Comparison of Numerical and Physical Hydraulic Models, Masonboro Inlet, North Carolina

APPENDIX 4

Simplified Numerical (Lumped Parameter) Simulation

by

C.J. Huval and G.L. Wintergerst

GITI REPORT 6

June 1977

GENERAL INVESTIGATION OF TIDAL INLETS

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report summarizes a mathematical model study of water motions in two horizontal dimensions for Masonboro Inlet, North Carolina. The study was part of the Corps of Engineers' General Investigation of Tidal Inlets research program (GITI) and was designed to meet two primary objectives. The first objective was to evaluate the effectiveness of state-of-the-art physical and mathematical modeling techniques in predicting the effects of major changes to an inlet on the hydraulics of the inlet. A second objective was to determine whether simple model tests, performed quickly and for a reasonable cost, could be relied on to evaluate the design of inlet improvements.

(continued)

Masonboro Inlet was in a natural state until August 1965, when major manmade changes to the inlet were initiated. By July 1966, construction of a weir jetty and dredging of a deposition basin and navigation channel had been completed. The mathematical and physical models were initially calibrated using bathymetric and hydraulic data collected at the inlet in September 1969. Selected parts of the calibrated model were subsequently remolded for prediction of hydraulic characteristics for the following conditions: (a) preproject undeveloped inlet conditions, November 1964 bathymetry; and (b) modified inlet and north jetty conditions, July 1966 bathymetry. Results of the mathematical model investigations are discussed in this report.

FOREWORD

This report was prepared by the Mathematical Hydraulics Division of the Hydraulics Laboratory at the U.S. Army Engineer Waterways Experiment Station (WES) as one in a series of reports on the General Investigation of Tidal Inlets (GITI). The GITI research program is under the technical surveillance of the U.S. Army Coastal Engineering Research Center (CERC), and is conducted by CERC, WES, and other government agencies, and by private organizations. This report was prepared by C. J. Huval and G. L. Wintergerst, and is one in a series of reports concerned with an evaluation of physical and numerical models of a tidal inlet performed as part of the GITI. Dr. G. H. Keulegan, Resident Consultant, Hydraulics Laboratory, advised on several aspects of the study.

The report preparation was supervised by M. B. Boyd, Chief, Mathematical Hydraulics Division, and H. B. Simmons, Chief, Hydraulics Laboratory. CERC technical direction was provided by B. R. Bodine and D. L. Harris. Technical Directors of CERC and WES were T. Saville, Jr., and F. R. Brown, respectively.

Comments on this publication are invited.

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PREFACE

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

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

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

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

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

b. Inlet Hydraulics. The objectives of the inlet hydraulics study are to define the tide-generated flow regime and water level fluctuations in the vicinity of coastal inlets and to develop techniques for predicting these phenomena. The inlet hydraulics study is divided into three areas: (1) idealized inlet model study, (2) evaluation of state-of-the-art physical and numerical models, and (3) prototype inlet hydraulics.

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

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

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

c. Inlet Dynamics. The basic objective of the inlet dynamics study is to investigate the interactions of tidal flow, inlet configuration, and wave action at tidal inlets as a guide to improvement of inlet channels and nearby shore protection works. The study is subdivided into four specific areas: (1) model materials evaluation, (2) movable-bed modeling evaluation, (3) reanalysis of a previous inlet model study, and (4) prototype inlet studies.

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

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

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

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

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

a. Appendix 1. Sager, R. A., and Seabergh, W. C., "Fixed-Bed Hydraulic Model Results."

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

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

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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:

Multiply	by	To obtain
inches	25.4	millimeters
	2.54	centimeters
square inches	6.452	square centimeters
cubic inches	16.39	cubic centimeters
feet	30.48	centimeters
	0.3048	meters
square feet	0.0929	square meters
cubic feet	0.0283	cubic meters
yards	0.9144	meters
square yards	0.836	square meters
cubic yards	0.7646	cubic meters
miles	1.6093	kilometers
square miles	259.0	hectares
acres	0.4047	hectares
foot-pounds	1.3558	newton meters
ounces	28.35	grams
pounds	453.6	grams
	0.4536	kilograms
ton, long	1.0160	metric tons
ton, short	0.9072	metric tons
degrees (angle)	0.1745	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins[1]

[1] To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use formula: $K = (5/9)(F - 32) + 273.15$.

SYMBOLS AND DEFINITIONS

A	variable bay surface area (constant for Keulegan model)
A_{HW}	bay surface area at high water
A_{LW}	bay surface area at low water
$A_{o_{MSL}}$	bay surface area at mean sea level datum
$A_{o_{MTL}}$	bay surface area at mean tide level datum
A_o	average surface area of tidal lagoon or bay
C_v	a velocity coefficient defined as $\frac{1}{2g}\left(1 + \frac{\lambda L}{r}\right)$ in units $\frac{T^2}{L}$
H	semirange ocean tide
H_1	elevation of basin water surface referred to MSL
H_2	elevation of ocean tide referred to MSL
H_{1m}	semirange of bay tide
$\dot{H}_1$	time derivative of bay tide, $\frac{dH_1}{dt}$
K	Keulegan's dimensionless coefficient of repletion, $\frac{T}{2\pi H}\frac{a}{A}\sqrt{\frac{2gH}{1 + L\lambda/r}}$
K_1	equivalent Keulegan's coefficient of repletion for nonprismatic inlets
K_F	friction constant defined as $\frac{2gn^2}{(1.486)^2}$
L	inlet length
M	subscript indicating maximum value
Q	total inlet discharge
Q_i	discharge in i^{th} channel
T	tidal period (usually 12.42 hours)
V	velocity in tidal inlet channel

V_{Mi}	maximum velocity in i^{th} channel
V_{xi}	velocity as function of x in i^{th} channel
a	tidal inlet cross-sectional area
a_m	inlet area at minimum cross section
a_{mi}	minimum cross-sectional area of i^{th} parallel channel
a_{xi}	area as function of x in i^{th} channel
a_o	inlet area at MSL
g	gravitational acceleration
h_1	dimensionless bay tide, $\frac{H_1}{H}$
h_{1+}	floodtide, maximum bay response, dimensionless
h_{1-}	ebbtide, maximum bay response, dimensionless
$\bar{h}_1$	average dimensionless bay tide
h_2	dimensionless ocean tide, $\frac{H_2}{H}$
i	channel index ($i = 1, 2, 3, \ldots i_M$)
i_M	the maximum number of channels
j	cross-sectional index ($j = 1, 2, 3, \ldots j_M$)
j_M	maximum number of cross sections
m	subscript indicating minimum value
n	Manning's roughness coefficient
q	discharge or flow into tidal bay
r	inlet hydraulic radius
r_e	effective inlet hydraulic radius at MSL

SYMBOLS AND DEFINITIONS–Continued

r_o	hydraulic radius of inlet at MSL
r_{ij}	hydraulic radius of j^{th} section of i^{th} channel
r_{xi}	hydraulic radius as function of x in i^{th} channel
t	time from beginning of tidal cycle
u	dimensionless factor used in the determination of inlet velocity ($u = \sqrt{h_2 - h_1}$, for floodtide; $u = -\sqrt{h_1 - h_2}$, for ebbtide)
u +	maximum value of u for floodtide
u–	maximum negative value of u for ebbtide
w_o	inlet width at MSL
x	distance measured along the channel axis
θ	dimensionless tidal time, $\frac{2\pi t}{T}$
π	3.14159 . . .
Σ	sum of following indexed items
Ω	volume of tidal prism through the inlet, $2H_{1m} A_o$
a	lag of bay tide behind ocean tide
$a+$	floodtide, lag of bay tide behind ocean tide
$a-$	ebbtide, lag of bay tide behind ocean tide
β	parameter to characterize bay surface area variation
ζ	inlet width variation parameter, inlet beach side slope, horizontal-vertical
η	average tide height through inlet
λ	dimensionless friction factor as expressed by Keulegan, $\frac{2gn^2}{(3.2808)^{2/3}\, r^{1/3}} = \frac{2gn^2}{(1.486)^2\, r^{1/3}}$

SIMPLIFIED NUMERICAL (LUMPED PARAMETER) SIMULATION

by

C. J. Huval

and

G. L. Wintergerst

I. INTRODUCTION

This study is concerned with the implementation and application of a hydraulic mathematical model for predicting ocean tide-induced current velocities within a coastal inlet and the water level fluctuation in an adjoining embayment. The study of mathematical models is part of a more general investigation of tidal inlets conducted by the U.S. Army, Corps of Engineers, and is intended to evaluate the degree to which mathematical and physical models can be used to predict quantitatively the hydrodynamics (other than sediment movement) of flow through tidal inlets. As a typical problem area, Masonboro Inlet, North Carolina, was selected as a case study for extensive field, mathematical model, and physical model investigations.

The mathematical model used in this study, referred to as the *lumped parameter approach*, is based on an extension of the method developed by Keulegan (1967). Although the method requires more effort to implement and apply than Keulegan's method, it is relatively simple to use in comparison to the more complete schemes which are presently available. Moreover, in most cases it should give a better solution of inlet velocities and basin response than Keulegan's method since it incorporates more of the physical processes involved.

The numerical system described in this study is composed of three computer programs, each performing a separate function. One program generates a set of tables to give generalized inlet hydraulics for some variable basin surface areas. A second program (INLET) gives serial calculations of the inlet flow and the basin variations. The third program (SECPLT) plots the ocean tide, basin tidal response, inlet velocity and inlet flow and computes inlet cross-sectional areas from digitized hydrographic data.

The objective of this study is to apply the lumped parameter model to Masonboro Inlet and determine the tidal response of the system of inner-connecting channels and velocities arising from a given ocean tide. The scope of this study is:

(a) Mathematical model implementation and confirmation.

(1) Adapt lumped parameter model to the 1969 bottom survey conditions.

(2) Calibrate the model for prototype currents and tides of 12 September 1969.

(b) Mathematical model application.

(1) Predict basin tides, tidal prism, and inlet currents for preproject undeveloped inlet conditions of November 1964.

(2) Predict basin tides, tidal prism, and inlet currents for modified inlet and north jetty conditions of July 1966.

In addition, a description of the model development is presented along with suggestions for applying the model to other inlets. A documented listing of the computer programs INLET and SECPLT are included.

The Masonboro Inlet study area (Fig. 1) is composed of an entrance channel and three inner-connecting watercourses referred to as Masonboro Channel, Banks Channel, and Shinn Creek. These inner channels all connect with the Atlantic Intracoastal Waterway. The mean high water (MHW) and mean low water (MLW) lines and locations where velocity measurements were made, and the tidal heights observed for the 1969 survey conditions are shown in Figure 1.

II. BACKGROUND ON COMPUTATIONAL METHOD

The subject of flows and corresponding water levels of tidal inlet-bay systems has been investigated by several researchers. Brown (1928) presented a useful solution technique for estimating flows through a coastal inlet and the variations of water level in an adjoining embayment. Keulegan (1967) extended this work and gave a more useful solution based on a dimensionless form of the equation for surface changes. Keulegan offered a simple and convenient tool for computing the main hydraulics of tidal inlets. Because the method presented in this study is based on an extension of Keulegan's method, a brief review of his basic assumptions and pertinent equations is given in this section.

An inlet system with a notation consistent with Keulegan's formulation is shown in Figure 2. Keulegan's method was based on several assumptions related primarily to the physical characteristics of the system and the description of the ocean tide. These are identified as:

(a) The basin responds only to the ocean tide. This implies that the basin is bounded except at the inlet; thus, there is no freshwater inflow from streams or lateral drainage and density currents are negligible. This condition also implies that wind effects are neglected.

(b) The ocean tide is sinusoidal. The representation of ocean tides as sinusoidal is simple, convenient, and often reliable; e.g., the east coast tides of the United States are well represented in this manner. Along the U.S. gulf and Pacific coasts and in many other coastal regions of the world, such a representation becomes significantly less accurate because the tides do not exhibit simple sinusoidal form.

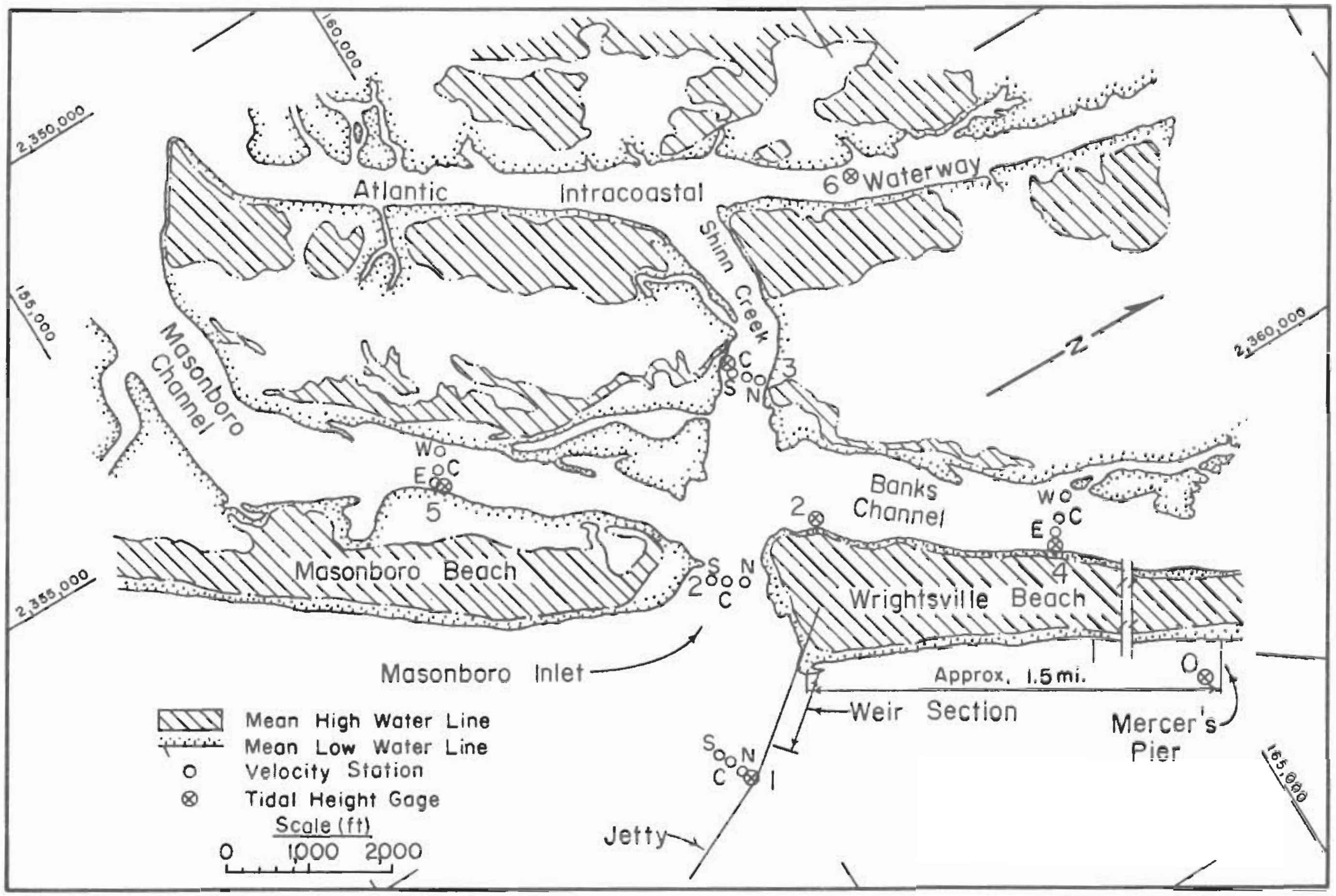

Figure 1. Masonboro Inlet study area.

