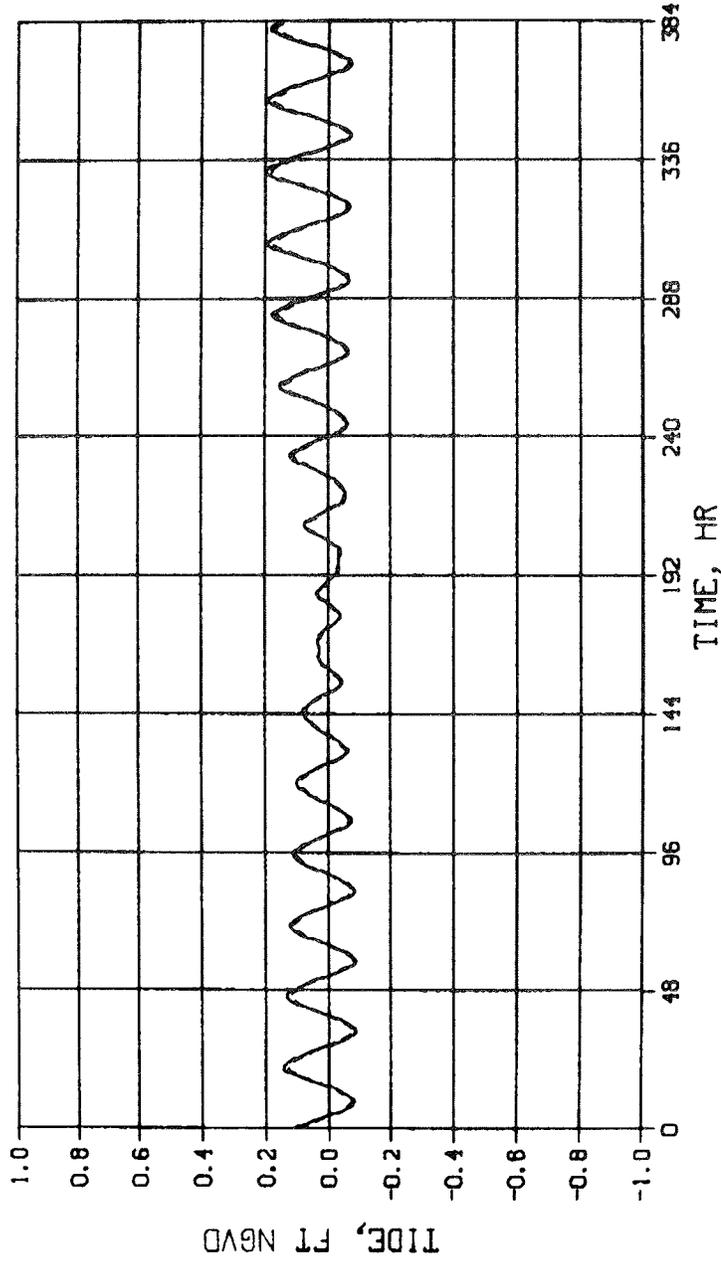
PLAN VS BASE

TEST CONDITIONS

16 DAY RUN
OCT 21-NOV 6, 1978

LEGEND
- - - BASE CONDITIONS
- - - WITH STRUCTURE

GAGE P9



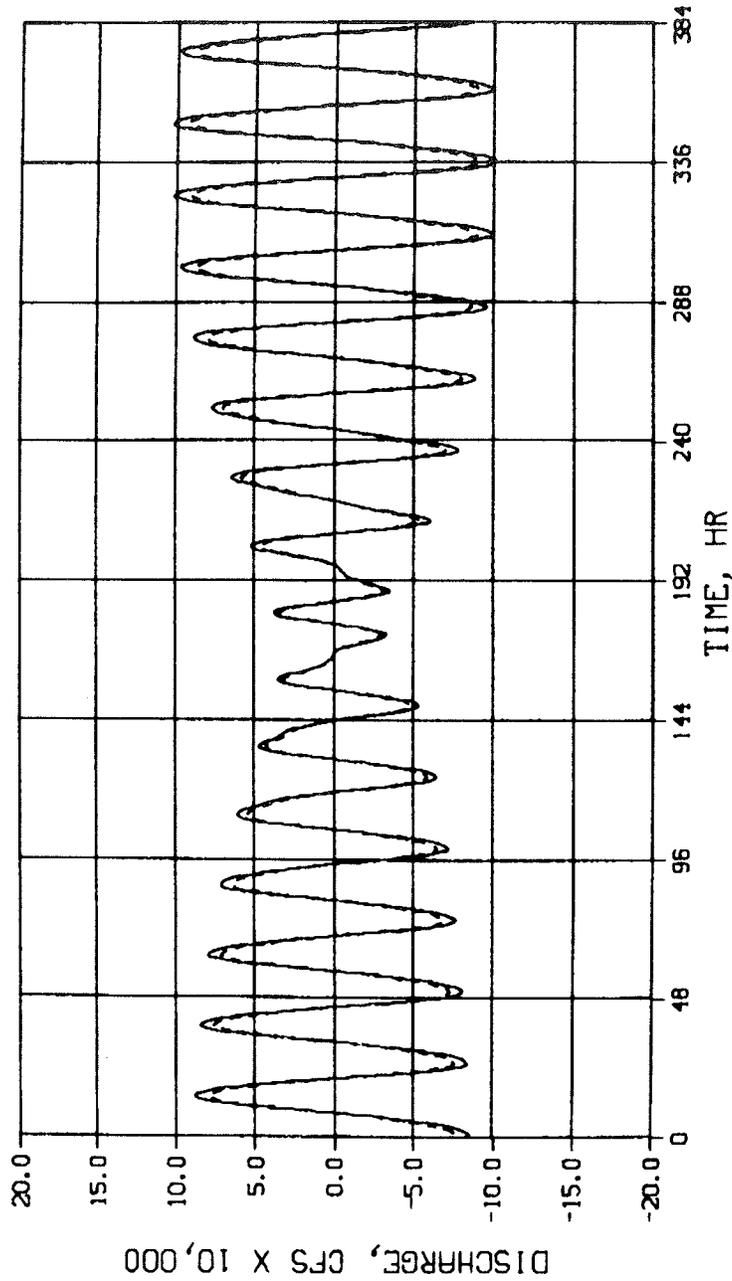
PLAN VS BASE

TEST CONDITIONS

16 DAY RUN
OCT 21-NOV 6, 1978

LEGEND
— - BASE CONDITIONS
- - - - WITH STRUCTURE

THE RIGOLETS



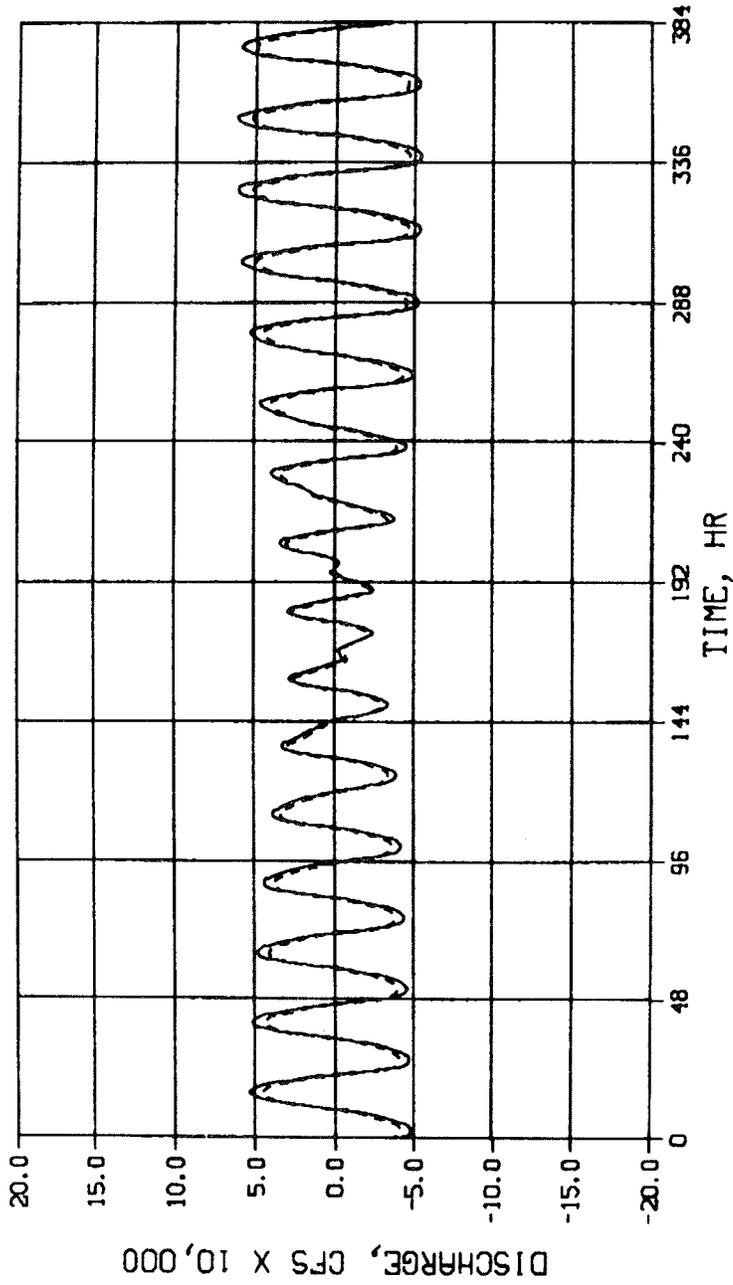
PLAN VS BASE

TEST CONDITIONS

16 DAY RUN
OCT 21-NOV 6, 1978

LEGEND
— - BASE CONDITIONS
- - - - WITH STRUCTURE

THE CHEF MENTEUR



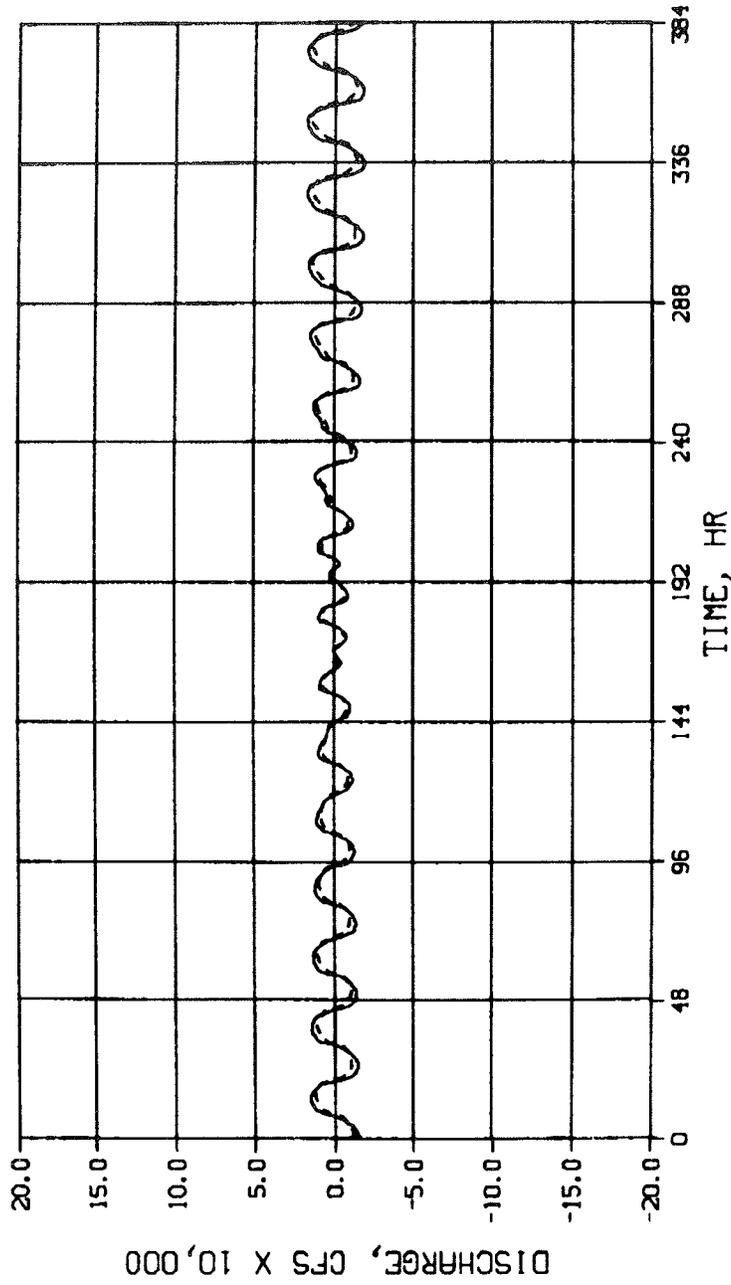
PLAN VS BASE

TEST CONDITIONS

16 DAY RUN
OCT 21-NOV 6, 1978

LEGEND
- - - - - BASE CONDITIONS
- - - - - WITH STRUCTURE

SEABROOK CANAL



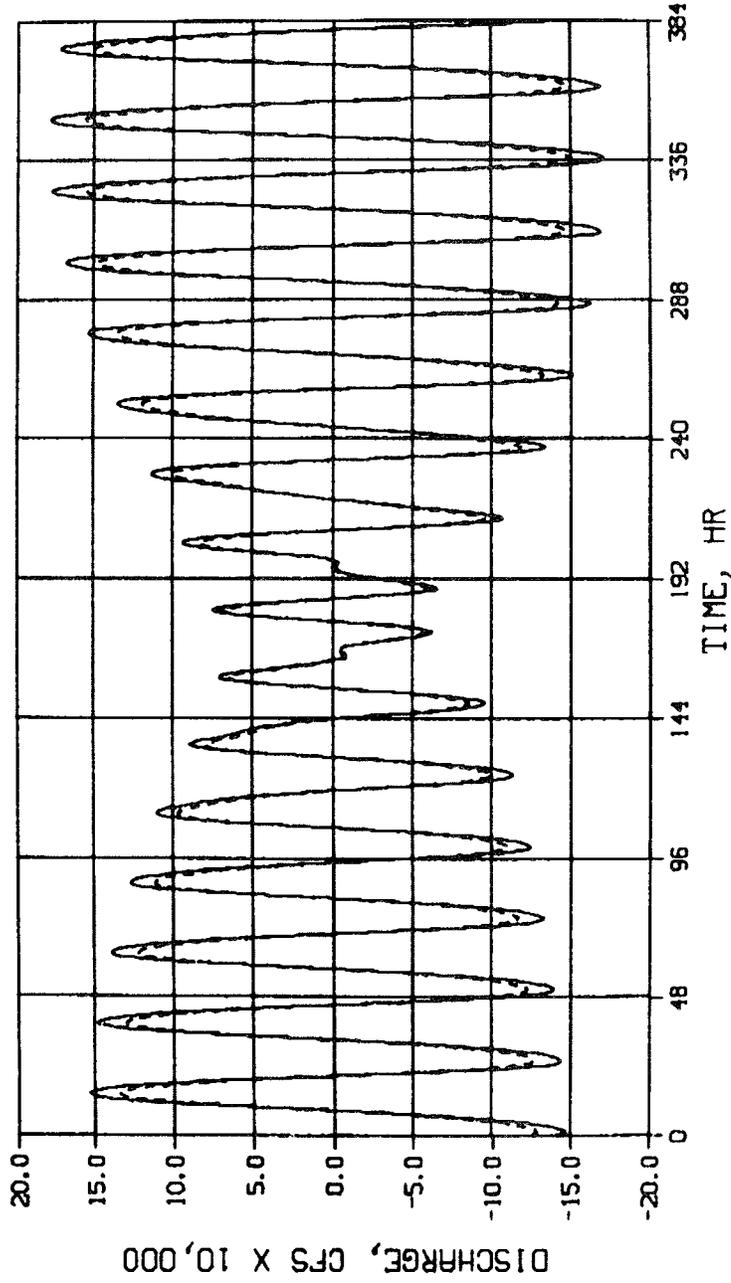
PLAN VS BASE

TEST CONDITIONS

16 DAY RUN
OCT 21-NOV 6, 1978

LEGEND
- - - - - WITH STRUCTURE
————— BASE CONDITIONS

LAKE PONTCHARTRAIN

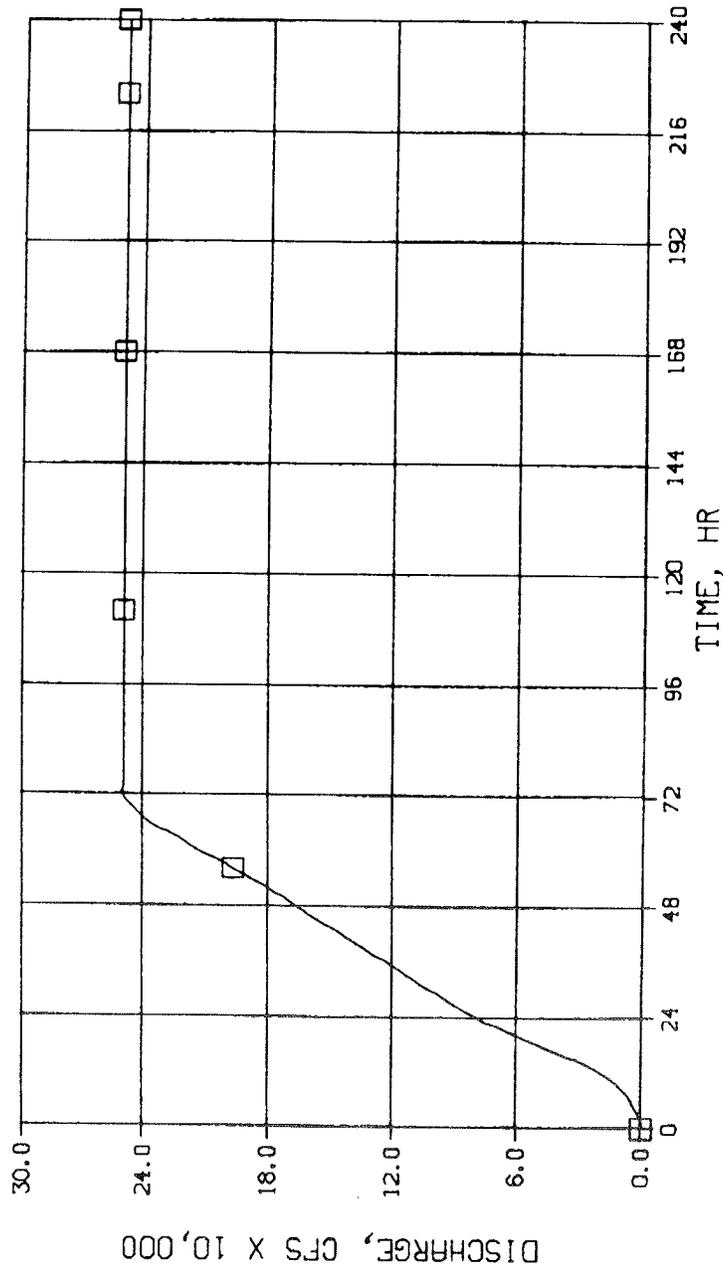


PLAN VS BASE

TEST CONDITIONS

16 DAY RUN
OCT 21-NOV 6, 1978

LEGEND
--- BASE CONDITIONS
- - - WITH STRUCTURE

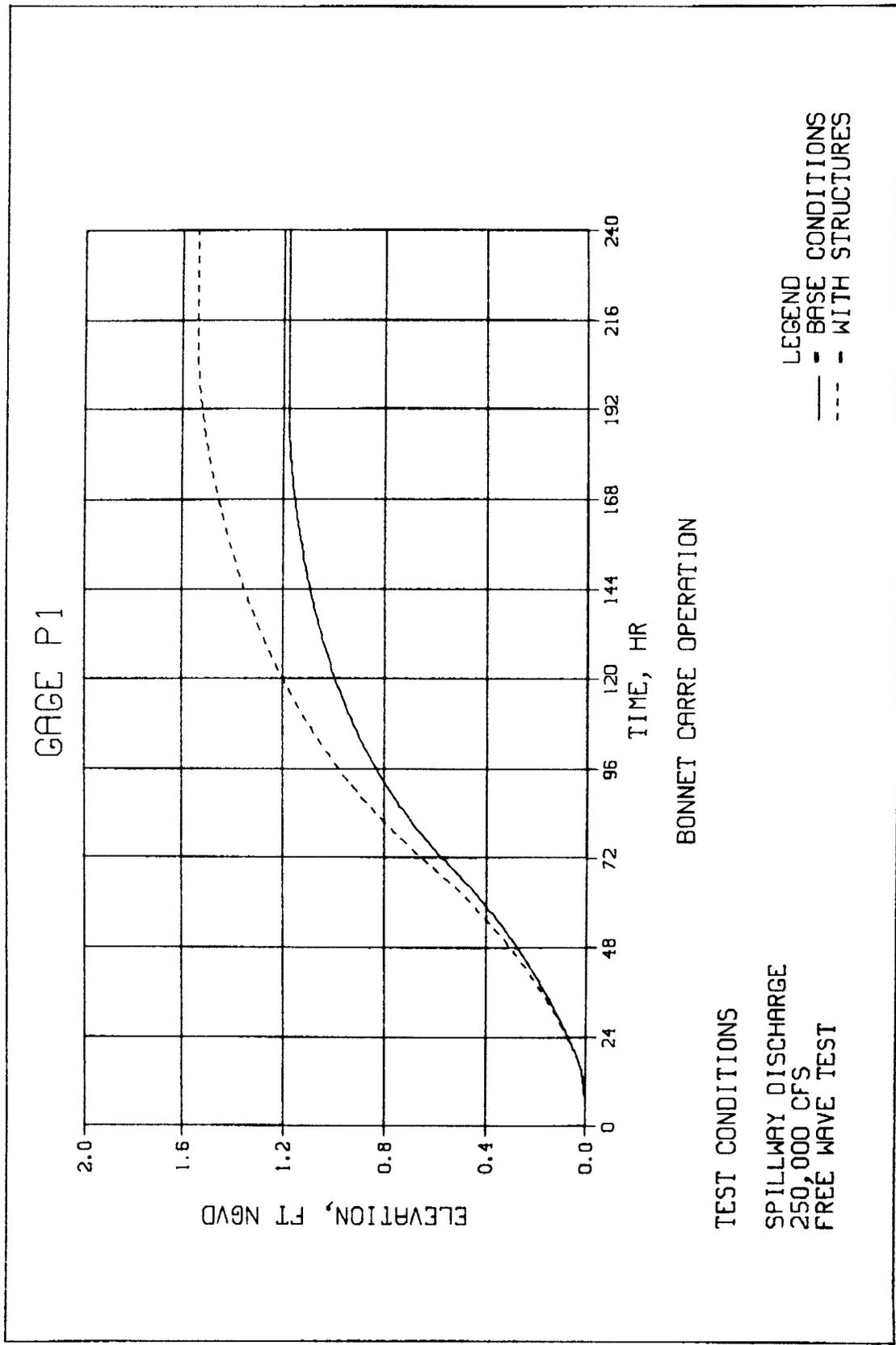


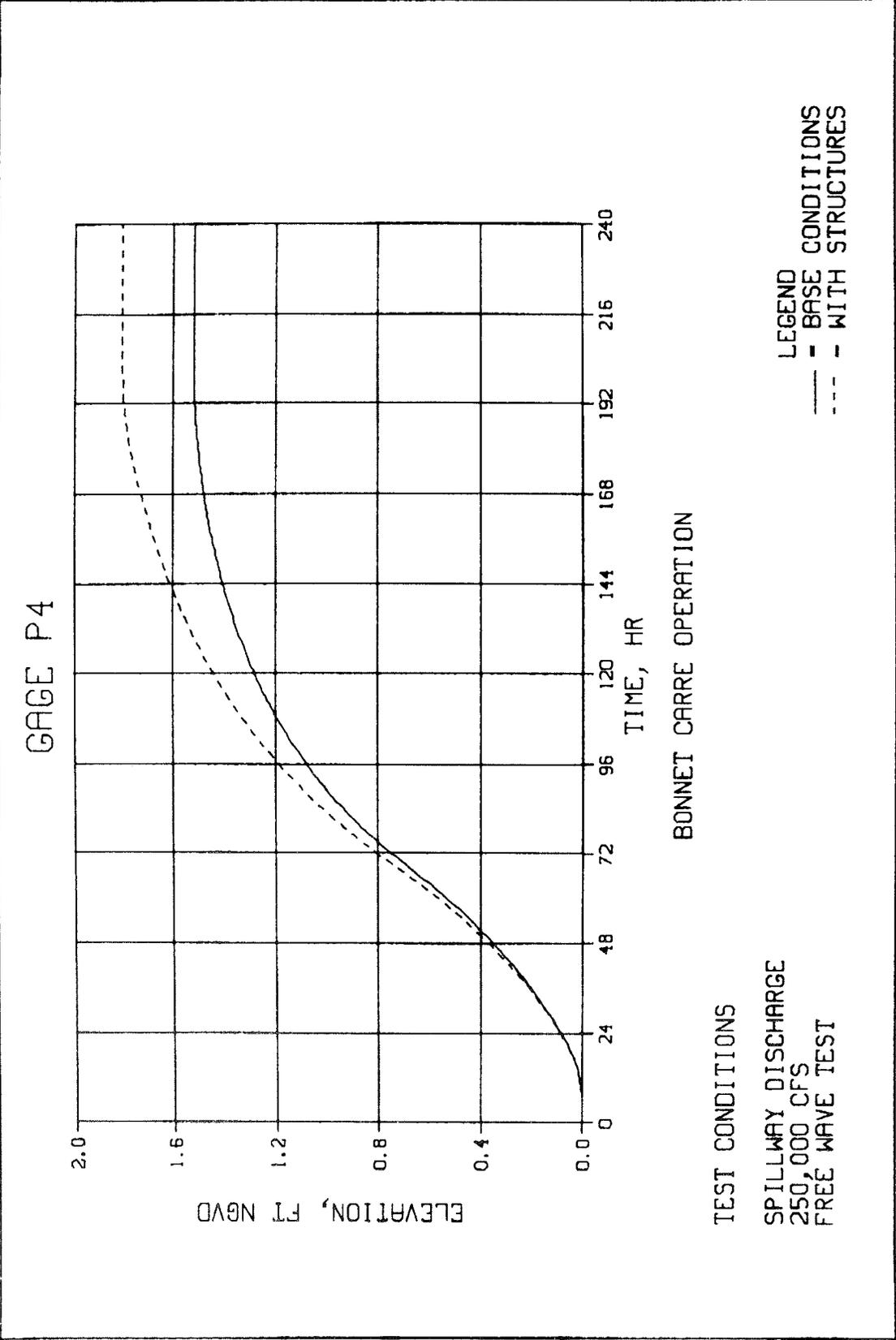
BONNET CARRE OPERATION

TEST CONDITIONS

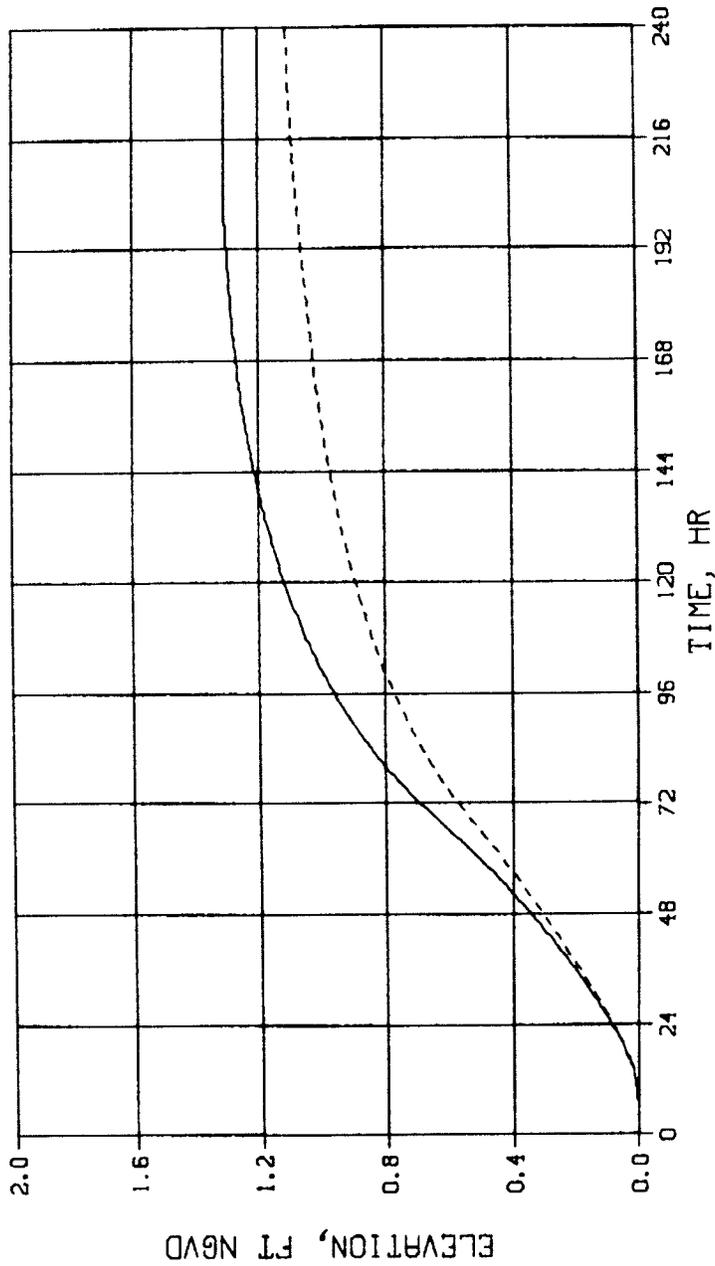
FREE WAVE TEST

LEGEND
 □ - DISCHARGE





GAGE P6



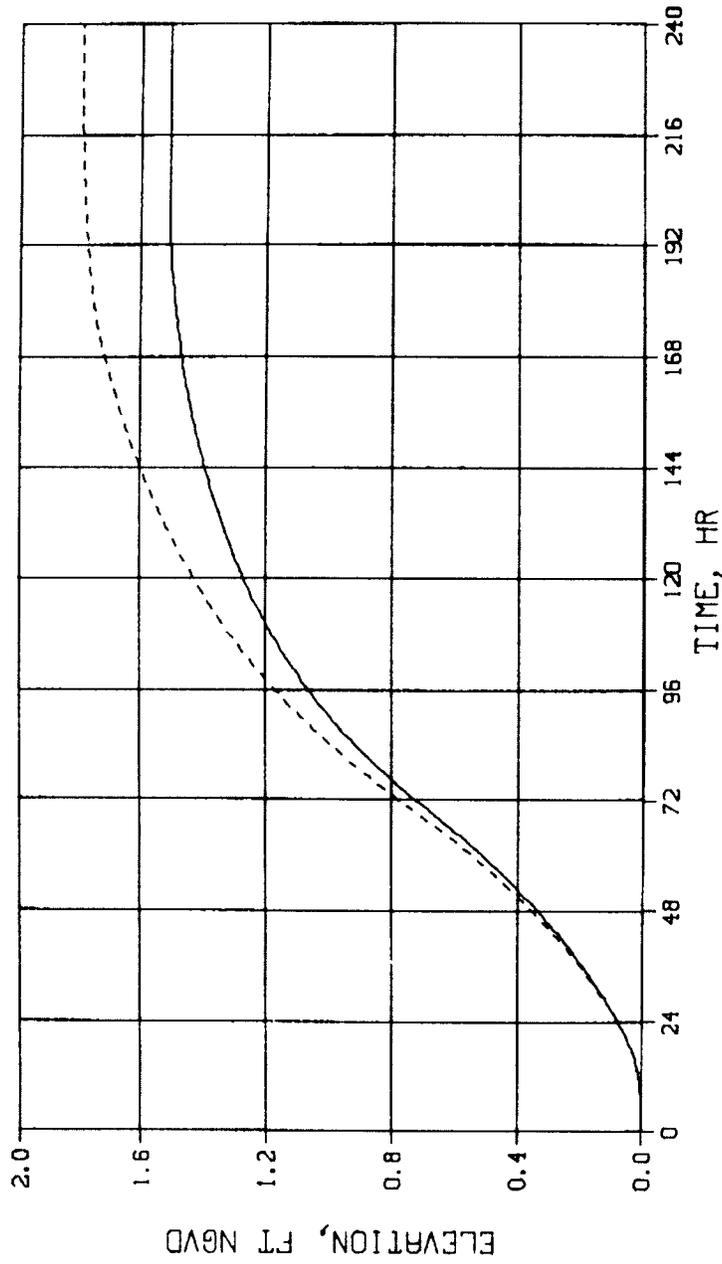
BONNET CARRE OPERATION

TEST CONDITIONS

SPILLWAY DISCHARGE
250,000 CFS
FREE WAVE TEST

LEGEND
— BASE CONDITIONS
- - - WITH STRUCTURES

GAGE P9

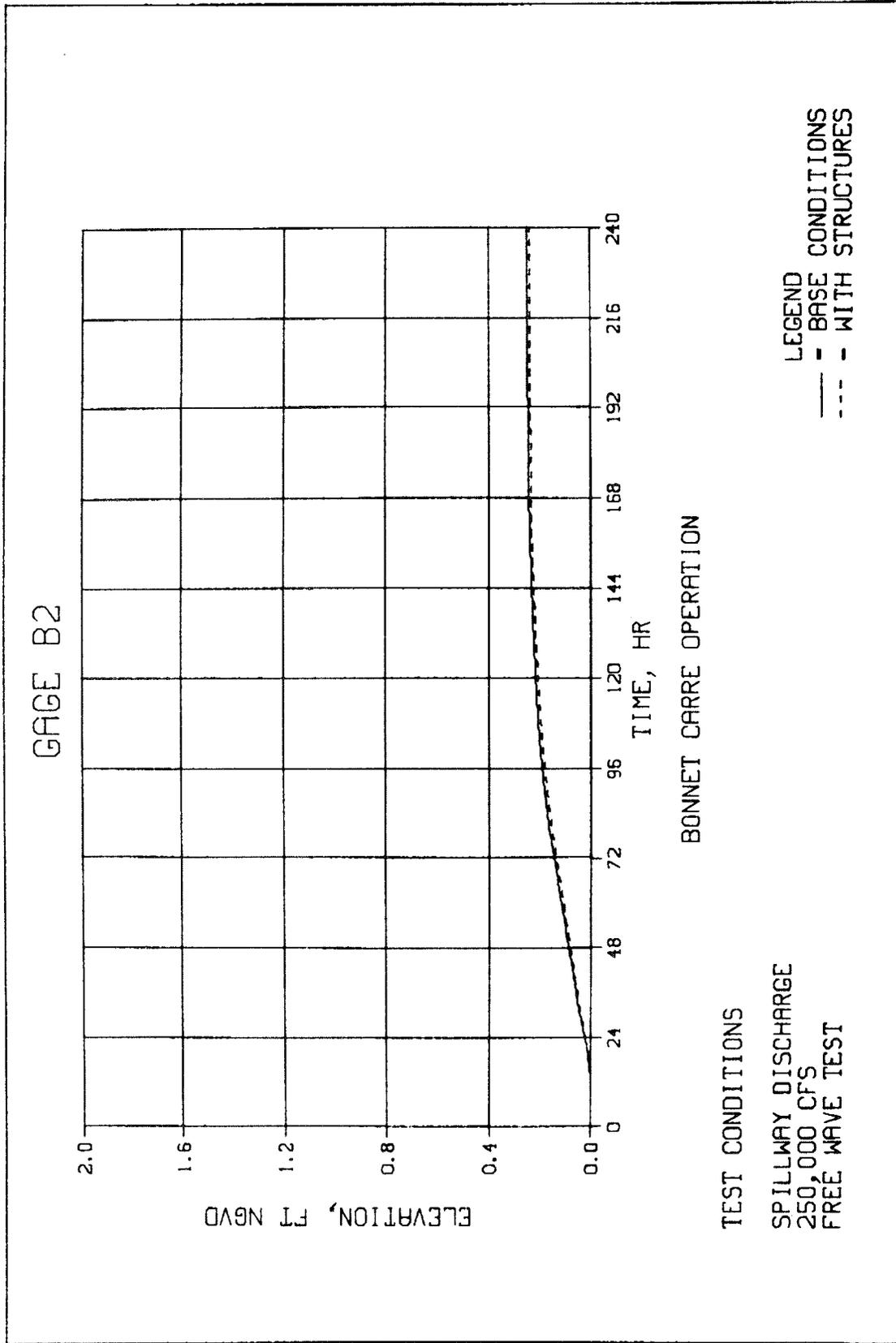


BONNET CARRE OPERATION

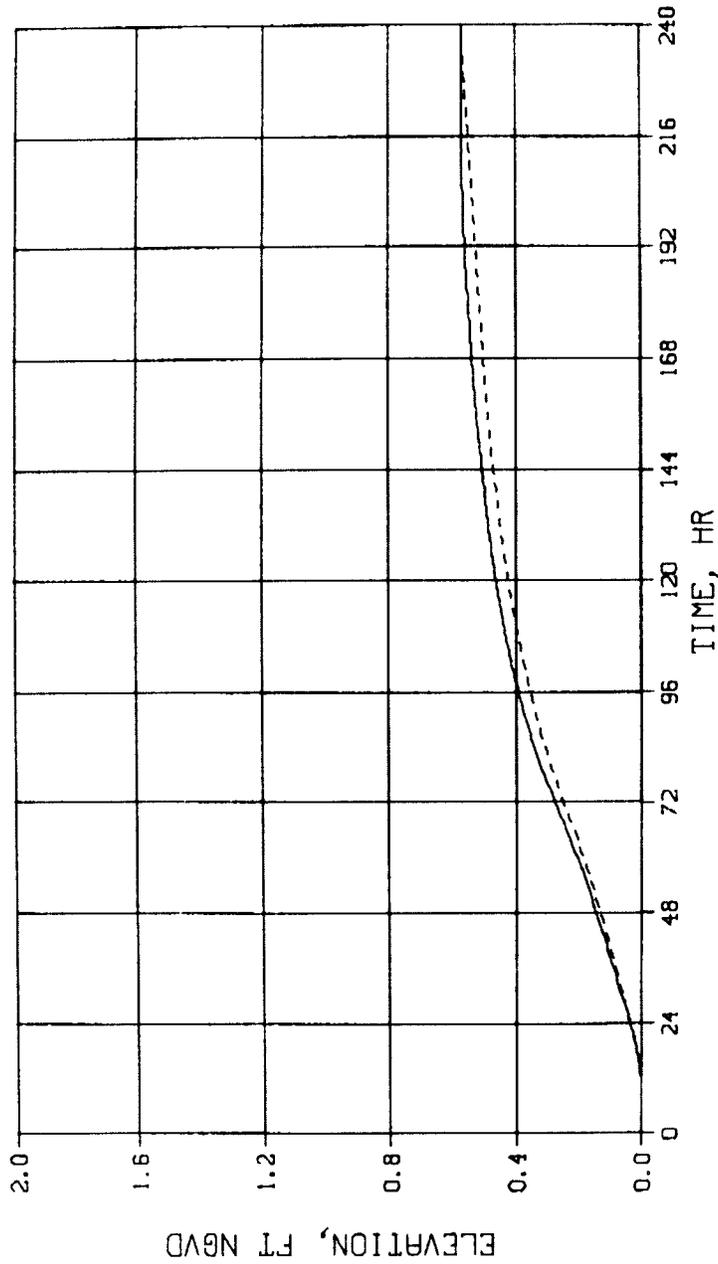
TEST CONDITIONS

SPILLWAY DISCHARGE
250,000 CFS
FREE WAVE TEST

LEGEND
— BASE CONDITIONS
--- WITH STRUCTURES



GAGE B4



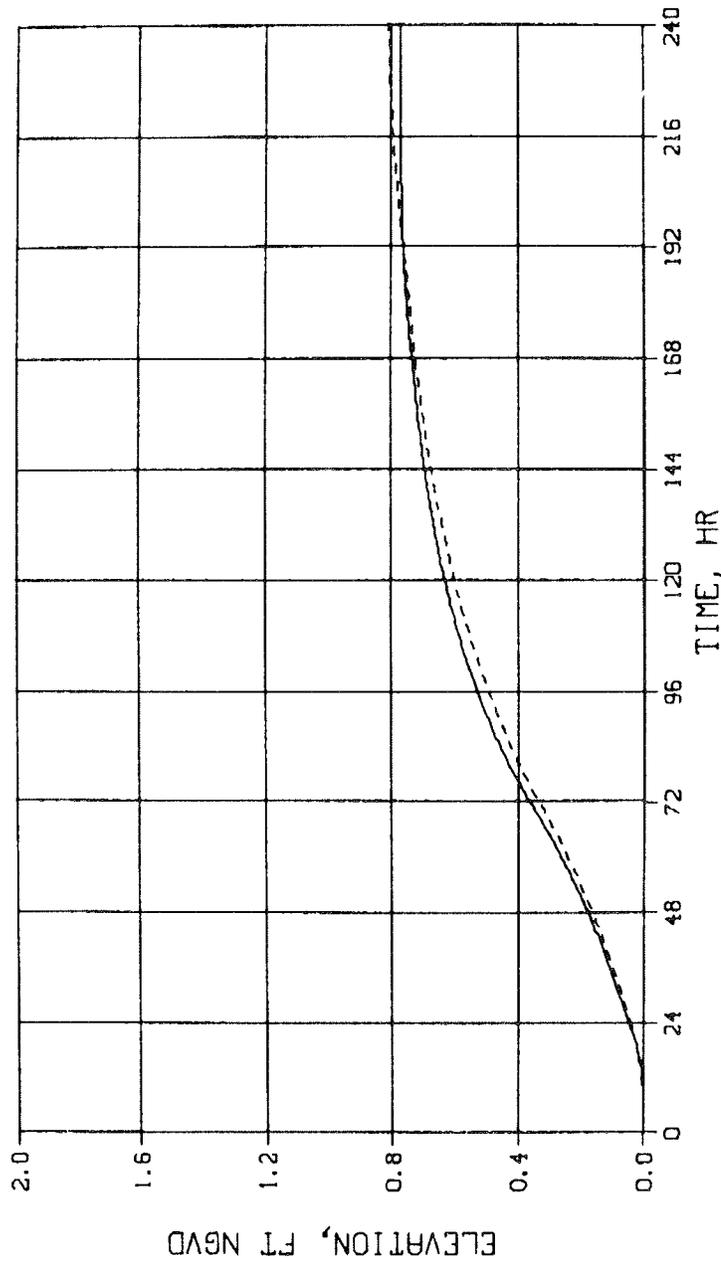
BONNET CARRE OPERATION

TEST CONDITIONS