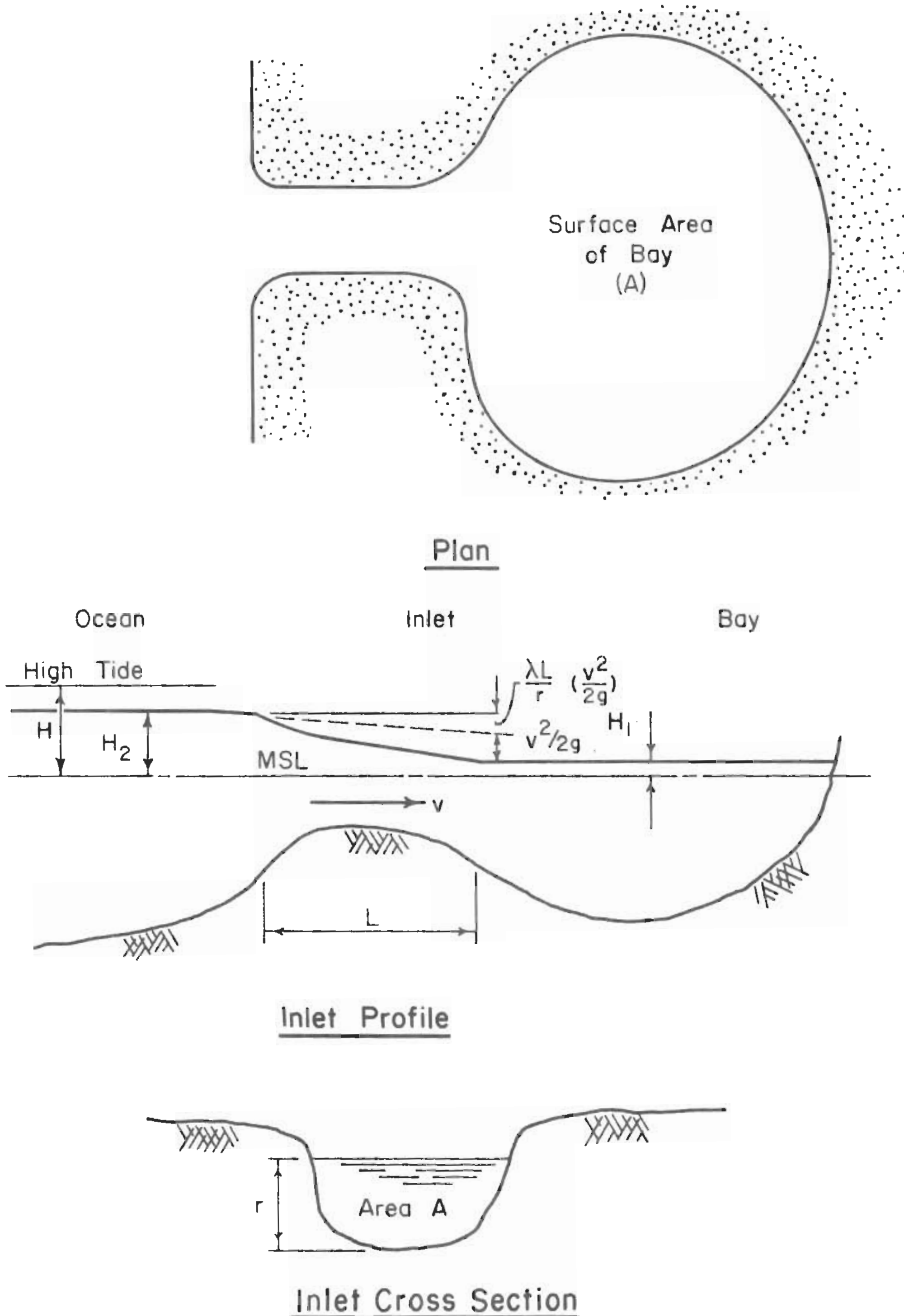

Figure 2. Typical inlet description.

(c) Inertia of the inlet flow is negligible. It is assumed that changes of flow in the inlet channel are gradual and that flow acceleration can be neglected. Specifically, the surface slope in the inlet channel is balanced by the velocity head and channel resistance.

(d) Length and width of bay is less than the tidal wavelength. This condition implies that the basin is small, and if deep enough, it can be assumed that the water surface elevation varies uniformly throughout the bay. For example, if a basin is square or circular (or similar in form) and flow is not seriously restricted, there may be a nearly homogeneous change of the water surface elevation over the entire basin in response to the ocean tide.

(e) The inlet is prismatic. The cross section of the inlet is assumed to be a uniform open channel with entrance and outlet well defined. However, inlet boundaries are often irregular.

(f) The inlet depth is large compared to the tidal range. This implies that the cross-sectional area of the inlet is considered constant over the tidal cycle.

(g) Basin walls are vertical. This implies that the differential storage for any differential change in water surface elevation within the basin remains constant.

Based on the above assumptions, it is possible to analyze the inlet-basin response for a given variation in the ocean tide. Keulegan (1967) derived the following relations for estimating the surface fluctuations in a basin when the surface of the sea is at a higher elevation or a lower elevation than the surface of the water in the basin.

For floodtide:

$$\frac{dh_1}{d\theta} = K\sqrt{h_2 - h_1}\,, \quad h_2 > h_1 \;. \tag{1}$$

For ebbtide:

$$\frac{dh_1}{d\theta} = -K\sqrt{h_1 - h_2}\,, \quad h_1 > h_2 \;, \tag{2}$$

where, K is Keulegan's dimensionless coefficient of repletion and defined by:

$$K = \frac{T}{2\pi H}\,\frac{a}{A}\sqrt{\frac{2gH}{1 + L\lambda/r}}\;, \tag{3}$$

where,

h_1 = dimensionless bay tide $= \dfrac{H_1}{H}$,

h_2 = dimensionless ocean tide $= \dfrac{H_2}{H}$,

$\theta = \dfrac{2\pi t}{T}$,

H = semirange of ocean tide ,

T = tidal period: 12.42 hours for M_2 tide ,

λ = dimensionless friction coefficient: $\dfrac{2gn^2}{(1.486)^2 r^{1/3}}$,

where r is measured in feet, and g is measured in feet per square second. Factor 1.486 is the conversion from metric units and has the dimensions $[(\text{length})^{1/3}/\text{time}]$ (Chow, 1959) .

r = inlet hydraulic radius ,

n = Manning's resistance coefficient ,

a = inlet cross-sectional area ,

t = time from beginning of tidal cycle ,

L = inlet length, and

A = bay or lagoon surface area .

An analytic solution to the above equations was found by a Fourier series. Tables by Keulegan (1967), give relations to predict the bay maximum amplitude (equal for floodtide and ebbtide), maximum inlet velocity (equal for floodtide and ebbtide), and the bay tidal prism.

III. VARIABLE BAY SURFACE AREA

Van de Kreeke (1967) presented a numerical solution of the inlet-bay problem which incorporated the effects of freshwater inflow. Mota Oliveira (1970) formulated and solved numerically, an inlet problem which accounted for variable inlet depth and variable bay surface area. A numerical computation method using bay inflow with solution curves was reported by Glenne, Goodwin, and Glanzman (1971). Mota Oliveira (1970) indicated the importance of including the effect of variable bay surface area in the computation because it can have a significant effect on bay tidal response and inlet velocity. He determined the bay surface area as a linear function of the bay surface elevation, and the inlet cross-sectional area by assuming that the inlet water surface elevation is the average of ocean and bay elevations. Because inlet depth was allowed to vary it was possible to vary the inlet area with respect to time. It was shown that inclusion of these improvements in the computational scheme would give better results for predicting inlet hydraulics.

Although Keulegan (1967) did not account for a variation of bay surface area, his method is useful because of convenience. The collection of inlet parameters of a single coefficient, the coefficient of repletion, allows solution values for the governing equation to be conveniently tabulated. On this basis, Keulegan's method is used here but extended by combining Mota Oliveira's scheme for including the variation of bay surface area. Such a solution technique would retain the essential simplicity of Keulegan's original solution but reduce the effect of the most restrictive assumption, that of vertical bay walls.

Figure 3 illustrates the linear variation of bay surface area with surface elevation of the bay as suggested by Mota Oliveira (1970). The varying surface area is given by:

$$A = A_o \left(1 + \beta h_1\right) , \tag{4}$$

where β is the linear bay surface area variation parameter, and A_o is the average surface area in the bay.

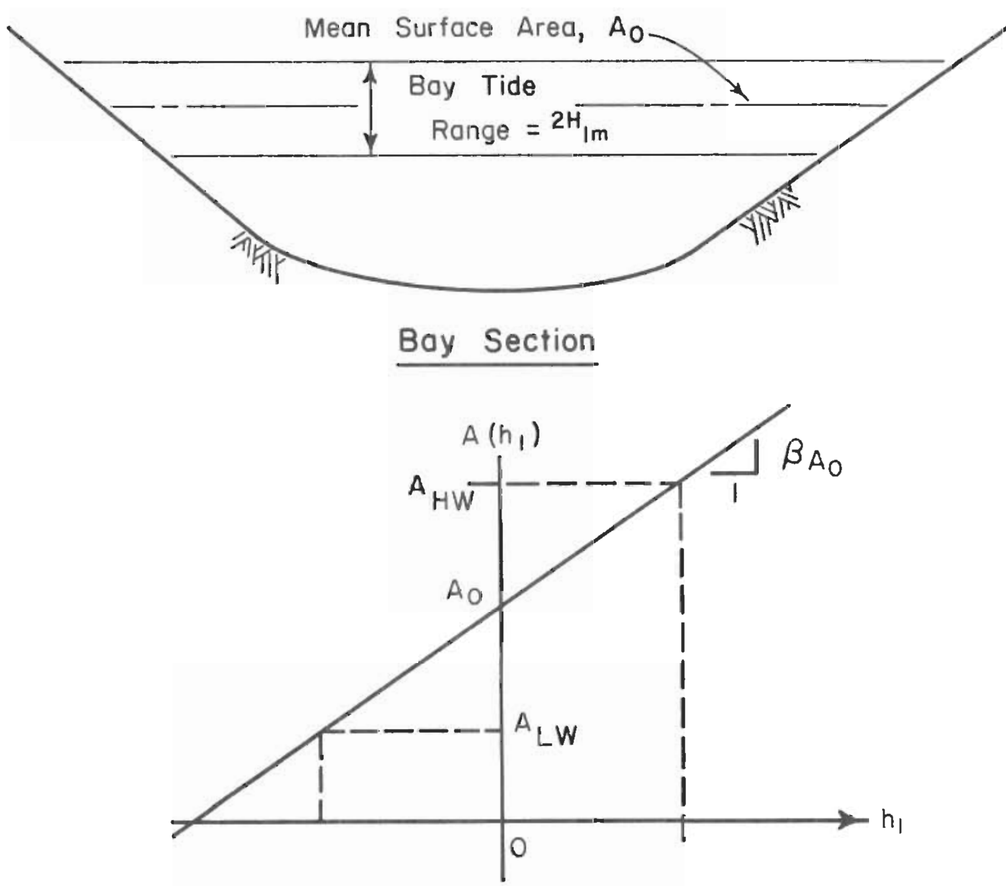

Figure 3. Variation of bay surface area.

If high and low water areas can be determined from hydrographic charts and topographic maps, A_o may be taken as the mean surface area. Moreover, the surface area variation parameter, β, can then be estimated. The area-water level relationship is often nonlinear for many problems encountered in practice. If the volume of the tidal prism, Ω, has been determined for the system from discharge measurements at the inlet and the tidal range in the bay is also known, then the value of A_o can be computed from:

$$A_o = \frac{\Omega}{2H_{1m}} , \tag{5}$$

where, H_{1m} is the tidal semirange in the bay. A corresponding value for β should be obtained from the best available information relating surface area A and bay elevation H_1.

To include the effects of the variation of the bay area, a direct substitution of equation (4) is made into equation (1). This gives for floodtide:

$$\frac{dh_1}{d\theta} = \frac{T}{2\pi H} \frac{a}{A_o(1+\beta h_1)} \sqrt{\frac{2gH}{1 + \lambda L/r}} \sqrt{h_2 - h_1} . \tag{6}$$

Rearranging terms yield the simpler expression:

$$\frac{dh_1}{d\theta} = K \frac{\sqrt{h_2 - h_1}}{(1+\beta h_1)} , \tag{7}$$

where the coefficient of repletion is now based on the average bay surface area and is given by:

$$K = \frac{T}{2\pi H} \frac{a}{A_o} \sqrt{\frac{2gH}{1 + \lambda L/r}} . \tag{8}$$

This gives a differential equation of the surface changes for the system in parameters K and β. The friction factor, λ, expressed in terms of Manning's n, and the hydraulic radius is given by:

$$\lambda = \frac{2g\,n^2}{(1.486)^2 r^{1/3}} . \tag{9}$$

Equation (7) is applicable if $h_2 \geqslant h_1$ and the corresponding equation for ebbtide or $h_1 \leqslant h_2$ is:

$$\frac{dh_1}{d\theta} = - K \frac{\sqrt{h_1 - h_2}}{(1 + \beta h_1)} . \qquad (10)$$

Equations (7) and (9) have been solved by numerical integration for various values of β and K using a simple harmonic ocean tide defined by:

$$h_2 = \sin \theta . \qquad (11)$$

Tables produced from these solutions are presented in Appendix A; a typical solution with symbol definition is shown in Figure 4. The use of the tables is described below.

For a well defined inlet, the determination of a, r, and L is relatively simple; n may be estimated from tables of Manning's n and from the available information about bottom roughness (more general cases will be discussed later). These data can be used with tidal data and bay area characteristics to determine K as defined in equation (8); for specific values of K and β, values of h_{1+}, $a+$, u+, h_{1-}, $a-$, u−, and $\bar{h}_1$ can be found from the tables in Appendix A. The first six values provide data on maximum conditions for both floodtide and ebbtide. For β greater than zero, $\bar{h}_1$ will, in general be nonzero. All h_1 values can be dimensionalized by multiplying the dimensionless form by the semirange of tide in the sea, H; e.g., the maximum bay response is:

$$H_{1m} = H \cdot h_{1+} . \qquad (12)$$

The phase lag in degrees between maximum tide in the sea and the maximum water level in the basin is denoted by a (Fig. 4), and may be converted to time by:

$$\Delta t = \frac{T}{360} a . \qquad (13)$$

Maximum dimensionless inlet velocities, u+ and u−, at floodtide and ebbtide, are determined from:

$$u = \frac{(1 + \beta h_1)}{K} \frac{dh_1}{d\theta} . \qquad (14)$$

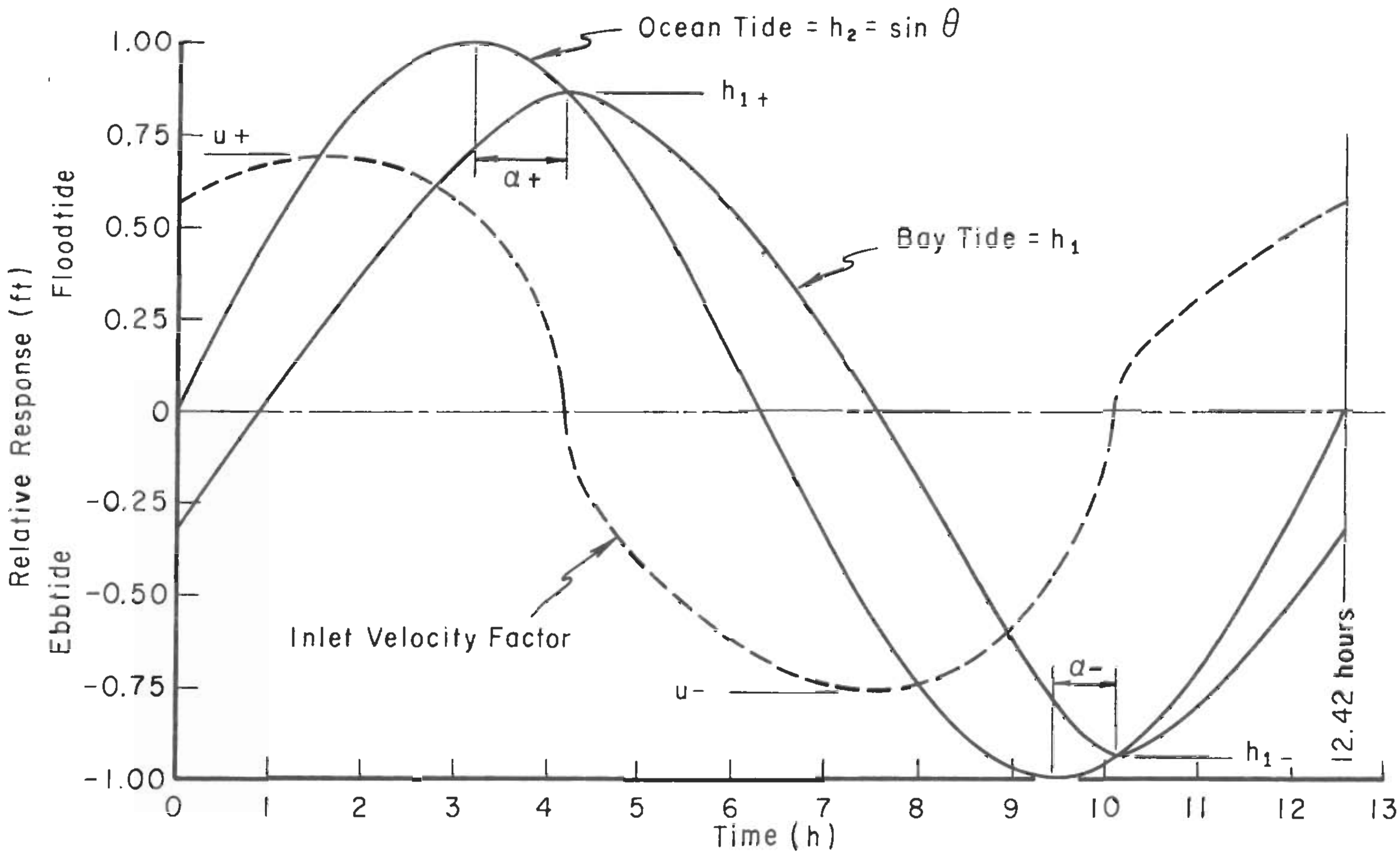

Figure 4. Typical solution and definition of terms for variable bay solutions.