SPILLWAY DISCHARGE
250,000 CFS
FREE WAVE TEST

LEGEND
- - - WITH STRUCTURES
— BASE CONDITIONS

GAGE R1

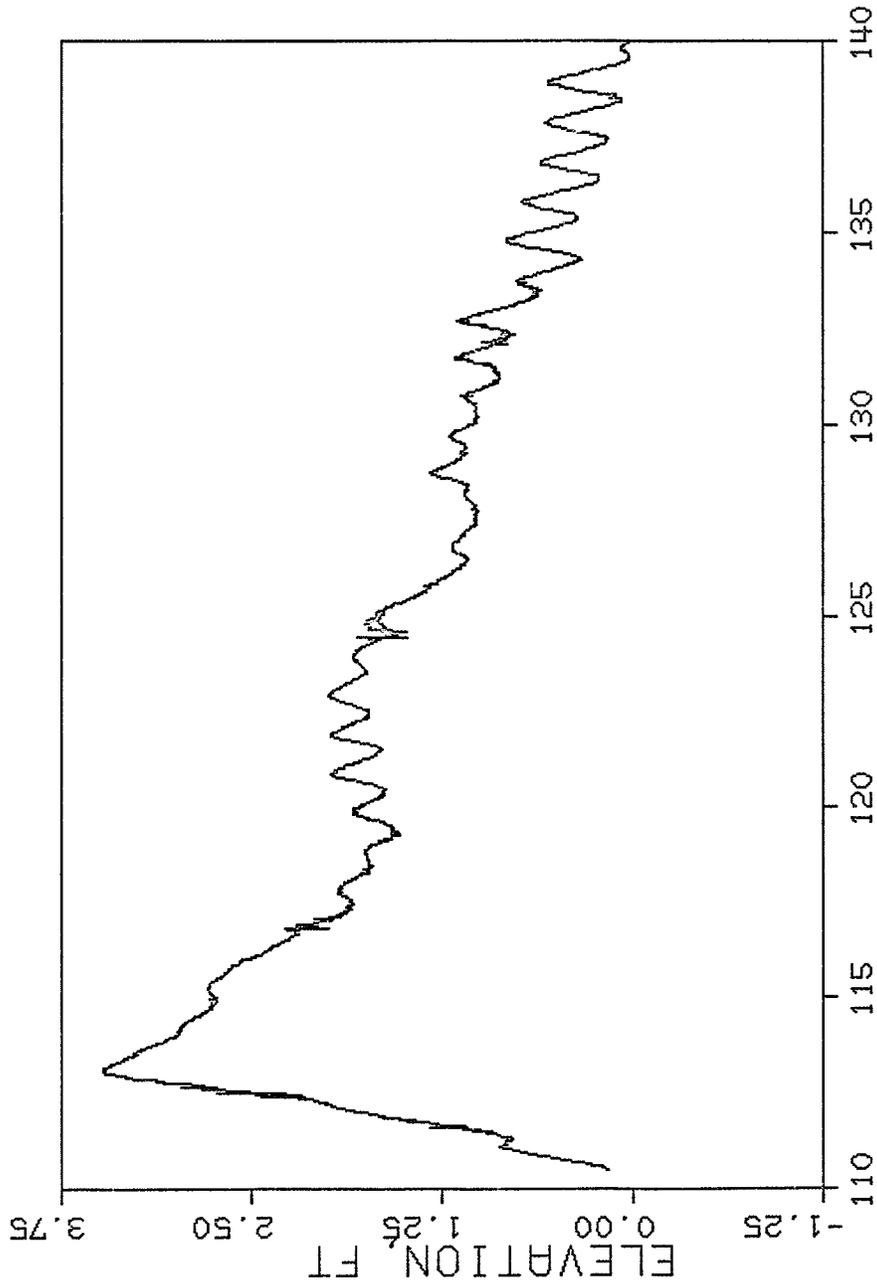


BONNET CARRE OPERATION

TEST CONDITIONS

SPILLWAY DISCHARGE
250,000 CFS
FREE WAVE TEST

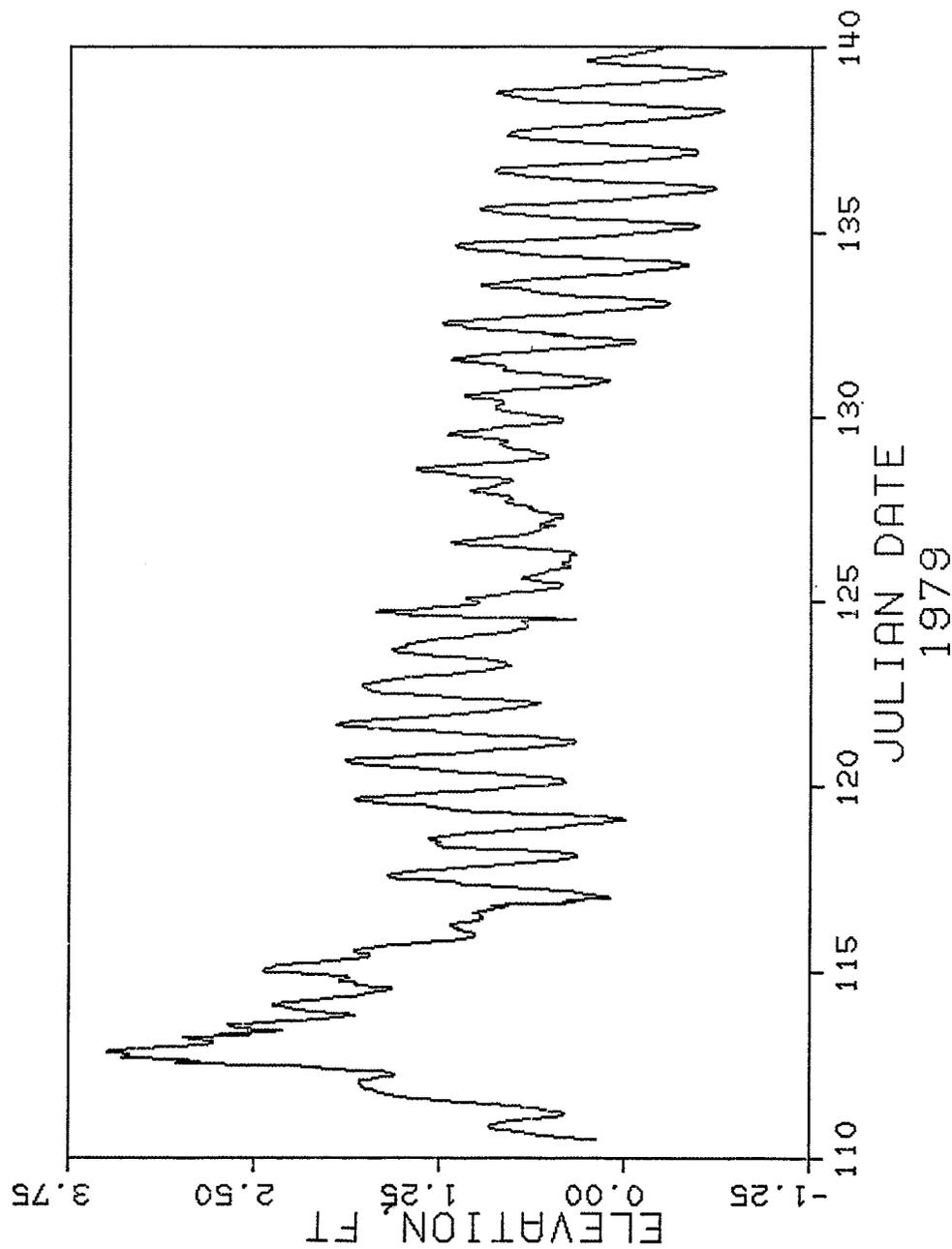
LEGEND
— BASE CONDITIONS
- - - WITH STRUCTURES



JULIAN DATE
1979

OBSERVED TIDE ELEVATION DATA
GAGE P-4
DAY 110 TO DAY 140 1979

NOTE: ZERO ELEVATION REFERENCE OF THE
PROTOTYPE DATA IS THE MEAN OF THE
RECORD.



NOTE: ZERO ELEVATION REFERENCE OF THE PROTOTYPE DATA IS THE MEAN OF THE RECORD.

OBSERVED TIDE ELEVATION DATA
GAGE B-4
DAY 110 TO DAY 140 1979

APPENDIX A: SEABROOK LOCK/STRUCTURE TREATMENT

1. The subsystem of the Inner Harbor Navigation Canal (IHNC), Lake Pontchartrain (in the vicinity of Lakefront Airport), the Mississippi River Gulf Outlet (MR-GO), and the Gulf Intracoastal Waterway (GIWW) form a highly complex lake-channel waterway, particularly complex for either numerical or physical modeling. The set of prototype tidal elevation and current gages deployed for the field study was a valuable contribution to our knowledge of the IHNC/MR-GO subsystem; however, due to the complexity of the system, these data (or perhaps any other set of field data) were not sufficient to completely quantify the hydrodynamics of the system. This fact increased the difficulty in establishing an appropriate boundary condition within the IHNC or MR-GO for the lock/structure in place. Prototype gages placed within the MR-GO were damaged (vandalized) and inoperative. Data obtained from a strip chart gage at Breton Island (for a period prior to the October 1978-October 1979 collection effort) appeared to be inconsistent with WES data. Thus the approach opted for involved