From continuity,

$$\frac{2\pi H}{T}\frac{dh_1}{d\theta} = \frac{a}{A} V , \tag{15}$$

where V = tidal inlet velocity. Solving for V gives:

$$V = \frac{2\pi H}{T}\frac{A}{a}\frac{dh_1}{d\theta} . \tag{16}$$

This may also be written in terms of the dimensionless channel velocity as:

$$V = \frac{2\pi H}{T}\frac{A_o}{a} Ku , \tag{17}$$

with $\beta h_1 \simeq 0.0$ or in the equivalent form:

$$V = \sqrt{\frac{2gH}{1 + \lambda L/r}} \cdot u . \tag{18}$$

IV. THEORY OF GENERALIZED LUMPED PARAMETER

In addition to improving the computational method by accounting for the effect of variable surface area in the basin, it is also possible to include inertia effects in the flow through the inlet without significantly increasing the computational effort. Although inertia effects are generally small compared to the principal effects which govern the flow through the inlet, their inclusion does provide a more complete description of the physical processes involved. Shemdin and Forney (1970) developed a model which included the effect of flow inertia in the inlet. The lumped parameter model developed below includes both the inertia effects and Mota Oliveria's technique for including the effect of variable surface area in the basin.

The formulation of the lumped parameter model is derived here from energy and continuity equations. The energy equation is taken as:

$$H_2 - H_1 = C_v |V| V + \frac{L}{g} \dot{V} , \tag{19}$$

where heights, H, and inlet velocity, V, and length, L, are as previously defined, and $\dot{V}$ represents the time derivative of velocity or simply dV/dt (inlet flow acceleration).

A velocity coefficient, C_v, introduced for notational simplicity, accounts for inlet resistance and exit losses. This coefficient is given by:

$$C_v = \frac{1}{2g}\left(1 + \frac{\lambda L}{r}\right) . \tag{20}$$

Based on procedures suggested by Mota Oliveira (1970), C_v is a function of the head differential $(H_2 - H_1)$ since the hydraulic radius, r, is allowed to vary with time. The value of r is taken approximately as the sum of r_o, the hydraulic radius at mean sea level (MSL), and the average of H_1 and H_2. Introducing η as the average of H_1 and H_2,

$$\eta = \frac{1}{2}\left(H_1 + H_2\right) , \tag{21}$$

then

$$r = r_o + \eta . \tag{22}$$

After substituting for λ, C_v becomes:

$$C_v = \frac{1}{2g}\left[1 + \frac{2gn^2 L}{(1.486)^2}\,(r_o + \eta)^{-4/3}\right] . \tag{23}$$

The expression of conservation of mass for the inlet-basin system, considering that the density of the water remains constant, is given by:

$$A\dot{H}_1 = aV + q , \tag{24}$$

where the overdot signifies the time derivative and q is any basin inflow which does not pass through the inlet. This expression is an equation of volume continuity. The term on the left-hand side of the equation represents the change in volume of water in the basin during an interval of time. On the right-hand side of the equation, the first term is the discharge through the inlet and the second term is the discharge either into or from the system other than through the inlet during the same time interval. Note that q is positive when there is inflow to the system and negative when there is outflow from the system. Inflow can be caused by stream discharge, lateral drainage or direct rainfall on the basin. Outflow may arise from water being discharged from the basin through channels which lead to other bodies of water of lower head. Clearly q is to be taken as the algebraic sum when there is both inflow and outflow; moreover, q must be specified as a known function of time.

Equations (19) and (24) expressed in the terms of the time derivatives of V and H_1, are:

$$\dot{V} = \frac{g}{L}(H_2 - H_1 - C_V |V|V) \ . \tag{25}$$

$$\dot{H}_1 = \frac{1}{A}(aV + q) \ . \tag{26}$$

This gives two simultaneous differential equations in which both H_2 and q are basic input to the problem and prescribed as a function of time.

Equation (25) is nonlinear because energy losses in the inlet channel are governed by the square of the inlet velocity and C_v is a function of the head differential between the sea and basin.

Mota Oliveira (1970) assumed vertical walls confining the inlet which yields a cross-sectional area function given by:

$$a = a_o + w_o \eta \ . \tag{27}$$

To eliminate the restriction of vertical inlet walls, a_o may be taken as the area at MSL, w_o is taken as the width at MSL and ζ is introduced as the beach slope, horizontal-vertical, within the tidal range. This gives a cross-sectional area function,

$$a = a_o + w_o \eta + \zeta \eta^2 \ . \tag{28}$$

It has been found that for beach slopes of less than 100:1, the quadratic term in equation (28) will seldom be more than a few percent. Consequently, it is concluded that a precise determination of ζ is unnecessary.

By using equations (25) and (26) both the bay tide, H_1, and inlet velocity, V, can be estimated if the following functions and parameters are known:

$H_2(t)$,	ocean tide,
$q(t)$,	inflow,
A_o,	mean bay surface area,
β,	surface area variation parameter,
a_o,	MSL inlet area,
r_o,	MSL inlet hydraulic radius,
L,	inlet length,
n,	Manning's n,
w_o,	MSL inlet width, and
ζ,	inlet beach slope.

As mentioned previously, these data, other than Manning's n, can be readily determined for a well defined inlet; their determination for the more common irregularly defined inlets is discussed in the following section. Manning's n is essentially estimated from a knowledge of bottom characteristics and later adjusted to a satisfactory calibration of the model.

V. DETERMINATION OF EQUIVALENT K FOR NONPRISMATIC INLETS

Because inlet channels are generally irregular in both width and depth throughout their length, the assumption of a prismatic inlet is not always valid. To account for such variations, the following method for calculating an equivalent K_1 has been developed.

The inlet vicinity is divided into several parallel channels (three shown in Fig. 5); partitioning of the channel is arbitrary. The goal is to obtain nearly uniform values of r, λ, v, and A in each cell, but generally these conditions cannot be satisfied exactly. At each cross section, A, B, C, D . . . the cross-sectional area for each channel 1, 2, 3, . . . is determined, including the width of the channel. Along each shoreline and between adjacent channels, longitudinal segment length can be measured and averaged so that each channel segment is given a representative length. Since an area and width are known for each section and since depths are small compared to widths, representative hydraulic radii can be computed for each section from:

$$r = \frac{\text{area}}{\text{width}} \; . \tag{29}$$

Table 1 illustrates the data needed in defining the inlet characteristics for the inlet shown schematically in Figure 5.

The coefficient of repletion represents the effect of inlet conditions on the energy conversion within the inlet. This conversion is related to the expression,

$$\left(\frac{V^2}{2g}\right)\left(1 + \frac{\lambda L}{r}\right) . \tag{30}$$

Within the parentheses, the first term represents the loss of energy necessary to convert potential energy in the sea to kinetic energy in the inlet channel. The velocity, V, in the inlet reaches a maximum value where the contraction is the greatest or at the location where a minimum cross-sectional area exists in the inlet. In general, this minimum inlet cross-sectional area, a_m, equals the sum of the minimum cross-sectional areas of the i^{th} channels,

$$a_m = \sum_{i=1}^{i_m} a_{mi} \; ,$$

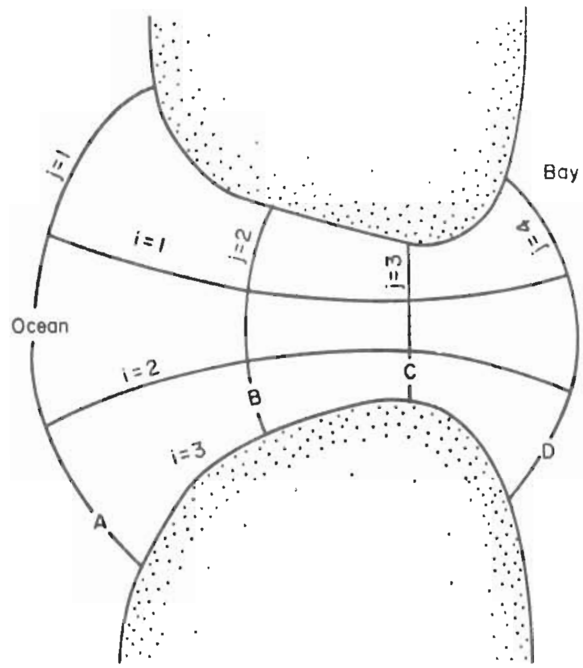

Figure 5. Nonprismatic inlet representation.

Table 1. Required data specifications for nonprismatic inlet computation.

Section	Channel		
	1	2	3
A-1	a_{11}	a_{12}	a_{13}
B-2	a_{21}	a_{22}	a_{23}
C-3	a_{31}	a_{32}	a_{33}
D-4	a_{41}	a_{42}	a_{43}
A-1	r_{11}	r_{12}	r_{13}
B-2	r_{21}	r_{22}	r_{23}
C-3	r_{31}	r_{32}	r_{33}
D-4	r_{41}	r_{42}	r_{43}
0	0	0	0
A-B 1	ΔL_{11}	ΔL_{12}	ΔL_{13}
B-C 2	ΔL_{21}	ΔL_{22}	ΔL_{23}
C-D 3	ΔL_{31}	ΔL_{32}	ΔL_{33}
4	0	0	0

where i_m = number of channels. For the example in Figure 5, the number of channels equals three, $i_m = 3$, and minimum cross-sectional areas for each i^{th} channel are at section C, so $a_{mi} = a_{Ci}$. For this example, the minimum inlet cross-sectional area, a_m, is found by:

$$a_m = \sum_{i=1}^{3} a_{Ci} .$$

The term $\lambda L/r$ represents the energy lost as a result of bottom friction. Its value can be determined by integrating the differential effects over the entire inlet. The segmatized inlet representation facilitates a numerical approximation to such a procedure.

According to Keulegan (1967), the energy loss in the inlet is equal to the head difference between sea and basin. This is given by:

$$V^2 \left(1 + \frac{\lambda L}{r}\right) = 2gH\,(h_2 - h_1) . \tag{31}$$

For the i^{th} irregular parallel channel this may be rewritten as:

$$V_{Mi}^2 + \int_0^L \frac{\lambda_{xi}\; V_{xi}^2}{r_{xi}}\, dx = 2gH\,(h_2 - h_1) , \tag{32}$$

where V, λ, and r are functions of x; V_{Mi}, the maximum velocity in the channel, is related to the flow Q_i. Thus,

$$Q_i = a_{mi}\; V_{Mi} , \tag{33}$$

and

$$Q_{xi} = a_{xi}\; V_{xi} . \tag{34}$$

Substituting equation (33) into equation (32) gives:

$$Q_i^2 = \left[\frac{1}{a_{mi}^2} + \int_0^L \frac{\lambda_{xi}}{r_{xi}\, a_{xi}^2}\, dx\right] = 2gH\,(h_2 - h_1) . \tag{35}$$

Solving for Q_i gives:

$$Q_i = \frac{\sqrt{2gH\ (h_2 - h_1)}}{\sqrt{\dfrac{1}{a_{mi}^2} + \displaystyle\int_0^L \frac{\lambda_{xi}}{r_{xi}\ a_{xi}^2}\, dx}} \ . \tag{36}$$

By combining equations (12) and (15) the continuity equation may be expressed in the form:

$$Q = \frac{dH_1}{dt} A \ , \tag{37}$$

and Q, the flow in the entire inlet, is the sum of the flows in the individual channels,

$$Q = \sum_{i=1}^{i_m} Q_i = A \frac{dH_1}{dt} \ . \tag{38}$$

Also,

$$\frac{dH_1}{dt} = \frac{2\pi H}{T} \frac{dh_1}{d\theta} \ . \tag{39}$$

Thus,

$$Q = \sum_{i=1}^{i_m} Q_i = \frac{2\pi HA}{T} \frac{dh_1}{d\theta} \ . \tag{40}$$

Solving equation (40) for dh_1/d_θ, substituting from equation (36) and multiplying both numerator and denominator by a_m give:

$$\frac{dh_1}{d\theta} = \underbrace{\frac{T}{2\pi H} \frac{a_m}{A} \sqrt{2gH} \sum_{i=1}^{i_M} \left[\frac{1}{\sqrt{\left[\dfrac{a_m}{a_{mi}}\right]^2 + \displaystyle\int_0^L \frac{\lambda_{xi}}{r_{xi}} \left[\frac{a_m}{a_{xi}}\right]^2 dx}} \right]}_{K_1} \sqrt{h_2 - h_1} \ . \tag{41}$$

To determine K_1, values of a_m, A, a_{mi}, a_{xi}, r_{xi} are taken at mean tide level. The integral in equation (36) is replaced by the numerical approximation

$$a_m^2 \int_0^L \frac{\lambda_{xi}}{r_{xi}\ a_{xi}^2}\, dx \simeq \frac{a_m^2\ 2gn^2/(1.486)^2}{2} \sum_{j=1}^{j_m} \frac{r_{ji}^{-4/3}}{a_{ji}^2} (x_j - x_{j-1})\ x_o = 0 \ . \tag{42}$$

Thus, an effective coefficient of repletion can be determined with the following equation:

$$K_1 = \frac{T}{2\pi H} \frac{a_m}{A} \sqrt{2gH} \sum_{i=1}^{i_M} \left[\frac{1}{\sqrt{\left[\frac{a_m}{a_{mi}}\right]^2 + \int_0^L \frac{\lambda_{xi}}{r_{xi}} \left[\frac{a_m}{a_{xi}}\right]^2 dx}} \right]. \tag{43}$$

If an inlet is not prismatic, the determination of a_o, L, w_o, and ζ is more difficult. An equivalent coefficient of repletion can be determined as described in the previous section. For reasons similar to those discussed, a_o, w_o, and ζ should be determined in the throat region; a_o being the MSL inlet area at the throat, w_o the MSL width, and ζ the representative beach slope of the inlet between high and low water.

The length, L, may be adequately defined as the average length of the parallel channels selected. Only r_o remains to be determined and the following procedure may be used. Since K_1 may be computed from equation (44), r_o may be taken as the unknown in the original definition of K (eq. 8).

Substitution from equations (8) and (9) rearranging terms and squaring both sides of the resulting equation gives:

$$\left[\frac{2\pi HAK_1}{Ta_o}\right]^2 = \frac{\sqrt{2gH}}{1 + \frac{2gn^2 L}{(1.486)^2} r_o^{-4/3}},$$

where K_1 has been substituted for K in equation (8), and finally,

$$r_o = \left\{\frac{1.104}{gn^2 L}\left[\frac{g}{2H}\left(\frac{Ta_o}{\pi K_1 A_o}\right)^2 - 1\right]\right\}^{-3/4}. \tag{44}$$

Application of the lumped parameter technique is discussed in Appendix B.

VI. APPLICATION: MASONBORO INLET, NORTH CAROLINA

The calibration, verification, and application of the mathematical model described to Masonboro Inlet, North Carolina, are discussed in this section (Fig. 6). The model was calibrated by reproducing the prototype inlet velocities of 12 September 1969. Application was then made to the system using hydrographic conditions of November 1964 and July 1966.

Hydrographic conditions in the immediate vicinity of Masonboro Inlet in October 1969 are shown in Figure 7. The grid shown in this figure indicates the independent channels adopted for representing an equivalent prismatic inlet.

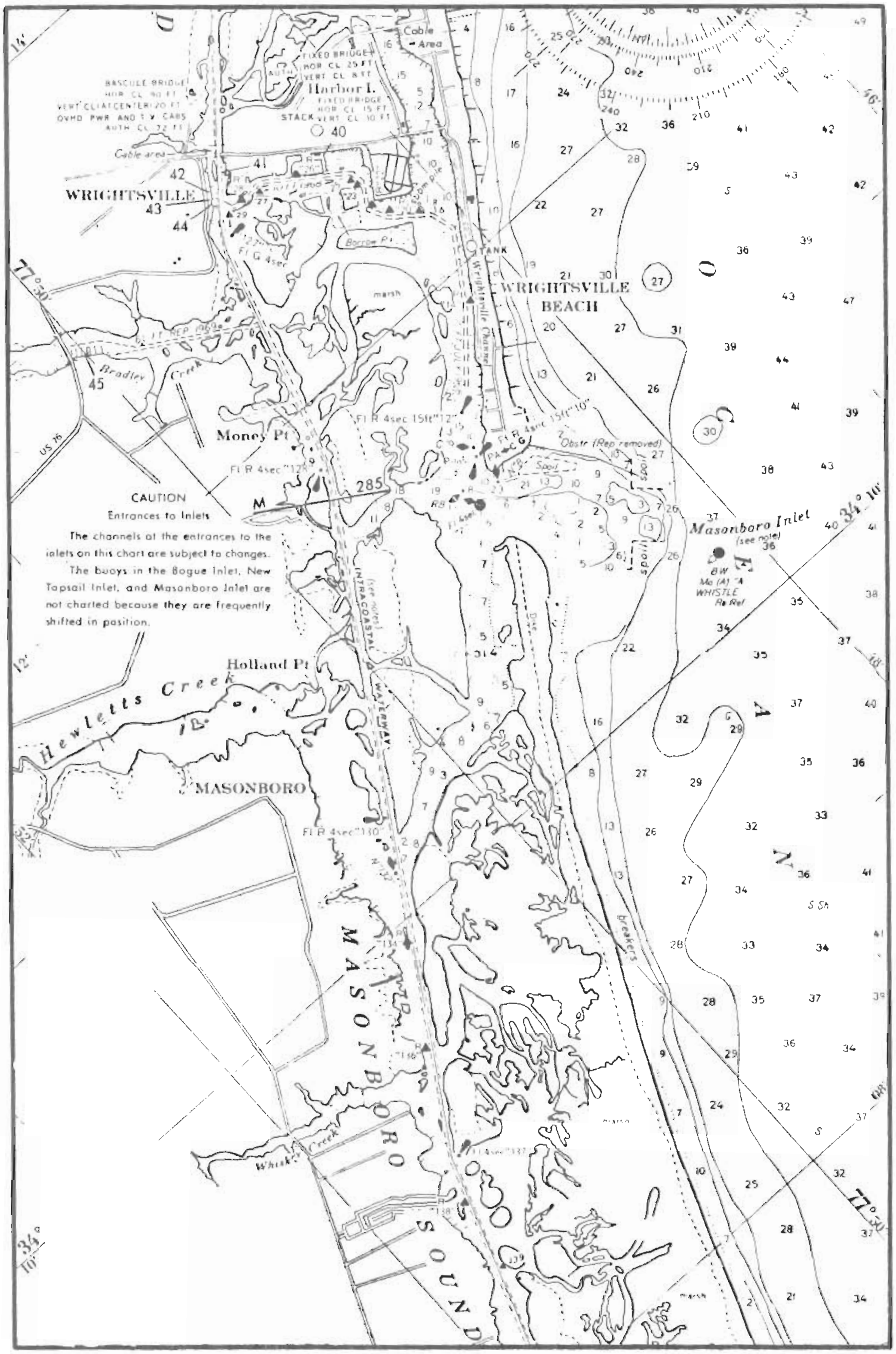

Figure 6. Masonboro Inlet, North Carolina.

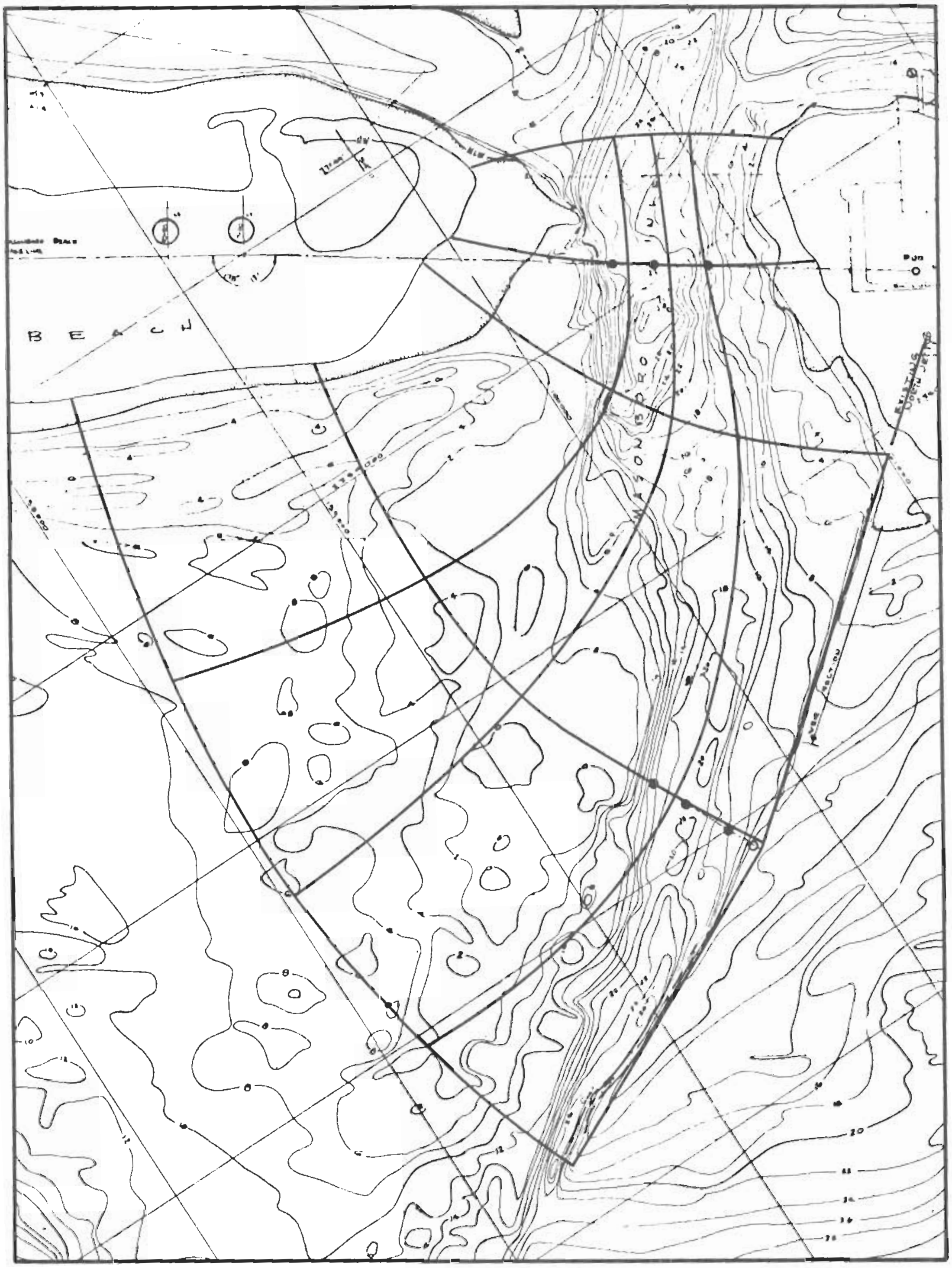

Figure 7. Hydrography and assumed flow grid, October 1969.

A tabulation of measured prototype velocities for 12 September 1969 taken at the inlet throat is included in Table 2. These velocities were used with the throat cross section (Fig. 8) to compute the flows given in Table 2 and the tidal prism in Figure 9. An attempt was made to compute the tidal prism from the bay surface areas but this method did not give satisfactory results. This is probably due to the problem of delineating the effective surface area which contributes to the tidal prism. On this basis the inlet velocity data were used to determine the tidal prism. A bay tidal range of 4 feet was assumed for calculating the mean bay surface area from the observed ocean tide for 12 September 1969 shown in Figure 10. While the flows shown in Figure 9 indicate a small outflow through other outlets, the magnitude is so slight in comparison to the total flow that its effect is considered negligible. If sufficient information was available for describing this outflow it could have been included in the numerical computations.

Using the procedure described previously, the grid of Figure 7 was cross-sectioned and segmented so that the equivalent prismatic inlet characteristics could be found. The cross sections used, indexing from ocean to lagoon, are shown in Figures 11 through 15. These sections were plotted and their areas computed by the program SECPLT (App. C). The various areas, widths, and lengths determined are listed in Table 3 with the resulting equivalent area, width, length, and hydraulic radius produced by program INLET (App. D). The values thus obtained are then used to define an inlet system which can be analyzed by the subroutine INLT2 whose output is tabulated in Table 4. An initial computation was made using a simple sinusoidal tide with a period of 12 hours and 25 minutes. A graphical presentation of this analysis is shown in Figure 16 as produced by subroutine GRAPHIC; this figure permits a comparison of computed and measured prototype velocities. The relatively good velocity agreement was obtained by positioning the grid in Figure 7 so that all of the channels at any given cross section had approximately the same cross-sectional area and then adjusting the value assumed for Manning's n to obtain maximum agreement for the calibration condition.

In a second computation for the 12 September 1969 inlet conditions (Tables 5 and 6, and Fig. 17), the observed ocean tide was used as input rather than approximating the ocean tide by a simple sine curve of appropriate amplitude. Overall agreement between observed and computed velocities was not substantially changed. Therefore, in later computations the ocean tide was approximated by a sine curve. The values of Manning's n, obtained in the calibration procedure were retained.

After the computations for 12 September 1969 resulted in an acceptable comparison of observed and calculated inlet velocities, the lumped parameter model was used to predict inlet-bay interaction for various conditions. In all predictive computations, equivalent inlet dimensions were developed by the same procedure used with the 12 September 1969 data and the same Manning coefficient (0.027) was used.

Table 2. Prototype data-velocities and flows (Range 2) 12 September 1969.

Time (h)	Surface (hgt)	Measured velocities (ft/s) Range S B	M	S	Range C B	M	S	Range N B	M	S	Velocity (mean)	Inflow ($M\#ft^3/s$)
8.50	1.78	0.8	1.0	−0.5	0.8	1.0	1.2	1.8	1.2	1.2	0.89	15.18
9.00	1.48	−1.0	−1.6	−1.8	−1.4	−1.4	−1.8	−1.2	1.0	1.0	−0.93	−15.42
9.50	1.06	−2.5	−3.5	−3.5	−2.8	−3.4	−3.4	−0.8	−1.0	−1.0	−2.60	−41.60
10.00	0.55	−3.0	−4.0	−4.2	−2.6	−4.0	−3.8	−1.4	−1.2	−1.0	−2.98	−45.75
10.50	0.00	−3.1	−4.8	−4.9	−4.0	−4.8	−4.7	−0.8	−0.8	−0.8	−3.45	−50.46
11.00	−0.50	−4.0	−5.5	−5.7	−4.2	−5.2	−5.5	−0.4	−0.6	−0.8	−3.80	−53.20
11.50	−0.96	−4.2	−5.6	−5.6	−3.0	−5.4	−5.0	−1.1	−1.2	−0.6	−3.83	−51.25
12.00	−1.43	−4.0	−5.0	−5.0	−2.4	−4.6	−4.4	−0.2	−1.2	−1.4	−3.34	−42.62
12.50	−1.82	−4.3	−4.9	−4.9	−2.8	−4.2	−4.2	−1.0	−0.4	−0.2	−3.18	−38.98
13.00	−2.06	−3.5	−4.0	−4.2	−2.0	−3.5	−3.7	−0.4	−0.6	−0.6	−2.61	−31.22
13.50	−2.11	−2.0	−3.5	−3.3	−2.2	−3.0	−3.0	−0.2	−0.5	−0.6	−2.19	−26.08
14.00	−2.10	−2.4	−2.6	−2.4	−1.8	−2.2	−2.2	−0.5	−0.3	0.4	−1.74	−20.70
14.50	−1.94	−1.0	−1.4	−1.5	−1.2	−1.2	−1.2	0.5	0.4	0.5	−0.77	−9.36
15.00	−1.54	0.6	0.6	0.5	0.5	0.6	0.5	0.5	0.6	0.6	0.57	7.19
15.50	−1.25	0.6	0.8	1.2	0.8	1.2	1.4	1.0	1.4	1.4	1.08	13.99
16.00	−0.65	1.3	2.1	2.0	2.6	2.6	2.8	1.8	2.2	2.8	2.29	31.61
16.50	0.00	1.7	2.6	2.0	2.8	2.8	2.6	2.3	2.7	3.0	2.57	37.61
17.00	0.50	2.5	3.1	3.4	3.0	3.6	3.0	2.5	3.0	3.3	3.12	47.77
17.50	0.97	2.4	3.4	2.6	2.8	3.6	3.0	2.6	3.3	3.6	3.13	49.86
18.00	1.30	2.6	2.8	2.6	2.2	3.8	3.4	2.2	2.8	3.3	2.97	48.53
18.50	1.57	2.8	3.2	3.0	2.6	3.4	3.2	1.8	2.9	3.4	3.03	50.51
19.00	1.90	3.0	3.4	3.0	2.7	3.4	3.2	2.0	3.0	3.2	3.08	52.74
19.50	2.10	2.6	2.8	2.6	2.0	3.0	3.0	1.8	2.5	2.9	2.66	46.30
20.00	2.10	2.0	1.8	2.2	1.8	2.0	2.2	1.8	2.0	2.0	2.00	34.69
20.50	1.89	0.6	1.2	1.3	0.9	0.8	0.8	0.7	0.8	1.0	0.93	15.91
21.00	1.50	−1.2	−1.6	−1.8	−1.2	−2.0	−1.8	−0.7	−0.6	−0.8	−1.39	−23.09