development of a boundary condition within the IHNC or MR-GO that would allow the filtering out or separation of incoming wave trains from outgoing wave trains in any wave record. A number of possible procedures were tested and found unacceptable for varying reasons. Usually, the difference formulation was inconsistent with the WIFM formulation, or unstable, or the boundary procedure simply would not work properly. Finally, a variation of the approach given by Orlanski* proved effective in eliminating reflection of energy back into the model region and this approach was found capable of rendering an accurate description of the hydrodynamics.

2. The suggested approach involves use of the scalar wave equation or Sommerfeld radiation condition

$$\frac{\partial \phi}{\partial t} + c \frac{\partial \phi}{\partial x} = 0 \quad (A1)$$

* See references at end of main text.

where ϕ is the surface elevation or fluid velocity and c is the phase velocity of the wave. What is required is an open-boundary condition that allows phenomena generated in the region of interest to pass through the boundary without undergoing significant distortion and without influencing the interior solution. Let Figure A1 describe the subsystem to be modeled. P6 is the location of the WES tide gage for

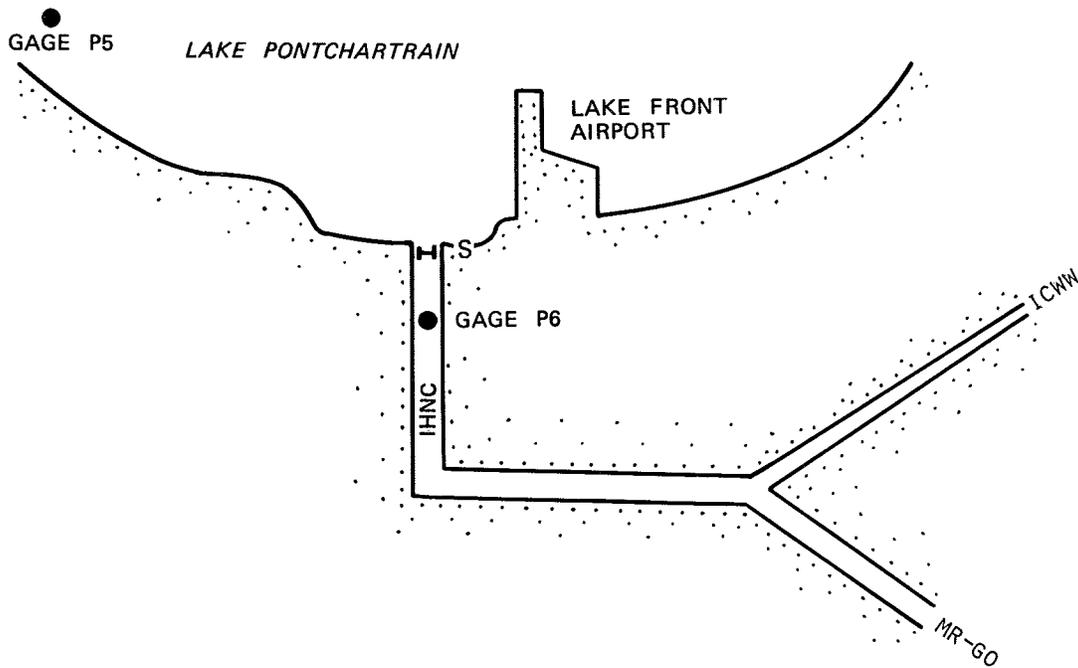


Figure A1. Vicinity map for Seabrook Canal sectional model

which observed data are known and S is the location of the proposed lock structure. Data from WES tide gage P5 are used for forcing the lake open boundary. If $a = f(x+ct)$ is the wave coming from GIWW/MR-GO and $b = f(x-ct)$ is the wave coming from the lake then the observed elevation at P6 is

$$\eta_{P6} = (a + b)_{P6} \quad (A2)$$

Substituting the value of η at P6 (Equation A2) for ϕ in Equation A1 and evaluating the expression on the left we obtain

$$\frac{\partial a}{\partial t} + c \frac{\partial a}{\partial x} + \frac{\partial b}{\partial t} + c \frac{\partial b}{\partial x} = ca' + ca' - cb' + cb' = 2ca'$$

Let $I = f(t)$ be the elevation of the incoming wave at P6. Since $a(x + ct)|_{P6} = I(t)$ then $ca' = I'$. Thus

$$\frac{\partial \eta}{\partial t} + c \frac{\partial \eta}{\partial x} \Big|_{P6} = 2I' \quad (A3)$$

This formulation permits the outgoing wave, b , to pass through the boundary at P6. What is needed at P6 is the derivative of the incident wave, I' . Since η_{P6} (containing both incoming and outgoing waves) is known, the model can be run for existing conditions using the tide at P6 for a boundary condition. I' can be determined from Equation A3 using the model solution. Having found I' , Equation A3 can be solved implicitly in conjunction with equations for the interior solution (full equations of motion) and consequently provide a boundary condition at P6. The structure to be placed at S will not substantially affect the tide in Lake Pontchartrain nor will it affect the incoming wave from the gulf/Lake Borgne. The lock/structure will only force a different combination of incoming and outgoing waves within the IHNC. Thus, the same I' with Equation A3 can be used to provide a boundary condition for the lock/structure in place.

3. The finite difference representation of Equation A3 must be consistent with the formulation used in WIFM. Since the IHNC is represented by a one-dimensional channel in the vertical grid direction, only the x-sweep in the WIFM algorithm is affected. Figure A2 represents the grid cell structure in the IHNC.