B = bottom
M = mean depth
S = surface

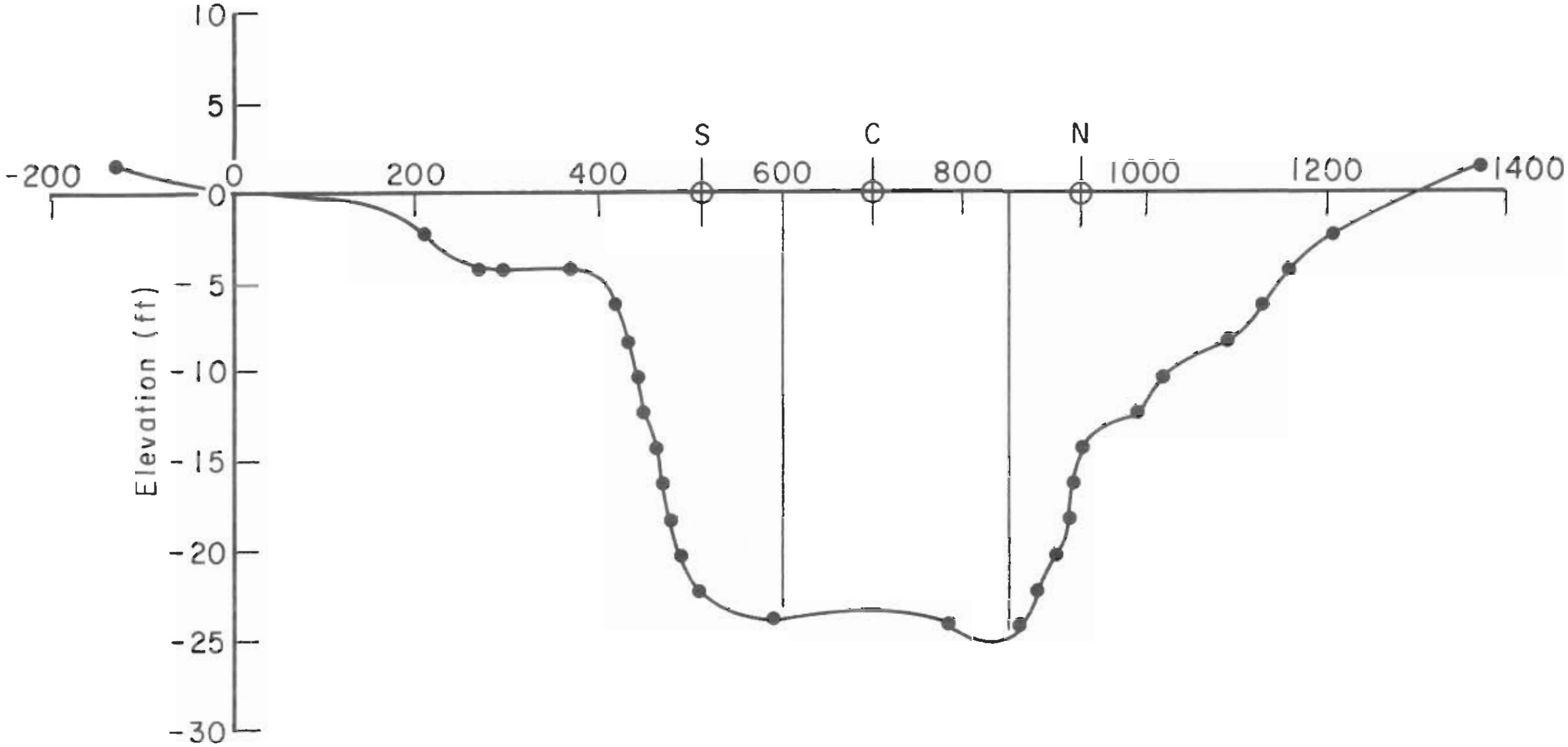

Figure 8. Range 2 gaging stations and assumed flow sections, 12 September 1969.

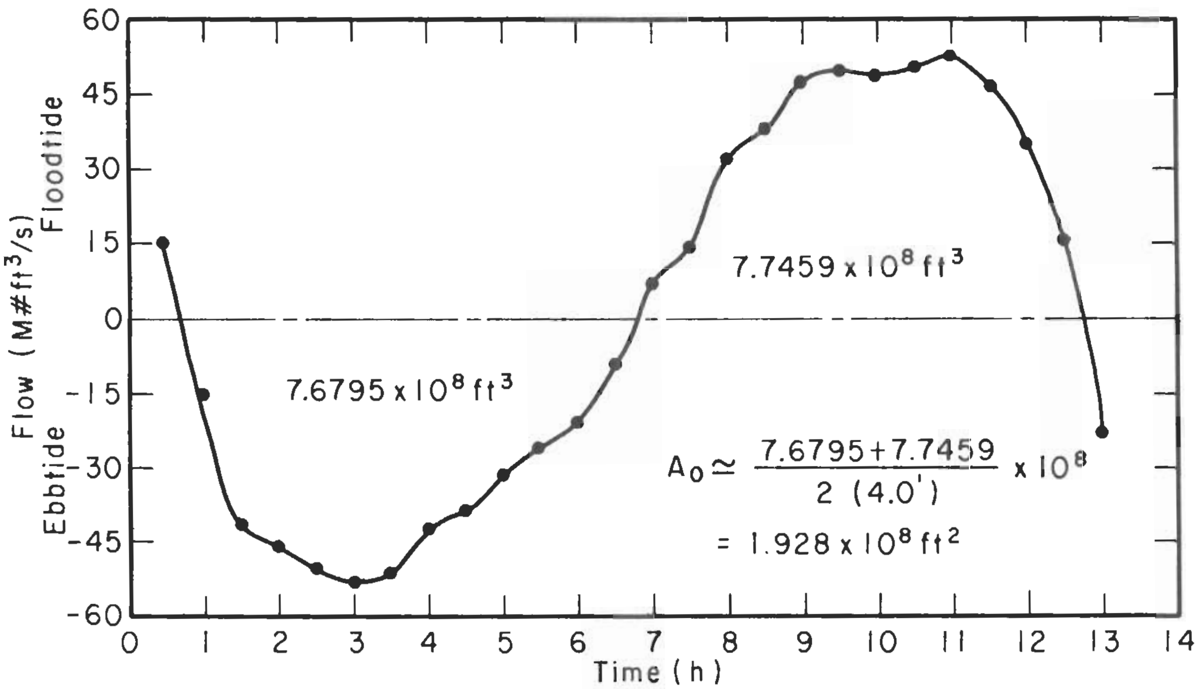

Figure 9. Tidal flows for Masonboro Inlet, 12 September 1969.

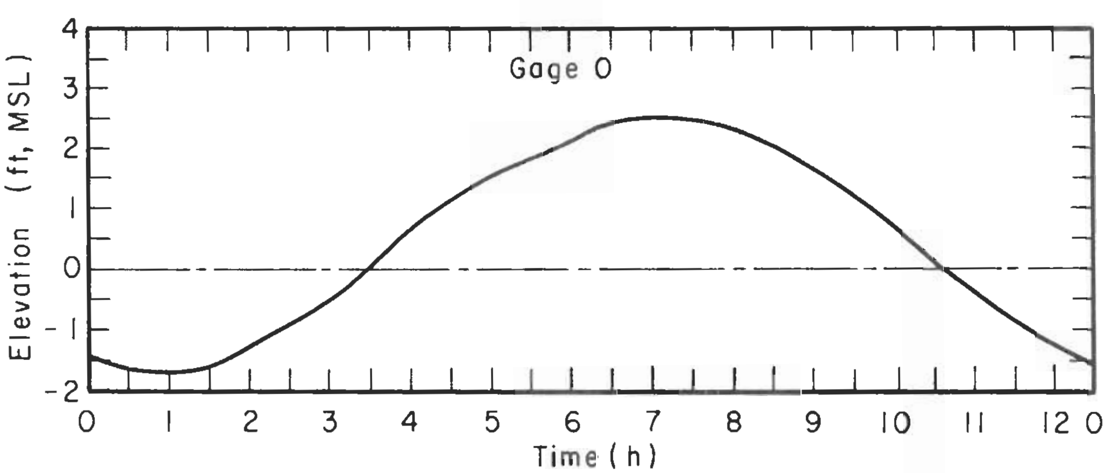

Figure 10. Prototype tidal elevations, 12 September 1969.

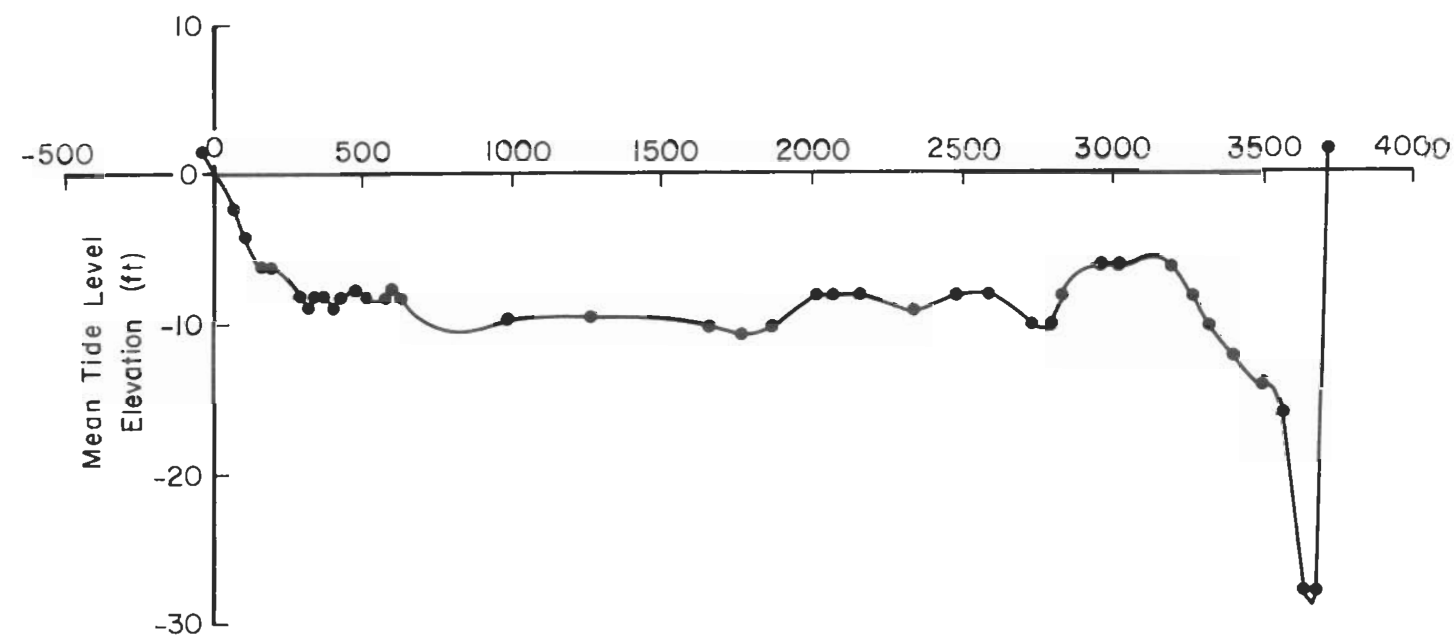

Figure 11. Cross section 1, 12 September 1969.

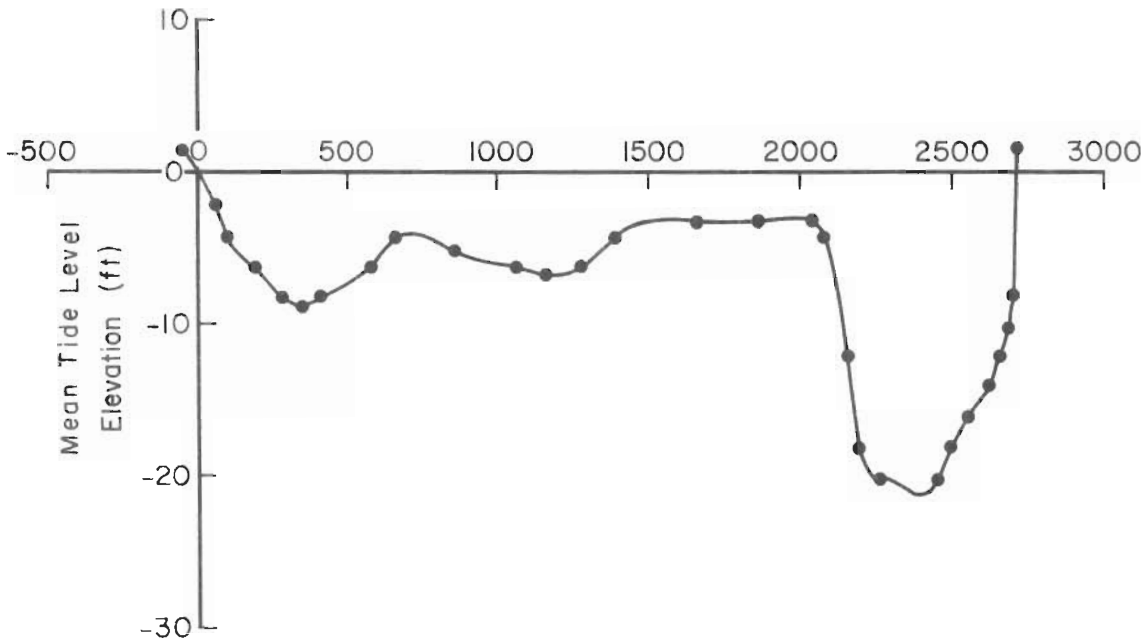

Figure 12. Cross section 2, 12 September 1969.

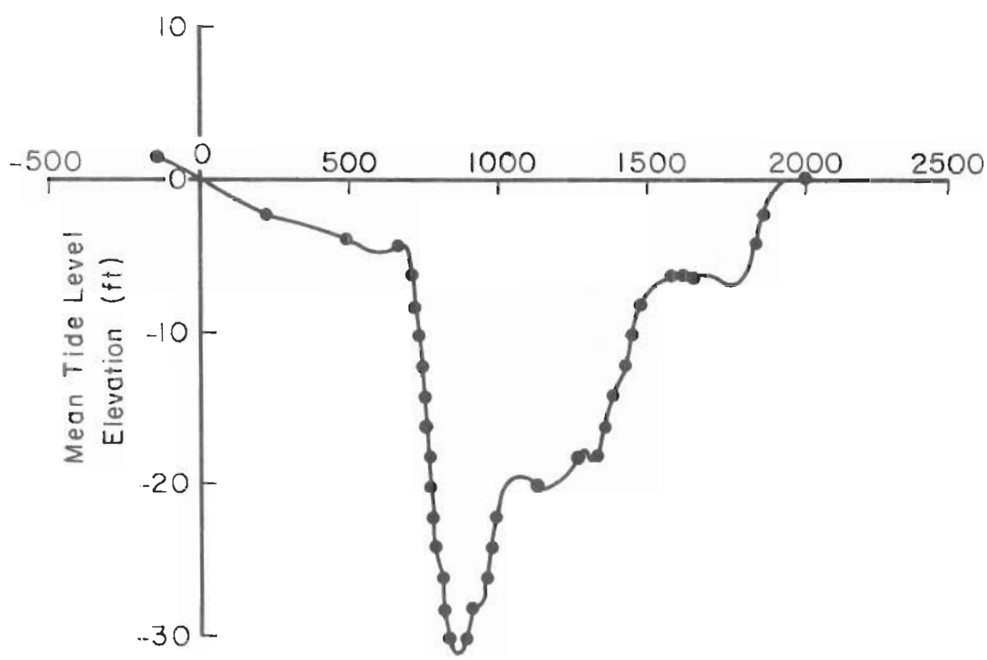

Figure 13. Cross section 3, 12 September 1969.