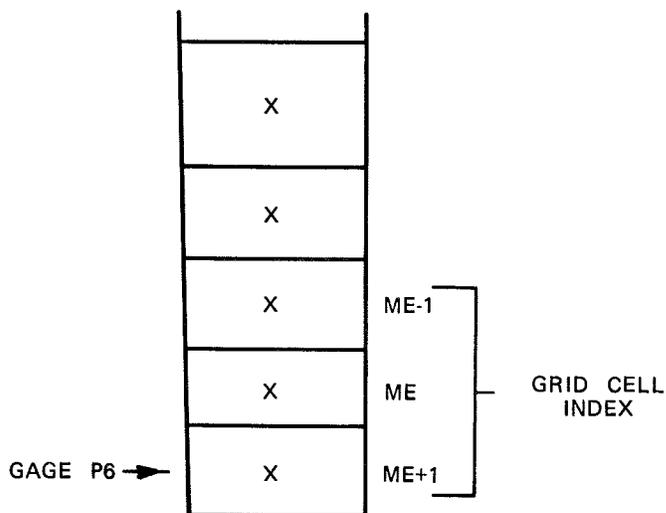


Figure A2. Grid cell definition at the canal open boundary

Equation A3 in difference form for the x-sweep is

$$\left(\frac{\partial \eta}{\partial t}\right)_{ME+1/2}^k + c^k \left(\frac{\partial \eta}{\partial x}\right)_{ME+1/2}^k = 2(I')_{ME+1/2}^k \quad (A4)$$

All derivative differences must be centered in both time and space around $k\Delta t$ and $(ME+1/2)\Delta x$.

Equation A4 can be expanded to give

$$\frac{\eta_{ME+1}^{k+1} + \eta_{ME}^{k+1} - \eta_{ME+1}^{k-1} - \eta_{ME}^{k-1}}{4\Delta t} + \frac{c^k}{2\mu} \frac{\Delta \alpha}{ME+1/2} \left[\eta_{ME+1}^{k+1} + \eta_{ME+1}^{k-1} - \eta_{ME}^{k+1} - \eta_{ME}^{k-1} \right] = 2(I')_{ME+1/2}^k \quad (A5)$$

where

$$c_{ME+1/2}^k = \left[\frac{g}{2} (\eta_{ME+1}^k + \eta_{ME}^k - h_{ME+1} - h_{ME})^{1/2} \right]$$

If
$$z^k = \frac{2\Delta t c_{ME+1/2}^k}{\mu \frac{\Delta \alpha}{ME+1/2}}$$

then Equation A5 can be rewritten to read

$$(1-z^k) \eta_{ME}^{k+1} + (1+z^k) \eta_{ME+1}^{k+1} = F(\eta^{k-1})$$

where
$$F(\eta^{k-1}) = 8\Delta t (I')^k_{ME+1/2} + \eta_{ME+1}^{k-1} + \eta_{ME}^{k-1} - z^k (\eta_{ME+1}^{k-1} - \eta_{ME}^{k-1})$$

or

$$\eta_{ME+1}^{k+1} = \frac{F(\eta^{k-1}) - (1-z^k) \eta_{ME}^{k+1}}{1+z^k} \quad (A6)$$

4. The last interior equation in the WIFM formulation is

$$-a_{ME} \eta_{ME}^{k+1} + a_{ME+1/2} u_{ME+1/2}^{k+1} + a_{ME+1} \eta_{ME+1}^{k+1} = B_{ME+1/2}^k \quad (A7)$$

Substituting Equation A6 into Equation A7 we get

$$\begin{aligned} & -\left(a_{ME} + \frac{(1-z^k)}{(1+z^k)} a_{ME+1} \right) \eta_{ME}^{k+1} + a_{ME+1/2} u_{ME+1/2}^{k+1} \\ & = B_{ME+1/2}^k - \frac{a_{ME+1} F(\eta^{k-1})}{1+z^k} \end{aligned} \quad (A8)$$

Since $a_{ME} = a_{ME+1} = \frac{\Delta t g}{\mu \Delta \alpha}$, Equation A8 becomes

$$-\frac{2a}{1+z^k} \eta_{ME}^{k+1} + \frac{a}{ME+1/2} u_{ME+1/2}^{k+1} = B_{ME+1/2}^k - \frac{a}{1+z^k} \frac{F(\eta_{k-1})}{ME} \quad (A9)$$

5. To implement Equation A9 (as a boundary condition at ME+1/2) only a few recursion coefficients need be changed. Using WIFM notation, the recursion coefficient R in the WIFM solution algorithm (see documentation of WIFM formulation (Butler, in preparation)) at ME becomes

$$R_{ME} = 0$$

Thus

$$u_{ME+1/2}^{k+1} = S_{ME} \quad (A10)$$

where

$$S_{ME} = \frac{B_{ME} - \frac{a}{1+z^k} F(\eta_{k-1}) + \frac{2a}{1+z^k} \frac{Q}{ME}}{\frac{a}{ME} + \frac{2a}{1+z^k} \frac{P}{ME}} \quad (A11)$$

Having solved the interior region for all (η, u) , Equation A6 can be evaluated for η_{ME+1}

6. To apply this condition for the Seabrook lock/structure, WIFM is run for the lake/channel subsystem using the tide at P6 for the channel open-boundary condition. Equation A5 is used to determine I' at P6 and the results are saved on files. WIFM is rerun implementing Equation A6 for the channel boundary condition. This run demonstrates

that the interior solution can be generated from the separation/radiation (S/R) boundary condition given by Equation A6. The lock/structure is placed in the model and tested again using Equation A6 (and the I' file) for a boundary condition at P6. The impact of the lock/structure is determined by comparing elevation and discharge changes relative to existing conditions.

7. Actual implementation of the S/R boundary condition for the existing Lake Pontchartrain tidal prism grid required additional efforts in overcoming obstacles to obtaining a solution to the problem. The coarseness of the grid did not permit the boundary condition to be applied exactly at P6 (cell 9,16) in the sectional model. The sectional model was driven with the P6 reconstructed observed tide at cell (9,18). The derivative I' is computed and saved on file. Because of the method used in modeling the Seabrook Bridge (existing conditions) and the lock/structure (plan conditions), the derivative required numerical smoothing to eliminate sharp peaks. The smoothing procedure preserved the character of I'. After extensive testing it was found that a central smoothing formula (Hildebrand 1956) of degree 3 over a subrange of 2M + 1 points (for M = 6) was effective. The required centered formula for $y = f(t)$ can be written in general as

$$y_o = \frac{-3}{(4M^2 - 1)(2M + 3)} \sum_{i=M}^M [(3M^2 + 3M - 1) - 5i^2] f_i \quad (A12)$$

The particular formula used (M = 6) was

$$y_o = \frac{1}{143} [-11f_{-6} + 9f_{-4} + 16f_{-3} + 21f_{-2} + 24f_{-1} + 25f_o + 24f_1 + 21f_2 + 16f_3 + 9f_4 - 11f_6] \quad (A13)$$

Equation A13 was applied to I' twice with a spacing of 10 time-steps (10 min) between values. Thus, the smoothing filter extended over a 2-hr subrange.

8. The Seabrook Canal sectional model was previously calibrated and verified to simulate steady-state flow conditions generated in an undistorted physical model of the subject area. Frictional coefficients associated with submerged barriers representing the canal constriction at the lake entrance and the lock/structure for various operating conditions were determined. The model was then run in a dynamic mode to develop an S/R boundary condition for the tidal events to be investigated in the area tidal prism model. The model was applied as described herein for O_1 , mean, spring, and neap tides. The O_1 tide was used to calibrate the tidal prism model. The other tidal events provide model verification as well as base conditions for assessing impact of the barrier protection plan. Figures A3 and A4 depict a comparison of analyzed prototype data with sectional model results in the IHNC using the S/R boundary condition. Figures A5-A8 described the impact of the lock/structure (with the lock and all structure gates open) on the various tidal events to be simulated in the tidal prism model. A small change in canal discharge is noted with a corresponding large change in tidal amplitude. This is consistent with the IHNC-lake stage versus discharge results developed in the physical model and duplicated in the steady-state sectional model. As expected, the impact is significantly less during a neap tide event.

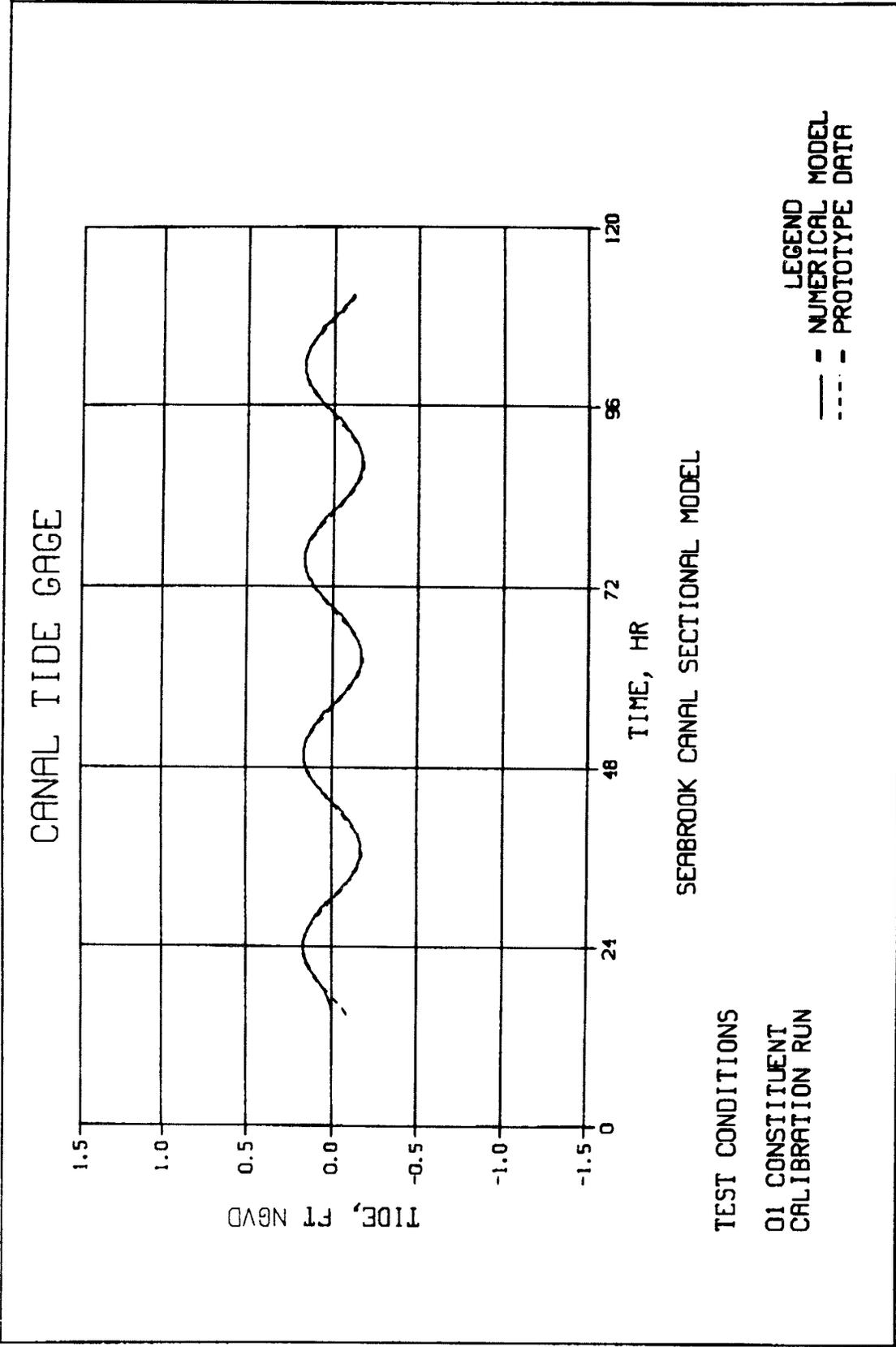


Figure A3. Comparison of analyzed prototype data (O1 constituent) with computational sectional model results at gage P6

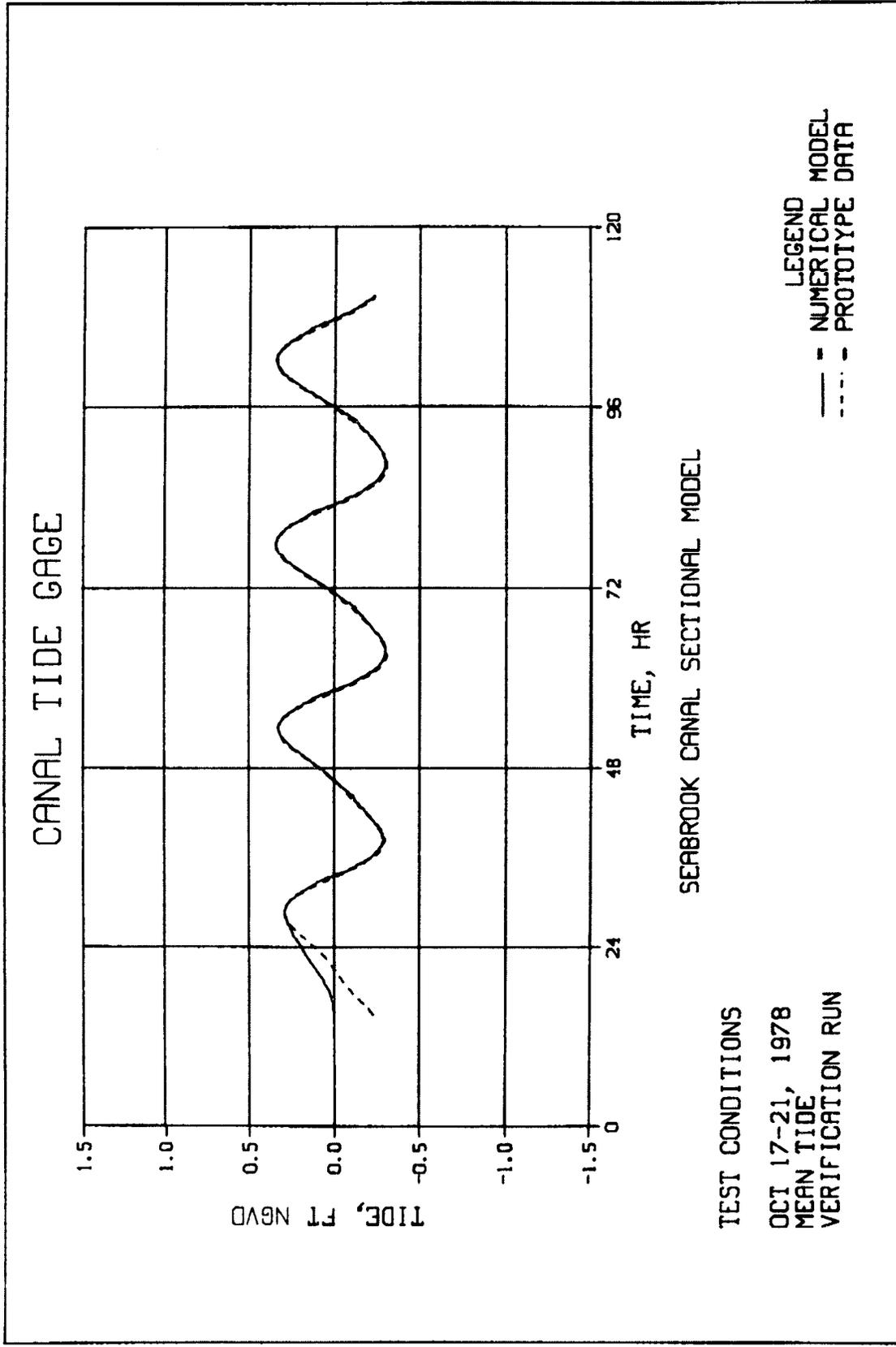


Figure A4. Comparison of analyzed prototype data (9 constituents, mean tide) with computational sectional model results at gage P6