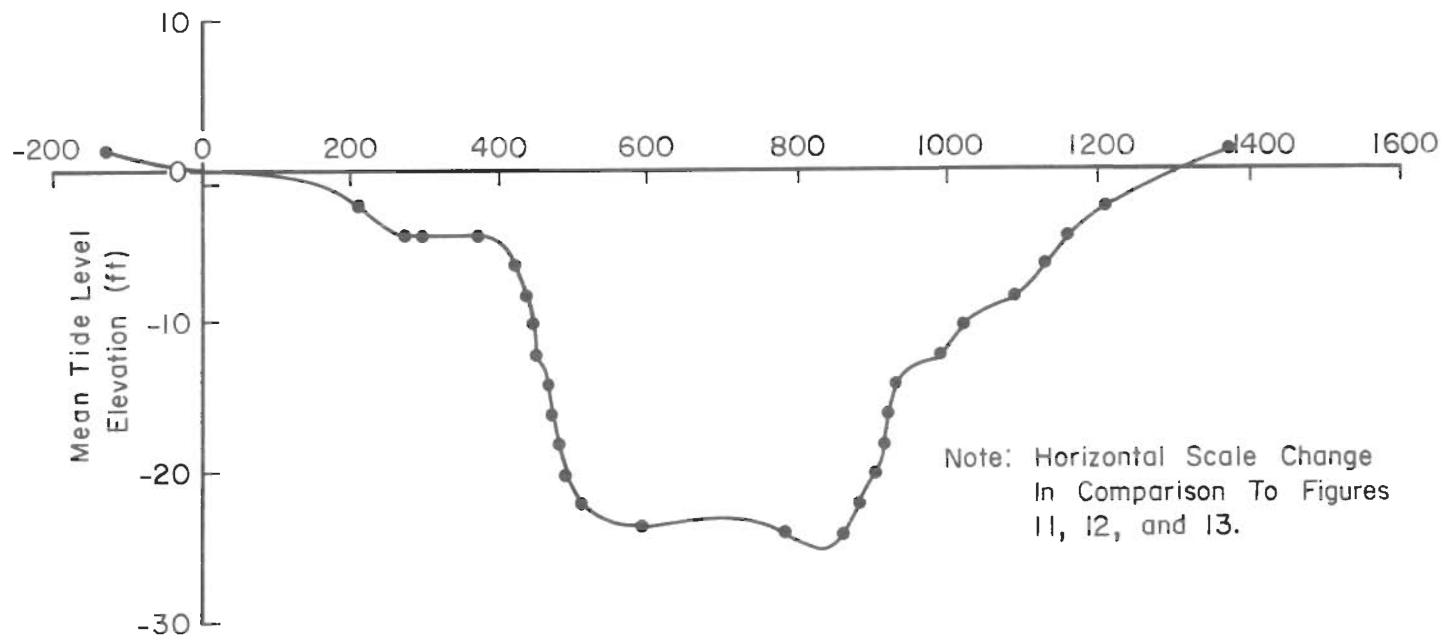

Figure 14. Cross section 4, 12 September 1969.

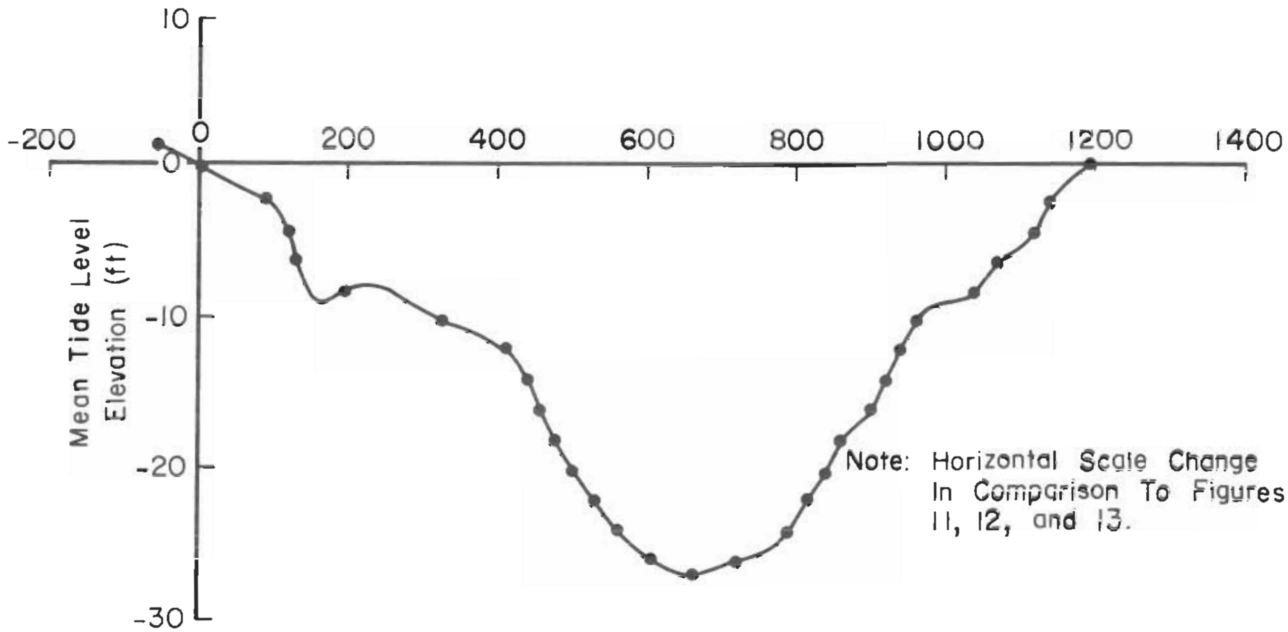

Figure 15. Cross section 5, 12 September 1969.

Table 3. Equivalent coefficient of repletion for nonprismatic inlet, 12 September 1969.

Verification conditions											
Area (ft^2)				Width (ft)				Length (ft)			
9610	9670	6910	8860	1170	1000	800	770	0	0	0	0
5530	3370	5540	6680	940	620	760	400	1030	1150	1320	1460
4260	6400	5130	4350	820	250	265	610	860	1180	1400	1570
3860	3900	3850	3030	575	165	160	410	365	585	665	725
4020	4020	4020	4020	485	160	160	340	437	532	545	550
								0	0	0	0

Tidal period = 12.417 hours.
Tidal semirange = 2.150 feet.
Bay area (mean sea level) = 1.928000E + 08 square feet.
Manning's n = 0.0270.
Coefficient of repletion = 1.553.
Inlet area = 1.464000E + 04 square feet.
Inlet length = 3.593500E + 03 feet.
Inlet depth = 12.545 feet.
Inlet width = 1,310 feet.

Table 4. Computed tides and flows, 12 September 1969.

Verification conditions					
Time (h)	H2 (ft)	Inflow (M#f•3/s)	H1 (ft)	Velocity (ft/s)	Discharge (M#ft3/s)
0.00	0.00	0.00	–0.56	3.10	44.27
0.50	0.54	0.00	–0.10	3.38	50.46
1.00	1.04	0.00	0.39	3.52	55.01
1.17	1.20	0.00	0.55	3.54[1]	56.01
1.50	1.48	0.00	0.86	3.50	56.98
1.58	1.54	0.00	0.94	3.48	56.99[1]
2.00	1.82	0.00	1.31	3.28	55.29
2.50	2.05	0.00	1.70	2.81	48.71
3.00	2.15	0.00	2.01	2.02	35.66
3.08	2.15[1]	0.00	2.05	1.84	32.68
3.50	2.11	0.00	2.19	0.71	12.70
3.67	2.06	0.00	2.21[1]	0.05	0.89
4.00	1.93	0.00	2.15	–1.54	–27.14
4.50	1.64	0.00	1.90	–2.26	–38.80
5.00	1.23	0.00	1.61	–2.64	–43.88
5.50	0.75	0.00	1.26	–3.05	–48.90
6.00	0.23	0.00	0.85	–3.39	–52.07
6.42	–0.23	0.00	0.49	–3.58	–52.96[1]
6.50	–0.32	0.00	0.41	–3.60	–52.95
6.92	–0.75	0.00	0.01	–3.67[1]	–51.95
7.00	–0.84	0.00	–0.07	–3.67	–51.57
7.50	–1.31	0.00	–0.56	–3.57	–48.10
8.00	–1.69	0.00	–1.04	–3.28	–42.65
8.50	–1.97	0.00	–1.50	–2.79	–35.16
9.00	–2.12	0.00	–1.90	–2.05	–25.27
9.33	–2.15[1]	0.00	–2.10	–1.37	–16.77
9.50	–2.14	0.00	–2.16	–0.95	–11.61
9.83	–2.08	0.00	–2.22[1]	0.20	2.45
10.00	–2.02	0.00	–2.18	0.92	11.21
10.50	–1.77	0.00	–1.95	1.59	19.80
11.00	–1.41	0.00	–1.66	1.89	24.24
11.50	–0.96	0.00	–1.32	2.35	31.12
12.00	–0.45	0.00	–0.93	2.79	38.42
12.50	0.09	0.00	–0.49	3.15	45.38

[1]Critical point value.

Tidal semirange = 2.150 feet.
Mean bay surface area = 1.9280E + 08 square feet.
Bay side slope parameter beta = 0.350.
Average bay level = 0.03 feet.
Inlet properties:
X-section area below mean tide level = 1.46400E + 04 square feet.
Inlet width at mean tide level = 1,310 feet.
Inlet beach slope = 75:1.
Mean tide level depth = 12.545 feet.
Inlet length = 3,594 feet.
Manning's n = 0.0270.

Table 5. Equivalent coefficient of repletion for nonprismatic inlet, 12 September 1969.

Observed tides											
Area (ft^2)				Width (ft)				Length (ft)			
9610	9670	6910	8860	1170	1000	800	770	0	0	0	0
5530	3370	5540	6680	940	620	760	400	1030	1150	1320	720
4260	6400	5130	4350	820	250	265	610	860	1180	1400	755
3860	3900	3850	3030	575	165	160	410	365	585	665	350
4020	4020	4020	4020	485	160	160	340	437	532	545	275
								0	0	0	0

Tidal period = 12.417 hours.
Tidal semirange = 2.150 feet.
Bay area (mean sea level) = 1.92800E + 04 square feet.
Manning's n = 0.0270.
Coefficient of repletion = 1.636.
Inlet area = 1.46400E + 04 square feet.
Inlet length = 3.04250E + 03 feet.
Inlet depth = 12.360 feet.
Inlet width = 1,310 feet.

Table 6. **Computed tides and flows for nonprismatic inlet, 12 September 1969.**

Observed tide conditions					
Time (h)	H2 (ft)	Inflow (M#ft³/s)	H1 (ft)	Velocity (ft/s)	Discharge (M#ft³/s)
0.00	0.13	0.00	–0.45	3.37	48.67
0.50	0.63	0.00	0.04	3.48	52.55
0.75	0.88	0.00	0.28	3.52[1]	54.32
0.92	1.01	0.00	0.44	3.49	54.62[1]
1.00	1.07	0.00	0.52	3.46	54.35
1.50	1.36	0.00	0.96	3.04	49.38
2.00	1.65	0.00	1.33	2.72	45.63
2.50	1.94	0.00	1.67	2.58	44.47
3.00	2.08	0.00	1.96	1.98	34.79
3.17	2.09[1]	0.00	2.04	1.61	28.34
3.50	2.04	0.00	2.13	0.56	9.93
3.67	1.99	0.00	2.14[1]	–0.24	–4.23
4.00	1.87	0.00	2.05	–1.74	–30.41
4.50	1.61	0.00	1.81	–2.07	–35.47
5.00	1.27	0.00	1.54	–2.36	–39.18
5.50	0.82	0.00	1.22	–2.84	–45.59
6.00	0.28	0.00	0.83	–3.34	–51.42
6.33	–0.07	0.00	0.54	–3.52	–52.59[1]
6.50	–0.24	0.00	0.39	–3.55	–52.32
6.67	–0.40	0.00	0.24	–3.56[1]	–51.68
7.00	–0.71	0.00	–0.07	–3.53	–49.92
7.50	–1.18	0.00	–0.55	–3.44	–46.73
8.00	–1.60	0.00	–1.03	–3.26	–42.52
8.50	–1.91	0.00	–1.49	–2.81	–35.52
9.00	–2.05	0.00	–1.88	–1.96	–24.22
9.33	–2.07[1]	0.00	–2.06	–1.18	–14.44
9.50	–2.07	0.00	–2.11	–0.72	–8.86
9.75	–2.05	0.00	–2.14[1]	0.07	0.81
10.00	–2.01	0.00	–2.10	0.85	10.37
10.50	–1.68	0.00	–1.89	1.70	21.26
10.83	–1.40	0.00	–1.67	2.18[1]	27.96
10.92	–1.36	0.00	–1.61	2.18	28.05[1]
11.00	–1.32	0.00	–1.56	2.14	27.64
11.25	–1.18	0.00	–1.39	1.98[1]	25.90[1]
11.50	–0.95	0.00	–1.23	2.13	28.36
12.00	–0.34	0.00	–0.84	3.00	41.72
12.50	0.22	0.00	–0.37	3.40	49.43

[1]Critical point value.

Tidal semirange	= 2.150 feet.
Mean bay surface area	= 1.928E + 08 square feet.
Bay side slope parameter beta	= 0.350.
Average bay level	= 0.05 feet.
Inlet properties:	
X-section area below mean tide level	= 1.4640E + 04 square feet.
Inlet width at mean tide level	= 1,310 feet.
Inlet beach slope	= 75:1.
Mean tide level depth	= 12.360 feet.
Inlet length	= 3,042 feet.
Manning's n	= 0.0270.

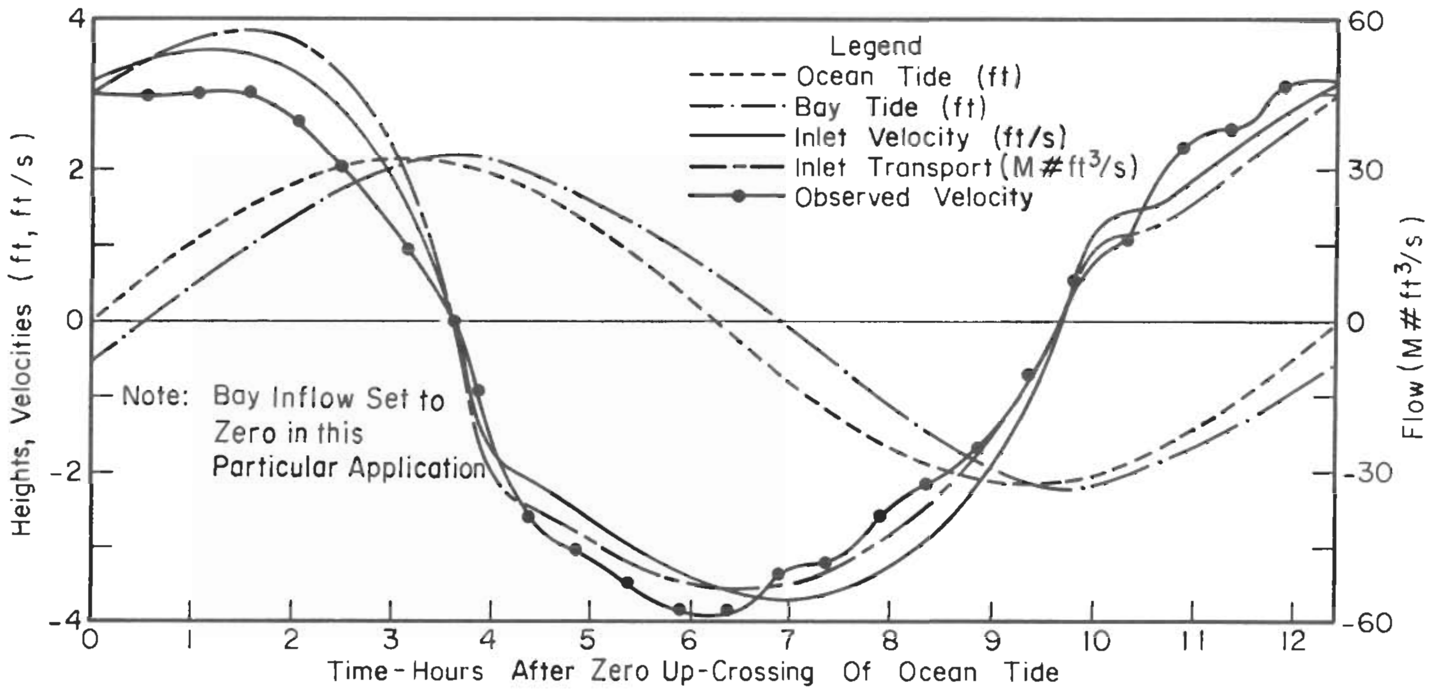

Figure 16. Verification conditions, 12 September 1969.