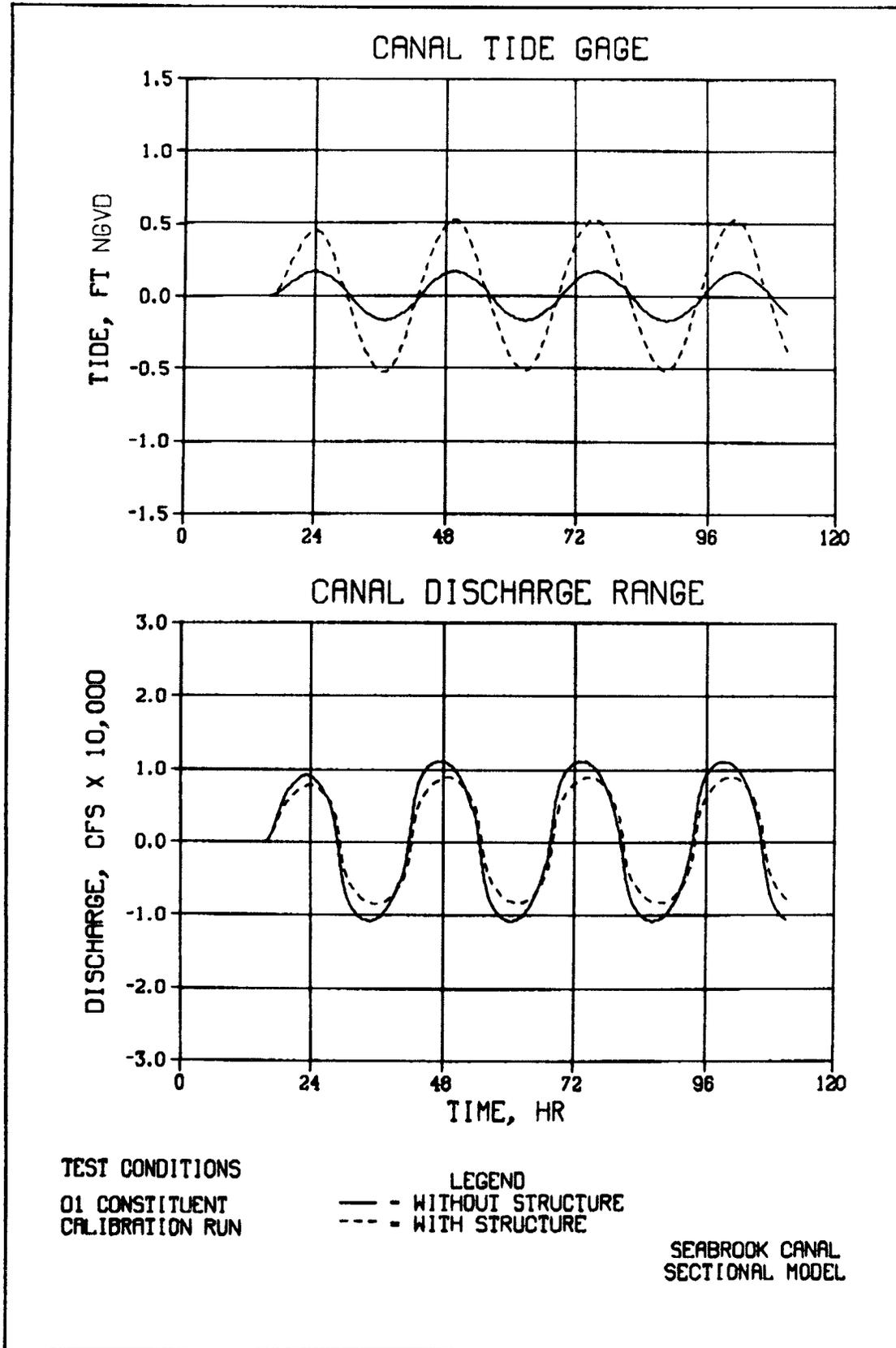


Figure A5. Impact of the Seabrook lock/structure system (all gates open) on the tide and discharge in the IHNC for a O_1 constituent mean tide

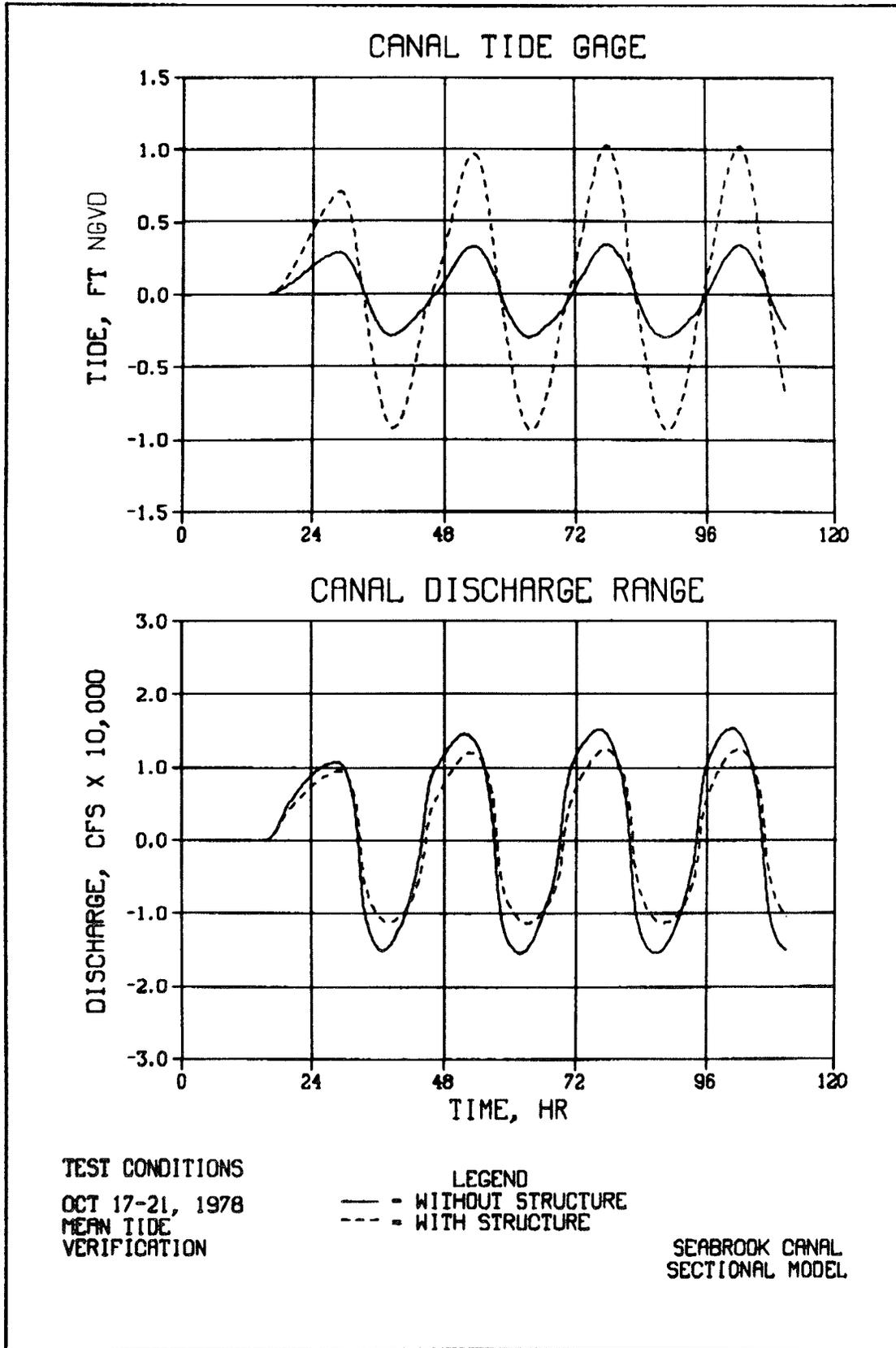


Figure A6. Impact of the Seabrook lock/structure system (all gates open) on the tide and discharge in the IHNC for a 9 constituent mean tide

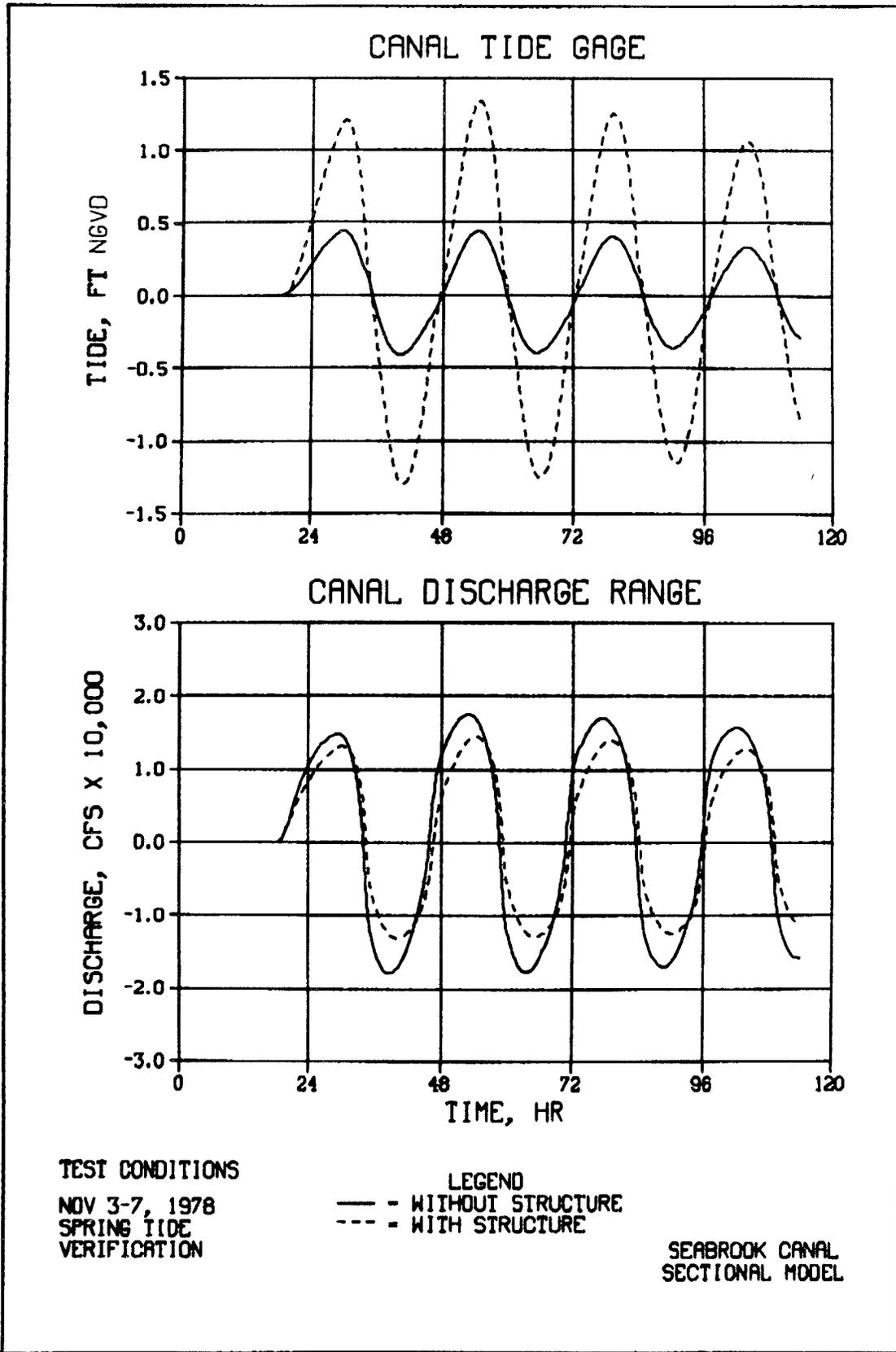


Figure A7. Impact of the Seabrook lock/structure system (all gates open) on the tide and discharge in the IHNC for a 9 constituent spring tide

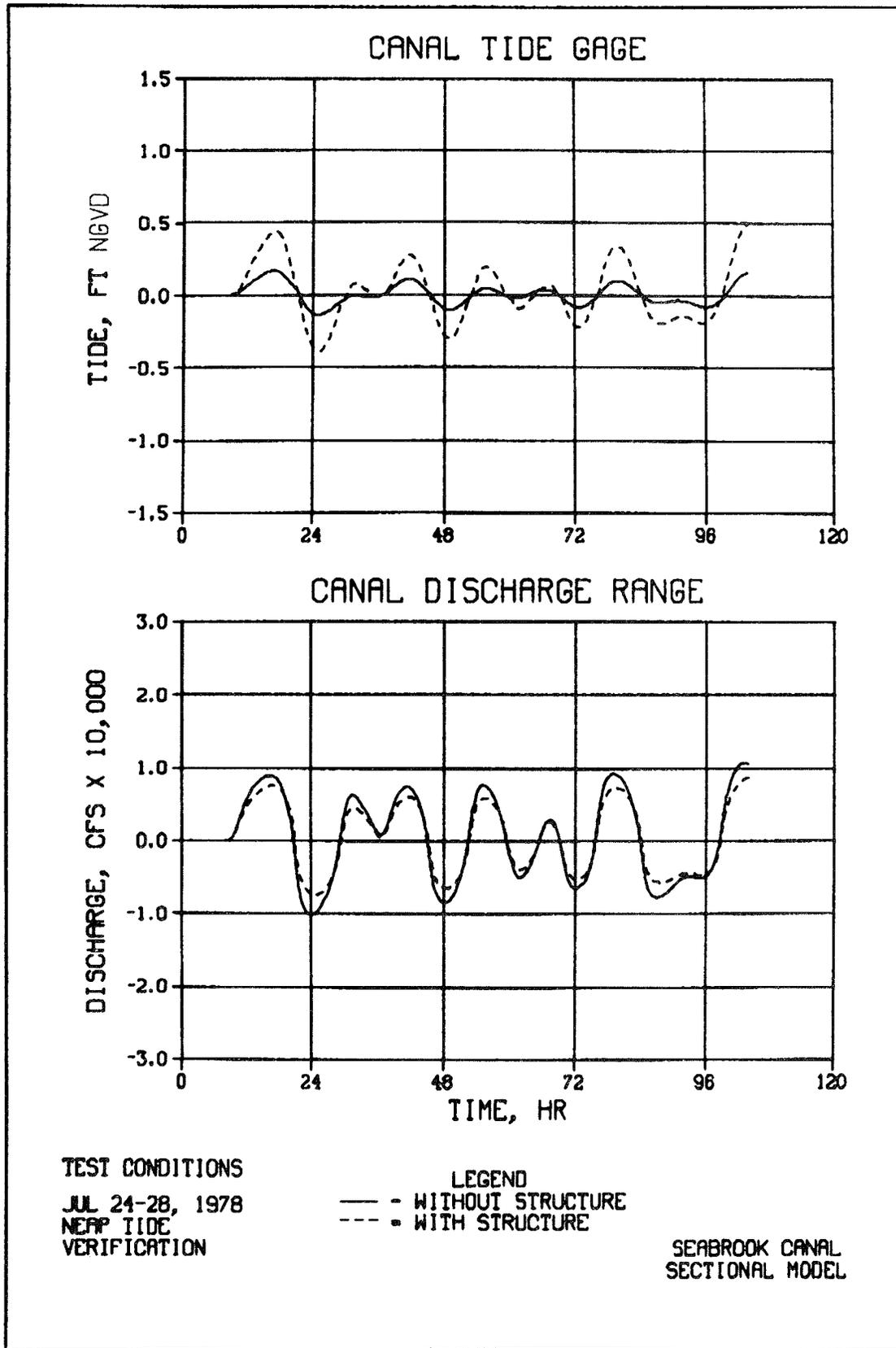


Figure A8. Impact of the Seabrook lock/structure system (all gates open) on the tide and discharge in the IHNC for a 9 constituent neap tide