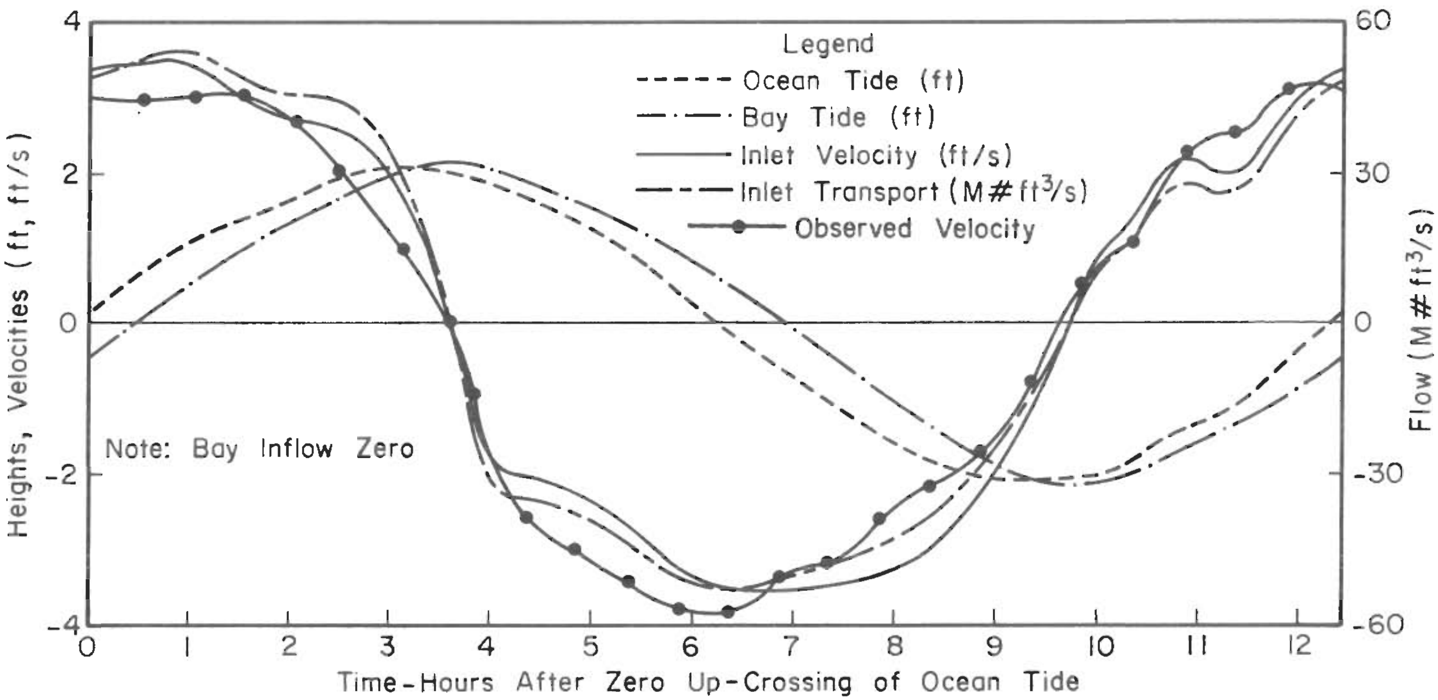

Figure 17. Observed tides, 12 September 1969.

The first such computation was for long-term mean conditions for 1969. Cross sections for 12 September 1969 were adjusted by 0.35 foot to lower the reference to MSL. Then the mean surface area of the bay was reduced from 192,800,000 square feet computed for MTL on 12 September 1969 to the area corresponding to MSL. This reduction was obtained by assuming that the area varies linearly with the water level and is governed by a β of 0.35. The mean surface area at the MSL datum is given by:

$$A_{o_{MSL}} = A_{o_{MTL}} \left[1 - \frac{\beta \bar{h}_1}{2H} \right] = 1.866 \times 10^8 \text{ ft}^2 .$$

where $\bar{h}_1$ is the MTL superelevation of 0.35 foot and H is the long-term mean semirange of 1.9 feet. Other inlet characteristics were revised accordingly and flow conditions computed (Tables 7 and 8, and Fig. 18).

Similar computations were made for the following conditions:

(a) 1964 hydrography; before construction of north jetty (Figs. 19 and 20, and Tables 9 and 10).

(b) 1966 hydrography; after north jetty was constructed (Figs. 21 and 22, and Tables 11 and 12).

(c) Proposed plan B; includes construction of south jetty and additional channel dredging (Figs. 23 and 24, and Tables 13 and 14).

With all conditions modeled, major results (Table 15) show a general reduction in maximum floodtide velocities from the 1964 through 1969 test conditions (3.50 to 3.20 feet per second). The introduction of the proposed south jetty would bring the maximum floodtide velocities to a higher level (3.33 feet per second). Maximum ebbtide velocities are similarly affected.

VII. SUMMARY AND RECOMMENDATIONS

A lumped parameter mathematical model has been adapted to the Masonboro Inlet, North Carolina, system. The model estimates tidal current velocities in the inlet and water level fluctuations in the adjoining embayment. Calibration and verification of the model is carried out by reproducing prototype conditions of 12 September 1969. Application is made for preproject undeveloped inlet conditions of November 1964 and modified inlet and north jetty conditions of July 1966.

The lumped parameter model is based on the method developed by Keulegan (1967), but extended to include:

(a) Variable inlet and basin surface area,
(b) variable inlet channel depths,
(c) variable (nonsinusoidal) ocean tide,
(d) inlet inertia effects, and
(e) bay inflows or outflows other than the sea.

Table 7. Equivalent coefficient of repletion for nonprismatic inlet, 1969.

Mean sea level condition											
Area (ft^2)				Width (ft)				Length (ft)			
8350	8290	8460	8280	1080	870	1050	725	0	0	0	0
4990	4240	6710	3950	905	995	475	330	1030	1150	1320	720
3090	6600	4770	4820	750	255	250	625	860	1180	1400	755
4010	4400	3370	2320	550	190	150	360	365	585	665	350
4550	3220	4510	3280	500	130	180	345	437	532	545	275
								0	0	0	0

Tidal period = 12.417 hours.
Tidal semirange = 1.900 feet.
Bay area (mean sea level) = 1.86600E + 08 square feet.
Manning's n = 0.0270.
Coefficient of repletion = 1.681.
Inlet area = 1.41000E + 04 square feet.
Inlet length = 3.04250E + 03 feet.
Inlet depth = 11.591 feet.
Inlet width = 1,250 feet.

Table 8. Computed tides and flows for nonprismatic inlet, 1969.

Mean sea level condition					
Time (h)	H2 (ft)	Inflow ($M\#ft^3/s$)	H1 (ft)	Velocity (ft/s)	Discharge ($M\#ft^3/s$)
0.00	0.00	0.00	–0.44	2.82	39.04
0.50	0.48	0.00	–0.02	3.07	44.22
1.00	0.92	0.00	0.41	3.20	47.83
1.17	1.06	0.00	0.55	3.20[1]	48.54
1.50	1.31	0.00	0.83	3.16	49.05[1]
2.00	1.61	0.00	1.22	2.93	46.97
2.50	1.81	0.00	1.56	2.47	40.50
3.00	1.90	0.00	1.82	1.69	28.18
3.08	1.90[1]	0.00	1.85	1.52	25.38
3.50	1.86	0.00	1.95	0.38	6.36
3.58	1.84	0.00	1.95[1]	0.06	0.96
4.00	1.71	0.00	1.87	–1.58	–26.16
4.50	1.45	0.00	1.65	–2.03	–32.87
5.00	1.09	0.00	1.39	–2.41	–37.93
5.50	0.67	0.00	1.07	–2.80	–42.75
6.00	0.20	0.00	0.71	–3.11	–45.70
6.42	–0.20	0.00	0.37	–3.27	–46.50[1]
6.50	–0.28	0.00	0.30	–3.29	–46.48
6.83	–0.59	0.00	0.01	–3.33[1]	–45.80
7.00	–0.74	0.00	–0.14	–3.33	–45.11
7.50	–1.16	0.00	–0.58	–3.19	–41.71
8.00	–1.50	0.00	–1.03	–2.87	–36.33
8.50	–1.74	0.00	–1.44	–2.35	–28.91
9.00	–1.88	0.00	–1.77	–1.58	–19.03
9.33	–1.90[1]	0.00	–1.92	–0.87	–10.48
9.50	–1.89	0.00	–1.96	–0.43	–5.20
9.67	–1.87	0.00	–1.97[1]	0.11	1.31
10.00	–1.79	0.00	–1.89	1.08	12.96
10.50	–1.57	0.00	–1.68	1.30	15.92
11.00	–1.25	0.00	–1.44	1.67	20.96
11.50	–0.85	0.00	–1.13	2.13	27.55
12.00	–0.40	0.00	–0.77	2.54	34.01
12.50	0.08	0.00	–0.37	2.87	39.98

[1]Critical point value.

Tidal semirange = 1.900 feet.
Mean bay surface area = 1.866E + 08 square feet.
Bay side slope parameter beta = 0.350.
Average bay level = 0.02 feet.
Inlet properties:
- X-section area below mean tide level = 1.4100E + 04 square feet.
- Inlet width at mean tide level = 1,250 feet.
- Inlet beach slope = 75:1.
- Mean tide level depth = 11.591 feet.
- Inlet length = 3,042 feet.
- Manning's n = 0.0270.

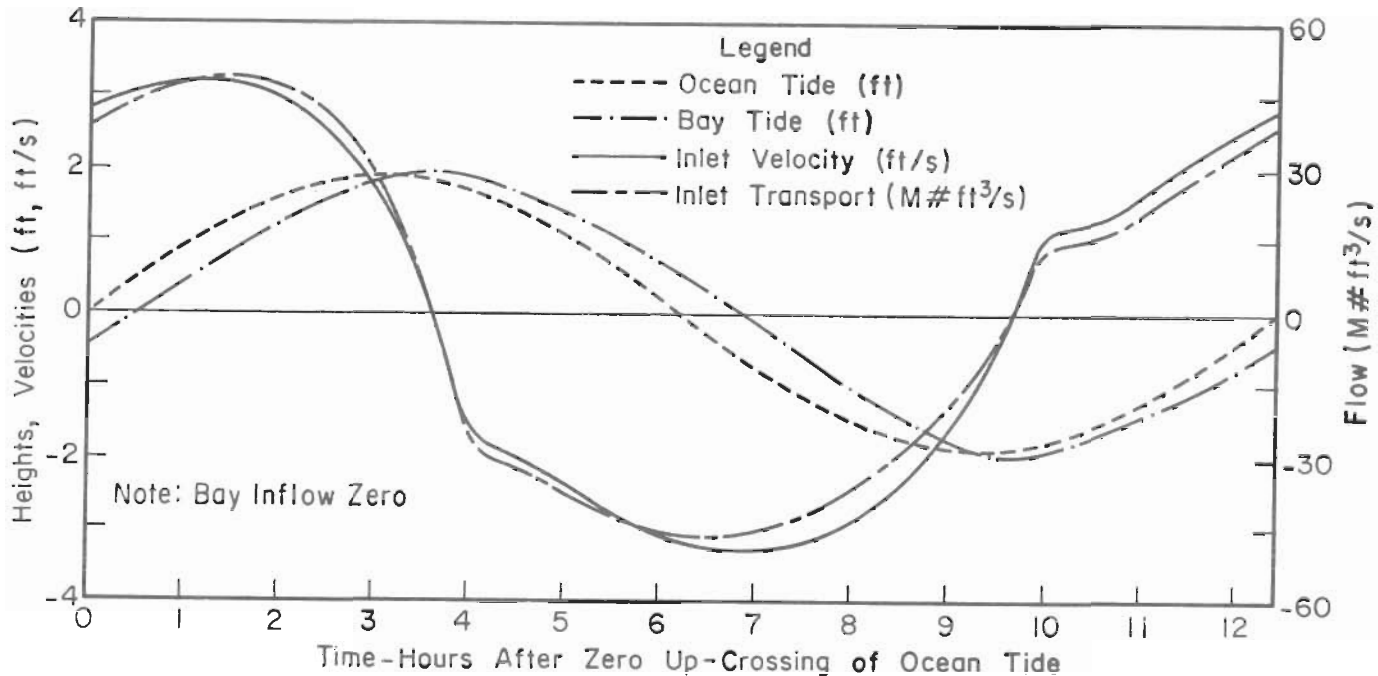

Figure 18. Mean sea level condition, 1969.

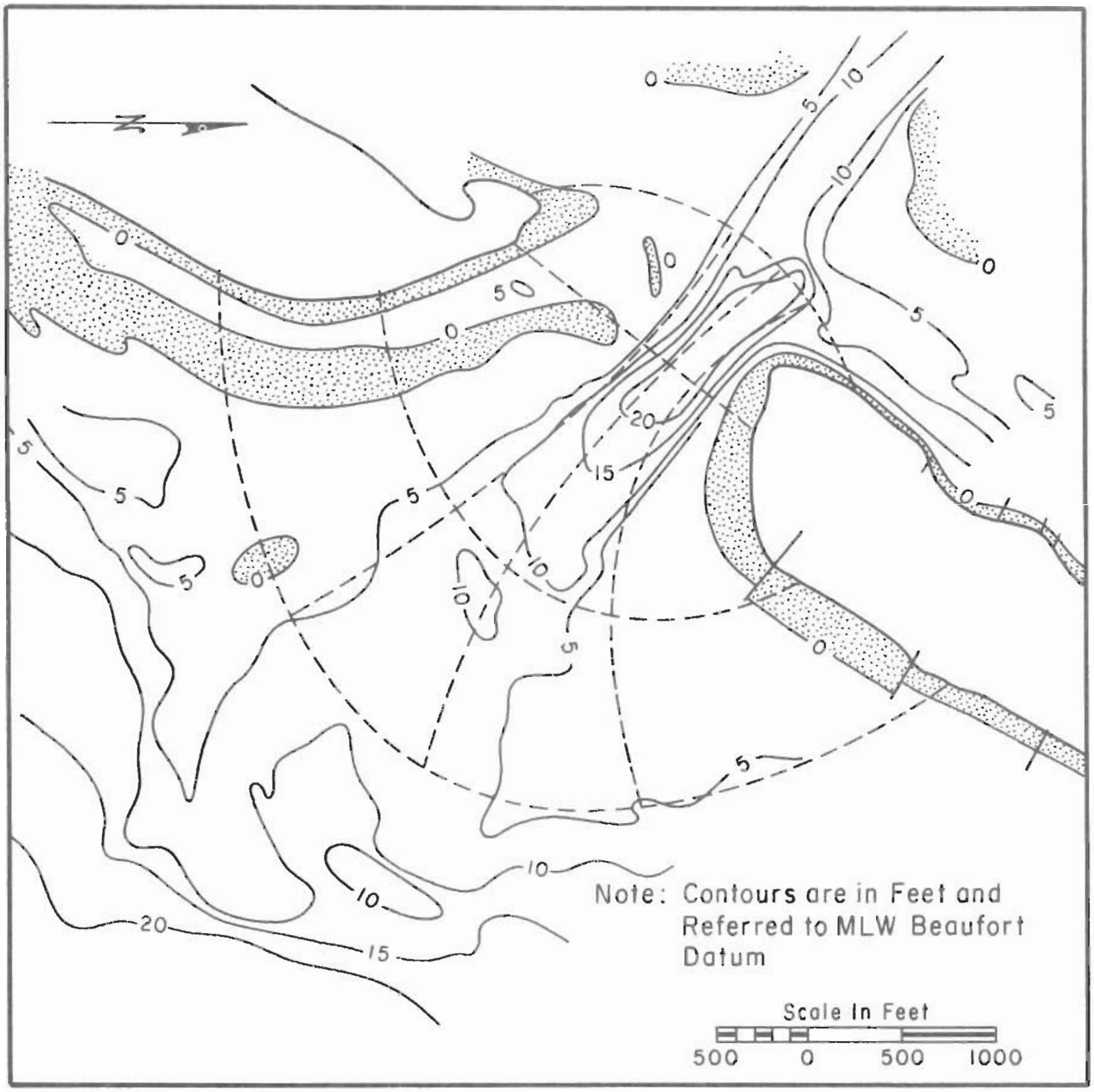

Figure 19. Hydrographic survey for November 1964.