APPENDIX B: CONSULTANTS' REVIEWS

1. A panel of five consultants was formed at the onset of the Lake Pontchartrain study. The group included Professor Robert O. Reid, Texas A&M University; Dr. D. W. Pritchard, State University of New York at Stony Brook, Long Island; Dr. Bernard Le Mehaute, University of Miami; Dr. L. Eugene Cronin, Chesapeake Bay Institute; and Dr. Shaw L. Yu, University of Virginia. This group of eminent scientists was tasked to assist in the planning of the subject study, evaluate results of each phase of the investigation, and to guide and concur in findings of the study.

2. This appendix includes the verbatim reviews of the subject report from each consultant. Changes were made to report paragraphs 8, 10, 19, 31, 35, 40, 44, 53, and 57 to reflect suggestions made by the reviewers.

Review of Report 3 of the Lake Pontchartrain and Vicinity
Hurricane Protection Plan on the Numerical Model Investi-
gation of Plan Impact on the Tidal Prism of Lake Pontchar-
train

Robert O. Reid, October 31, 1982

General remarks.

Overall, the model performance is quite reasonable in terms of its method of calibration, the verification and the use of the model in assessing the impact of the control structures on the tidal response within Lake Pontchartrain. The model is an updated version of an existing WIFM model which has been thoroughly tested in many other applications. The new version has a revised capability for allowance of convection of momentum and lateral diffusion of momentum via an eddy viscosity closure parameterization. In the comments below I address certain specific points and offer some suggestions for possible clarification, amplification and enhancement of the final version of the report. The more substantive comments have to do with the method of calibration and are intended mainly for consideration in future studies of tidal response of a basin with constricted passageways to the open sea, as in the present study. All in all, the study has been carefully carried out, the model appears sound, and the communication of the study via the draft version of the report is adequate but there is room for improvement by way of some amplification. Hopefully the comments which follow will be useful in this connection. Like any manuscript submitted to a journal for review, I view my task as that of offering a constructive critique.

Stability and Non-linear Aspects of Model

The model is known to be stable in the linear mode. The use of the three level time centered scheme for rendering the advection of momentum terms is clearly the right step. The rendition spatially is in the form velocity times velocity gradient in an equation for the time rate of change of velocity. The reviewer has had experience with advective simulation in explicit time marching schemes and finds that the use of the divergence form of advection, which occurs with the volume flux form of the momentum equation, is superior to the alternative mentioned above. One of the attributes of the divergence form of the momentum advection is the telescoping property which it should and does possess.

Since there does appear to be some residual long term stability problems with the non-linear version of the model, some consideration might be given in later studies to the

use of the divergence form of the momentum equations. This form is employed in most long term time marching calculations in numerical weather prediction and global ocean circulation models in order to achieve stability and accuracy.

With regard to the present report, some additional comments seem to be in order which address the above point. Specifically, these alternate methods should be recognized and some rationale given as to the choice of options selected for the present model methodology. A saving point which of course could be stressed is that the results for the tidal prism response is really not too sensitive to the presence or absence of the advection of momentum terms, as shown by the inter-comparison of four day runs with and without advection.

Lateral Eddy Viscosity

An important aspect of modelling of advection of momentum is the inclusion of lateral viscosity in order to assist in stabilizing the numerical solution. This is recognized in the report and provided for in the WIFM model. The reason for the necessity of including the lateral eddy viscosity terms is of course to provide a sink for the transfer of energy which occurs, due to the non-linear advection terms, across the spectrum from low to high wave number. Without the eddy viscosity, the energy would accumulate at the highest wave number (shortest scale) and appear as an unstable amplitude growth at scales comparable to the grid size. The proper parameterization of the subgrid size viscous effect should take the grid size into account. The eddy viscosity used in the model under consideration is that suggested by Vreugdenhil which depends on depth, velocity and Chezy coefficient, but is independent of grid size.

The report should recognize that other parameterizations are commonly employed in related oceanic and weather prediction problems. A common form for the eddy viscosity in such models is that first introduced by J. Smagorinski (Mo. Wea. Rev.:99-163, 1963); this is proportional to the grid size squared multiplied by the norm of the velocity strain tensor (which has the dimensions of frequency). The strain tensor is essentially determined by the velocity shear in the horizontal. Hence if there is a tendency for the momentum to accumulate at the small scales, then the latter velocity shear will increase. But such increase will produce a greater eddy viscosity, which in turn will tend to suppress the build up. Thus the Smagorinski parameterization is designed to be self-limiting.

While the combination of non-linearity and the companion eddy viscosity have little impact on the present model

results, it should be recognized that there may be more adequate methods for dealing with long term stability. A rationalization of the present parameterization of eddy viscosity based upon the shallowness of the basin system might be in order to assure the reader of its justification in the application under consideration.

Boundary Conditions

The use of the Sommerfeld type radiation boundary condition in the Inner Harbor Navigation Canal, with allowance for forcing, is a very appropriate solution to an otherwise cumbersome problem of modelling the whole Gulf Outlet Canal and its interconnections with other bodies of water. The boundary condition employed is basically equivalent to the admittance formulation with forcing employed by Mungall, Able and Olling in their Gulf Tide study and is a special case of the boundary condition used in the Gulf Tide model developed for WES by Reid and Whitaker. The method employed in the Lake Pontchartrain study to determine the forcing is in my judgement quite clever.

Bonnet Carre Operation

The tests as described in the report with pure radiative type boundary conditions at all open boundaries seem appropriate for assessing the response to sustained discharge into the Lake system from Bonnet Carre Spillway. However, an additional run (or extension of the same run) with the discharge turned off would have been of interest to determine the natural decay. Indeed this is what I interpret to be the observed sequence, namely a buildup during opening of the spillway followed by the expected decay after closing of the spillway. If this interpretation is incorrect, then it is a signal that the discussion in the report on this matter ought to be clarified.

Calibration and Verification

Clearly the accuracy of the simulations of the tidal response within Lake Pontchartrain and of the velocities within the three main passes depends critically on: a correct calibration of the hydraulic characteristics of the passes (with or without structures present); and a proper input at the boundaries of the system. This is certainly recognized in the overall study plan and great care has gone into the calibration of the model representation of the hydraulic characteristics of the passes, as thoroughly discussed in Report 2 of the sequence. Likewise, great care has also

gone into the proper modelling of the boundary forcing on the system, with good matching of observed tidal signals at the open boundary of Lake Borgne and the exterior side of Seabrook Lock. The only room for adjustment of hydraulic characteristics beyond the findings of Report 2 is the Mannings n for channels, exclusive of structures or natural constrictions and in the value of lateral eddy viscosity (which within the Rigolets Pass may contribute a significant part to the head loss).

The final calibration of hydraulic characteristics of channels (for as is conditions) was carried out such as to give good amplitude response within the interior of the Lake Ponchartrain system when the O_1 tidal constituent by itself was employed as forcing. Subsequent verification for the mean combined tide (four day run with non-linearity) and a simulation of an actual fortnightly cycle (16 day run with out non-linearity), show a qualitatively reasonable comparison of observed and calculated hydrographs. However there are some notable quantitative discrepancies as follows:

- (1) All tests disclose a bias of too much lag for the computed response in Lake P. versus observed (of order 1 to 2 hours); this includes the calibration run for O_1 tide as well.
- (2) The 4-day run and 16-day run show that the computed response within Lake P. (nominally gage P4) is too low in range by a significant per cent of the observed.
- (3) The above discrepancy increases with increase in range of the tide at the open boundary of Lake Borgne (nominally gage B2). My summary of the pertinent results on this point are given in the attached Table 1.

One might discount these discrepancies from the point of view that: it is the change in the response due to the hurricane protection structures which is of primary concern; and the relative changes in response as predicted by the model are more accurate than the absolute values. Clearly this rationale should be stressed in the report. However to refrain from asking the question as to why the bias in the verification would be like ending the 1981 season of "Dallas" without asking who shot JR, even though one might well be satisfied with the result.

The tidal response of a constricted body of water connected to the open sea by constricted passages has been the subject of many studies in the past (eg. by Kuelegan, Caldwell, Love and others). These studies show that the ratio of the amplitude within the basin to that outside depends not only on the frequency of forcing and the hydraulic characteristics of the constrictions, but also on the amplitude of the tide outside the basin. For a reasonable range in amplitude outside the basin (A_0), the amplitude inside the basin (A_i) can be approximated by the power law

$$A_i = b A_0^n,$$

where n lies between 0 and 1. For the data summarized in Table 1 of these comments, a log-log plot of the the response versus input shows that:

$n = 0.80$ for the observed data

$n = 0.43$ for the WIFM model results.

This demonstrates a rather startling difference between model and prototype which is unexpected. It shows that if one calibrated to the spring tide then the model would overpredict for the smaller tides and vice versa.

The natural question to ask is: Why is the observed response seemingly at variance with well established hydraulic relations between head loss and discharge? Basically this is a quadratic relation and should imply a power n in the above response relation of about 0.5 (ie, closer to the WIFM results than the observed data). The key to explaining the observed response may be the background "noise" in the current and water level records, which is clearly ignored in the model application to pure tidal forcing. The presence of substantial non-tidal signal in both the water level and velocity data is clearly evident in the raw records shown in Report 1 (D. Outlaw). Snyder *et al* (1979, J. Phys. Oceanogr., vol 9, no. 1) show that in the presence of non-tidal noise, the normal quadratic law for head loss (which indeed does apply to the combined flow) becomes equivalent to a linear plus quadratic, when expressed in terms of the tidal velocity. The coefficient of the linear term depends upon the rms residual velocity. The net result of allowing for non-tidal currents is that the power n in the response relation should be in the range 0.5 to 1.0. The observed data for LakeP. would tend to imply that the effect of the non-tidal currents play a significant role in producing the rather anomolous behaviour of the system. If the tidal signal were much stronger, then the background noise effect would be less important.

It would seem prudent to add some discussion addressing the above issue in the report, so that the reader is alerted to the difficulties inherent in a non-linear system in which there is a large noise to signal ratio.

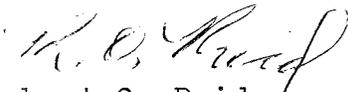

Robert O. Reid
College Station, TX

TABLE 1

Summary of observed and calculated ranges of tide at representative gages for input and inner Lake P. response

RUN	Gage B2		Gage P4		Ratio of P4/B2	
	Obs	Calc	Obs	Calc	Obs	Calc
O ₁ calib	0.70 ft		0.20 ft	0.20 ft	0.29	0.29
Mean tide	1.25		0.33	0.25	0.26	0.20
16 day **	1.90*		0.45	0.30	0.24	0.16

* From Plate 33, Report 1

** It is not clear whether this run included lateral friction or not (although it is stated that it omits the advection of momentum terms). The report should make this clear, since lateral friction contributes to the head loss through the channel.

TO : H. Lee Butler, Project Manager, Wave Dynamics Division,
U.S. Army Waterways Experiment Station.

FROM : D. W. Pritchard

SUBJECT: Review of Report 3, Lake Pontchartrain and Vicinity
Hurricane Protection Plan, Numerical Model Investigation
of Plan Impact on the Tidal Prism of Lake Pontchartrain.

1. As requested in your letter of 29 September, I have reviewed the subject report in detail. In general, I find this to be an excellent report which represents the application of the most advanced state-of-the-art numerical modeling procedures to the stated problem. Your letter stated that the U. S. Army Engineer District, New Orleans (LMN) asked for my opinion on stability and non-linear aspects of the model, and on the effect that the magnitude of the eddy viscosity term may have on the computed circulation patterns in Lake Pontchartrain. My specific comments on these and other subjects follow.

2. I believe that the computational scheme utilized in the WIFM model incorporates the best techniques now available for assuring model stability over a wide range of realistic forcing conditions. Improved stability of this model as compared to earlier implementations results from the adoption of a fully time centered scheme. Computational stability is also provided by use of a digital filter and by inclusion of eddy viscous terms. Excessive smoothing of the results by use of a weighted averaging filter can result in overly damping the time dependent output of the model for a time varying input. The damping is frequency dependent, and is determined by the ratio of the inverse time step to the frequency of the forcing terms. It has previously been shown that the weighted three time step filter used in the present implementation of the WIFM model imposes an insignificant damping of the tidal signal, which for this study is the most important forcing term.

2. The non-linear field acceleration terms are a primary cause of instability in numerical hydrodynamic models. The fully time centered scheme for time stepping of the model mentioned above was introduced primarily so that these terms could be included for a wide range of conditions without introducing significant numerical instabilities. The form of the non-linear acceleration terms contained in the equations of motion simulated by the WIFM model represent an approximation to the correct form of these terms. The WES group has previously shown that for computations of the flow regime in a tidal waterway of the type under consideration here, the approximation used in the WIFM model does not introduce a significant error. It has been my experience that for strongly forced motions, the non-linear acceleration

terms are relatively quite small. These terms must be included if there is an interest in details of the circulation pattern, such as the features of topographically induced eddies. However, computations of the integrated flow through a cross section give very nearly the same results whether or not the non-linear acceleration terms are included.

3. A number of vertically integrated numerical models for simulation of the tidal hydraulics of coastal waterbodies have been implemented and successfully run for certain simple situations without horizontal eddy viscous terms. For the most part these terms have been included in the formulation of such models primarily for the purpose of providing computational stability. However, eddy viscous terms do represent real terms which arise from the vertical integration of the Reynolds stress terms and from added terms which arise out of the vertical integration of the non-linear acceleration terms. There is not complete agreement among scientist and engineers working in the field as to what is the proper form for the eddy viscous terms. From a theoretical standpoint, I consider that the most appropriate form is based on the assumption that the eddy stress term is proportional to the deformation tensor of the velocity field. The form of the eddy viscous terms in the vertically integrated equations of motion which result from the above assumption differ somewhat from the terms which appear in the WIFM model. However, I do not consider this difference significant. This is because these terms function primarily to improve the stability of the model, and the form used in the WIFM model have been shown to successfully accomplish this. I have not experimented with the WIFM model, but on other vertically integrated numerical hydrodynamic models I have used, there is a minimum value of the coefficient of eddy viscosity, for a given grid geometry and time step, necessary to attain numerical stability. Over a range of values from this minimum value to about five times this minimum value, the computed values of elevation and velocity varied only slightly with variations in the value of the coefficient used in the model. Use of the minimum value of the eddy coefficient which produced numerical stability resulted in the best verification of the model results. This also appears to agree with results obtained from use of WIFM.

4. Thus experience with WIFM and with other models are in agreement that a value of the eddy coefficient should be selected which is close to the minimum value which will provide numerical stability for the particular spatial grid and time step used. Once this value is selected, adjustment of the model to match observed elevation and velocity data should be accomplished by adjustment of the bottom frictional coefficient, and not by

further adjustment of the eddy coefficient. It should be pointed out that, at least for some models, there is some interaction between these coefficients. That is, the larger the bottom frictional coefficient, the smaller the value of the eddy coefficient necessary to attain stability. This is not a strong relationship, however, and the preliminary test runs to determine the value of the eddy coefficient which will provide stability can be made using preliminary approximations for the bottom frictional coefficients in the model waterway.

5. I consider that the calibration of the model using the O1 tidal component of the observed elevation and current meter data was adequate for the purposes of this report. The verification was overall quite good. It is obvious from a comparison of the elevation data at Station P-3 with the data from Stations P-2, P-4, and P-5, that the phasing of the observed data at Station P-3 must be in error as a result of instrument malfunction. Some of the other apparent discrepancies between the model and prototype data for the verification appear to me to most likely result from: (a) errors in assigning the elevation of the tide gauge zero for the observed data; and (b) the model runs may not have been long enough to have eliminated all spin up effects. There is also some theoretical justification for concluding that the bottom frictional coefficient may vary somewhat with the frequency of the velocity oscillations. However none of these factors appear to be sufficiently significant to alter the conclusion that the model was adequately verified for the purposes of the subject study; that is, for the purpose of determining the impact of the proposed control structures on the tidal prism and on the circulation in Lake Pontchartrain.

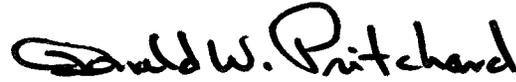
4. It should be pointed out that meteorologically induced changes in water level are also likely to contribute significantly to the exchange of water between Lake Maureas and Lake Pontchartrain, between Lake Pontchartrain and Lake Borgne, and ultimately between Lake Borne and the open coastal waters via Mississippi Sound. These meteorologically induced variations in water level and the consequent variations in flow through the various interconnecting waterways are, on the basis of a number of studies conducted elsewhere, likely to be of lower frequency (longer period) than the tide. Considerable power has been found in sea level variations with periodicities of about two and one-half days, four days, and seven days. The proposed control structures in the passes should have less impact on flows through the passes at these frequencies than at tidal frequencies.

5. It should also be noted that the internal circulation in Lake Pontchartrain is probably controlled more by direct wind induced motion than by tidally induced flows. This internal circulation

Pontchartrain Review, page 4

is thus most likely highly variable and not affected in any way by the installation of the proposed control structures.

6. Finally, for whatever value you may find them, there follows a couple of editorial suggestions. First, in paragraph 8, I suggest that the following sentence be added to sub-paragraph a: "An embedded subgrid of this model is here after referred to as the tidal prism model". Secondly, in paragraph 40, the last sentence, some explanation as to why velocity vectors which exceeded 0.5 ft/sec were set to zero would aid the reader. Also, in paragraph 31, the 8th line, I believe the reference to Figure 5 should be to Figure 8.

A handwritten signature in black ink that reads "Donald W. Pritchard". The signature is written in a cursive style with a large, prominent initial 'D'.

Donald W. Pritchard

21 October 1982

Dr. H. Lee Butler
Project Manager
Wave Dynamics Div
Waterways Experiment Station
Corps of Engineers, U. S. Army
P. O. Box 631
Vicksburg, MI 39180

Ref: WESHH

Dear Lee:

I have read with great interest the two WES reports that you have sent: HL-82-2 "Physical and Numerical Model Investigation of Control Structures and the Seabrook Lock", and HL-81-3 "Lake Pontchartrain and Vicinity Hurricane Protection Plan."

I have found nothing of major importance to comment about. The work is commendable and well done. The results on the effects of the control structures at Rigolet, Chef Monteur and IHNC are clear. The effect of the barrier plan is also clearly evidenced.

Two topics commonly argued about when there is not much else to target upon.

- The friction coefficients (Manning's n)
- The vertical shear and the diffusion coefficients

These are always easy targets because they are relatively ill-defined. The answer to these questions lies in analyzing the effect of some variations around the selected values. In the case that you have investigated, the friction coefficient has been calibrated from prototype data. Therefore, the only argument which remains is about the validity of this calibration under hurricane surge condition. Eventually, it would be easy to demonstrate that any realistic variations around the selected values will have little influence on the results.

The vertical shear influences the flow pattern into the lake (and subsequently the diffusion). In particular, the printed arrows on the graphs can misrepresent the real circulation. On the other hand, this has practically no effect on the time history of the surface elevation. More sophisticated relationship for the eddy viscosity can be used. This may lead to a slightly different flow pattern in the lake. The calibration of the diffusion coefficient would require an extensive field survey. The state of the art is such that such sophistication is probably not worth doing. Furthermore, a simply defined diffusion coefficient embodies some very

21/Oct/82
Page two

complex phenomenae. The effect of depth, wind, and turbulence generated by whitecaps influence the diffusion process significantly.

A sophisticated computer tool has been successfully developed. This has required considerable skill, time and effort. Like a permanently built scale model, the math model can be used to answer more questions than the one which has been analyzed in your report. For this reason, I recommend that the corresponding computer program be fully documented and explained as a complement to the present report for future investigations. When fully documented, the model should be made available to any potential user.

I enjoyed very much being on the consulting board of the New Orleans district, and working with you on this project.

Sincerely,



Bernard Le Mehaute
Consultant

L. EUGENE CRONIN
12 MAYO AVENUE
BAY RIDGE
ANNAPOLIS, MARYLAND 21403
—
267-6744
(AREA CODE 301)

October 25, 1982

Commander and Director
U.S. Army Engineer W.E.S., CE
P.O. Box 631-Halls Ferry Road
Vicksburg, MS 39180

Re: DACW39-83-M-093

Dear Sir:

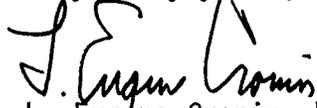
In accordance with the referenced order and letter instructions from Dr. H. Lee Butler, Project Manager, Wave Dynamics Division, I have reviewed a Draft copy of Technical Report HL-81-3, Numerical Model Investigation of Plan Impact on the Tidal Prism of Lake Pontchartrain, by H. Lee Butler, relating to the Lake Pontchartrain and Vicinity Hurricane Protection Plan, and related documents.

My professional background and experience do not involve the development and application of numerical modeling systems and I have no comment on the relevant theory, the components of the model, calibration or other mathematical or conceptual aspects of the Report. Others among your consultant group can comment competently and constructively.

Because of my continuing association since 1976 with the development of the Hurricane Protection Plan from the environmental perspective, I offer the comments and queries that occurred to me during this review. They relate generally to the realism of the model, to its suitability for application to the preferred plan for the barriers and to several questions about the use of available data in the model and its application in estimating the effects of the barrier structures on Lake Pontchartrain.

It is my impression that Dr. Butler has competently conducted and interpreted a highly relevant study. Perhaps he can derive some benefit from my quite different point of view, naive in many respects and more knowledgeable in others.

Very truly yours,


L. Eugene Cronin, Ph.D.
Consultant

LEC:swi

Enclosure

DRAFT OF
TECHNICAL REPORT HL-81-3
Numerical Model Investigation of Plan Impact
on the Tidal Prism of Lake Pontchartrain
H. Lee Butler

Review by
L. Eugene Cronin, Ph.D.
Consultant
25 October 1982

1. Paragraph 10. Are the assumptions valid? Is integration of flow from sea bottom to water surface fully satisfactory since vertical gradients in salinity, and presumably net flow, occur in the passes, especially the Inner Harbor Navigation Canal?
2. Paragraph 20. Rigorous efforts have obviously been made in expressing and varying boundary conditions. Are they fully sufficient to provide adequately for the rather massive effects of wind, pressure and spillway releases on this system and its component cells?
3. Paragraph 23, 24. Is the failure of some of the gages significant? The statement "In general the overall quality of data was good and thus..." is not fully comforting, but this judgement must be with the investigator. The inconsistency in phase components for Station P3 requires similar consideration and judgement.
4. Paragraph 26 etc. Are the field observations on currents, and the results of Model use, consistent with, or at substantial variance from, the observations by Drs. Chuang, Swenson and Murray at LSU for the New Orleans District? These were, unfortunately, more restricted than those planned, but they offer an interesting and separate, perhaps unique, basis for learning about these currents.
5. Paragraph 29. If I interpret correctly, Dr. Butler's work was done under the assumption that Plan 2A-1 would be employed for the Barrier Structure, providing 21 bays. However, it is my understanding that the preferred plan, the one to be presented in the Environmental Impact Statement, is Plan 2A, with only 16 bays. Is this significant to the Model Investigation?
6. Paragraph 41. Plates 17, 19, 21, etc. depict the Chef Menteur Pass as a small, straight and simple tube between Lake Pontchartrain and Lake Borgne. Previous estimates indicate that it has about the same average cross section as The Rigolets, 45% of the minimum cross section of The Rigolets, and transports about 70% as much waters as The Rigolets. Table 4 indicates that the Chef discharges about 60% as much water as The Rigolets during spillway operation. Is the modeled size correct?

7. The lower Chef is now an inverted L-shape system, to be replaced by a straight pass of equal size from Lake Borgne to the middle Chef. Will this change affect tidal responses? If so, are the effects in the Model - or needed in it?
8. Paragraph 42. It is my understanding that the control structure of the Seabrook Complex will be operated to achieve the salinity regime requested by non-Corps interests - and that this regime has not yet been selected. Your use of the open control structure is appropriate, even though later decisions may modify the real effects.
9. Paragraph 46, 47, 55, 56b. See Comments 5, 6 and 7 above. Do these change these estimates?

COMMENTS ON
Technical Report HL-81-3

"LAKE PONTCHARTRAIN AND VICINITY HURRICANE
PROTECTION PLAN - Report 3
Numerical Model Investigation of Plan Impact
on the Tidal Prism of Lake Pontchartrain".

H. Lee Butler US Army Engineer Waterways
Experiment Station, Vicksburg, MS 39180

by

Shaw L. Yu
Department of Civil Engineering
University of Virginia
Charlottesville, Virginia 22901

A) General Comments

1. The author is to be commended for the successful application of the WIFM model to the simulation of the hydrodynamics of the 3-LAKE System. The development and the subsequent refinement of the model represents a major contribution to the state of the art of hydrodynamic modeling. It is expected that the model will be widely used for other similar systems since, as the author indicated that: "A major advantage of WIFM is the capability of applying a smoothly varying grid to the study region permitting simulation of complex landscapes by locally increasing grid resolution and/or aligning coordinate along physical boundaries."

2. The tidal prism model was successfully calibrated and verified with field data. Results on surface elevations and circulation patterns were quite good. Verification of current velocities showed some significant differences between calculated and observed data. For example, at Station V15 maximum difference was about 50% and at V8, about 100%. On the other hand, results for the other four stations were good. Limited velocity data precluded more comparisons.

3. Paragraph 22 stated the three major elements of the impact analysis, i.e.
 - a. Tidal prism and circulation in Lake Pontchartrain.
 - b. Hurricane surge levels in Lake Pontchartrain and vicinity.
 - c. Water quality in Lake Pontchartrain.

This report addresses Item a, while a subsequent report will discuss Item b.

As noted previously in the Consultant's reports, some of the concerns raised about the project were about possible changes in the distribution of salinity and other water quality parameters resulting from the existence of the proposed structures in the passes during normal, non-storm periods. Even if the hydrodynamic model indicates only small changes in the lake tidal prism it may be advisable to provide some demonstration of the changes which might be expected in the salinity distribution and possibly in some other water quality parameters.

The water quality data collected during the field sampling runs should provide the necessary data needed for a preliminary water quality modeling effort if one is to be made.

B. Specific Comments

1. Paragraph 44

Perhaps the maximum surface elevation increase due to the structures should be stated. For example at Station P6 the maximum increase was about 1 foot.

2. Paragraph 47 and Paragraph 51

Tidal prism decrease due to neglecting the navigation channels was stated as about 2%. However, in Paragraph 51 the decrease was stated as 1½%. In Report 2, page 47, a decrease of 0.7% was mentioned for neglecting the channel in the Chef Menteur Pass. For the Rigolets the decrease was smaller. Therefore, the total decrease should be about 1.4% or less. This will result in an overall impact on lake tidal prism of about 9%.

It is suggested these figures be made consistent.

3. Table 1

For neap tide conditions, the Chef Menteur Pass showed a decrease of 0.6% in discharge due to the structures. This is considerably smaller than the decreases for spring and mean tide conditions and did not follow the trend.

4. Paragraph 57

Perhaps a sentence could be added to note that data collected on water quality (temperature, DO, conductivity and pH) will provide the necessary data for possible future water quality modeling efforts.