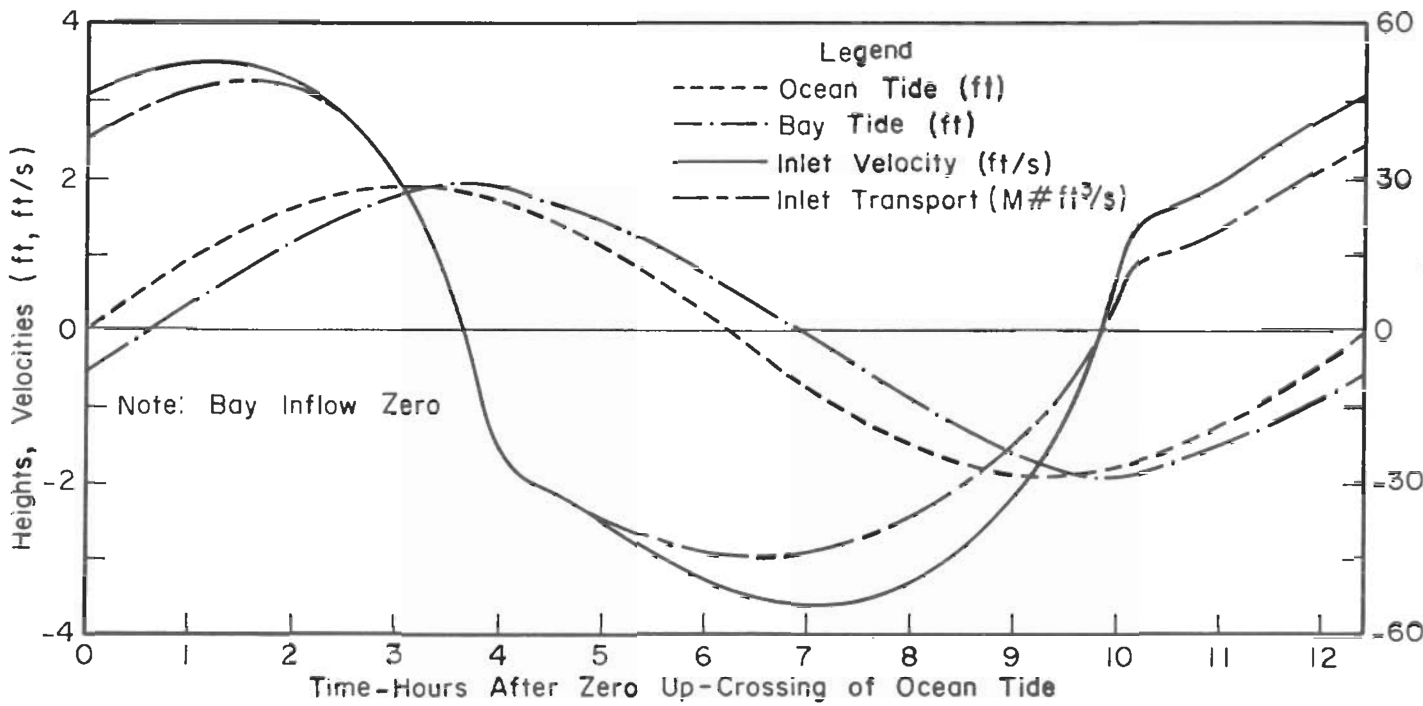

Figure 20. Mean condition, 1964.

Table 9. Equivalent coefficient of repletion for nonprismatic inlet, 1964.

Mean condition											
Area (ft^2)				Width (ft)				Length (ft)			
5315	10875	8910	10310	1870	1080	1250	1710	0	0	0	0
4685	4190	4425	3430	1200	420	600	960	965	1130	1145	545
2890	3095	3330	3250	860	185	140	340	1075	1375	1375	675
5320	4730	4925	5470	1150	310	250	520	600	800	800	400
								0	0	0	0

Tidal period	= 12.417 hours.
Tidal semirange	= 1.900 feet.
Bay area (mean sea level)	= 1.86600E + 08 square feet.
Manning's n	= 0.0270.
Coefficient of repletion	= 1.520.
Inlet area	= 1.25650E + 04 square feet.
Inlet length	= 2.72125E + 03 feet.
Inlet depth	= 11.003 feet.
Inlet width	= 1,525 feet.

Table 10. Computed tide and flow for nonprismatic inlet, 1964.

Mean condition					
Time (h)	H2 (ft)	Inflow ($M\#ft^3/s$)	H1 (ft)	Velocity (ft/s)	Discharge ($M\#ft^3/s$)
0.00	0.00	0.00	–0.52	3.10	37.75
0.50	0.48	0.00	–0.10	3.36	43.20
1.00	0.92	0.00	0.32	3.49	47.21
1.17	1.06	0.00	0.47	3.50[1]	48.09
1.50	1.31	0.00	0.75	3.46	48.95
1.58	1.36	0.00	0.82	3.43	48.96[1]
2.00	1.61	0.00	1.14	3.23	47.49
2.50	1.81	0.00	1.49	2.76	41.79
3.00	1.90	0.00	1.77	1.97	30.50
3.08	1.90[1]	0.00	1.80	1.80	27.92
3.50	1.86	0.00	1.92	0.67	10.43
3.67	1.82	0.00	1.94[1]	–0.01	–0.21
4.00	1.71	0.00	1.88	–1.56	–23.99
4.50	1.45	0.00	1.67	–2.13	–32.03
5.00	1.09	0.00	1.41	–2.54	–36.91
5.50	0.67	0.00	1.10	–2.97	–41.37
6.00	0.20	0.00	0.75	–3.31	–44.01
6.42	–0.20	0.00	0.43	–3.50	–44.63[1]
6.50	–0.28	0.00	0.37	–3.53	–44.59
7.00	–0.74	0.00	–0.04	–3.61[1]	–43.24
7.50	–1.16	0.00	–0.47	–3.54	–40.16
8.00	–1.50	0.00	–0.88	–3.30	–35.58
8.50	–1.74	0.00	–1.28	–2.86	–29.56
9.00	–1.88	0.00	–1.62	–2.19	–21.90
9.33	–1.90[1]	0.00	–1.80	–1.57	–15.47
9.50	–1.89	0.00	–1.86	–1.18	–11.60
9.83	–1.83	0.00	–1.93[1]	–0.12	–1.15
10.00	–1.79	0.00	–1.92	0.68	6.71
10.50	–1.57	0.00	–1.73	1.60	16.26
11.00	–1.25	0.00	–1.48	1.94	20.42
11.50	–0.85	0.00	–1.19	2.38	26.32
12.00	–0.40	0.00	–0.84	2.81	32.63
12.50	0.08	0.00	–0.45	3.15	38.72

[1]Critical point value.

Tidal semirange	= 1.900 feet.
Mean bay surface area	= 1.866E + 08 square feet.
Bay side slope parameter beta	= 0.350.
Average bay level	= 0.03 feet.
Inlet properties:	
X-section area below mean tide level	= 1.2565E + 04 square feet.
Inlet width at mean tide level	= 1,525 feet.
Inlet beach slope	= 30:1.
Mean tide level depth	= 11.003 feet.
Inlet length	= 2,721 feet.
Manning's n	= 0.0270.

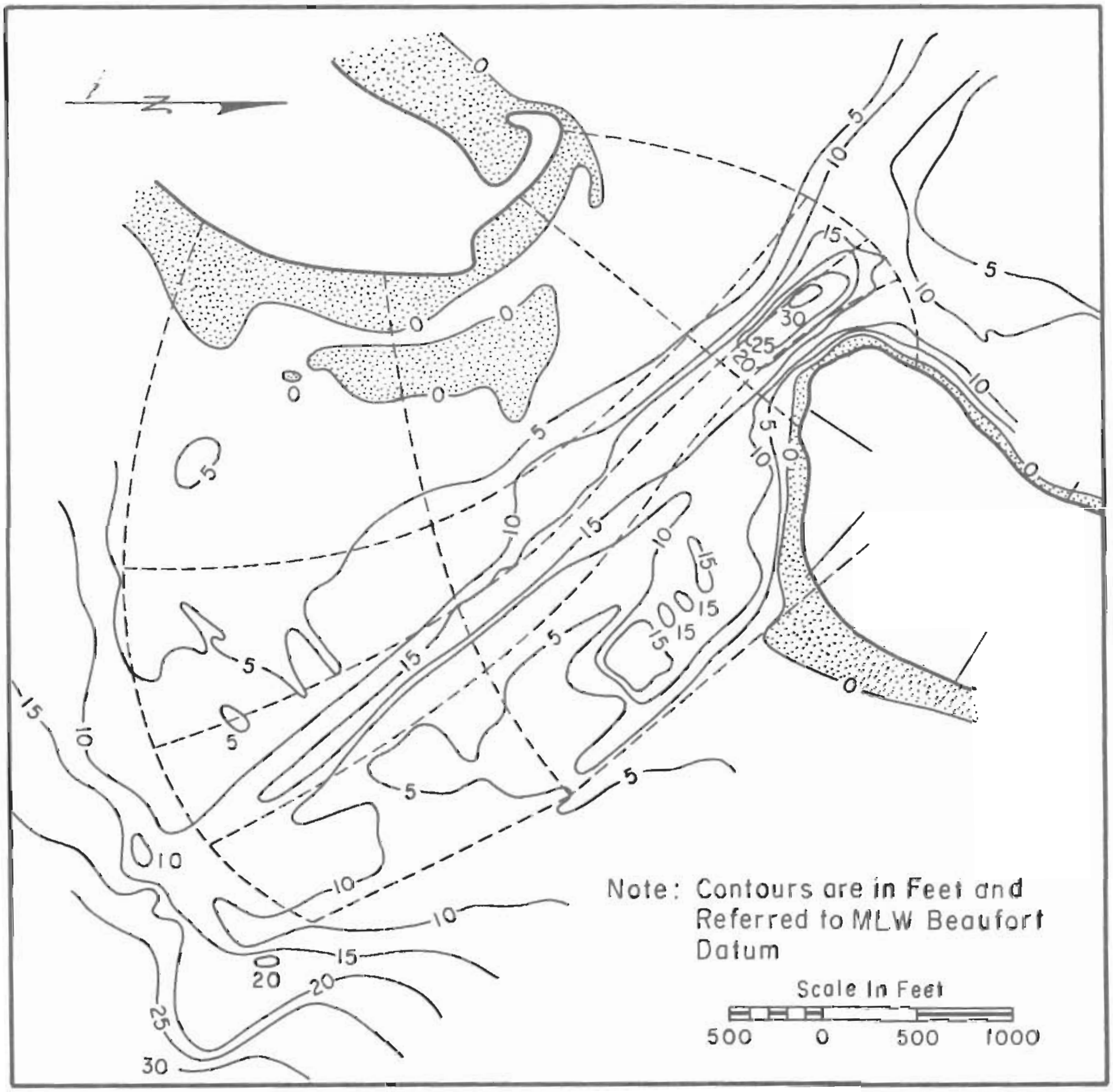

Figure 21. Hydrographic survey, 7 July to 1 August 1966.

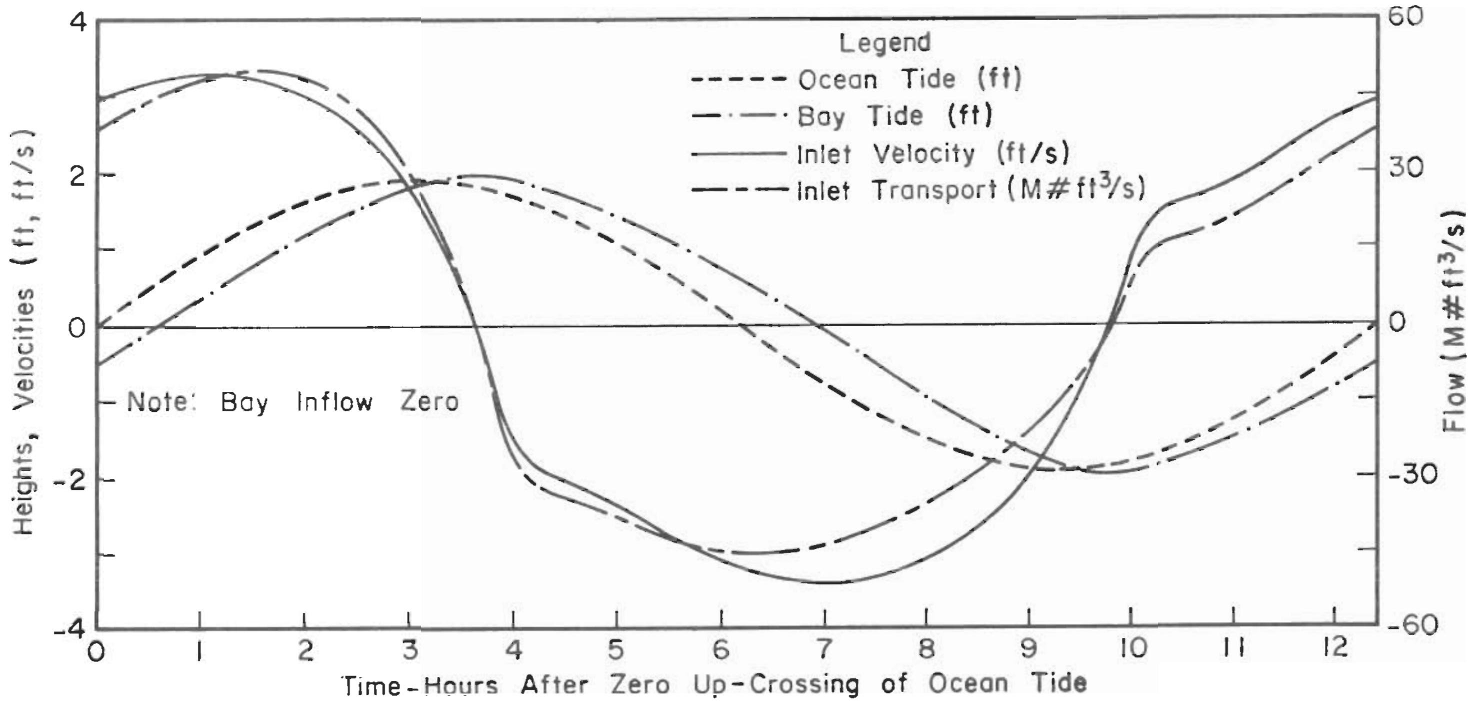

Figure 22. Mean sea level condition, 1966.

Table 11. Equivalent coefficient of repletion for nonprismatic inlet, 1966.

Mean sea level condition											
Area (ft^2)				Width (ft)				Length (ft)			
7860	6940	6900	9300	1670	940	620	665	0	0	0	0
4790	4840	5170	5060	1210	450	370	780	1375	1730	1775	880
4450	2630	2970	3510	1050	220	150	370	1340	1815	1990	1030
5340	6550	6510	4990	1300	400	310	440	715	1000	1015	505
								0	0	0	0

Tidal period = 12.417 hours.
Tidal semirange = 1.900 feet.
Bay area (mean sea level) = 1.86600E + 08 square feet.
Manning's n = 0.0270.
Coefficient of repletion = 1.585.
Inlet area = 1.35600E + 04 square feet.
Inlet length = 3.79250E + 03 feet.
Inlet depth = 13.125 feet.
Inlet width = 1,790 feet.

Table 12. Computed tide and flow for nonprismatic inlet, 1966.

Mean sea level condition					
Time (h)	H2 (ft)	Inflow (M#ft³/s)	H1 (ft)	Velocity (ft/s)	Discharge (M#ft³/s)
0.00	0.00	0.00	-0.50	2.93	38.46
0.50	0.48	0.00	-0.08	3.17	44.06
1.00	0.92	0.00	0.35	3.27	48.19
1.08	0.99	0.00	0.43	3.27[1]	48.67
1.50	1.31	0.00	0.78	3.22	49.93[1]
2.00	1.61	0.00	1.19	2.98	48.26
2.50	1.81	0.00	1.54	2.51	42.04
3.00	1.90	0.00	1.81	1.74	29.86
3.08	1.90[1]	0.00	1.85	1.58	27.10
3.50	1.86	0.00	1.96	0.50	8.63
3.67	1.82	0.00	1.97[1]	-0.13	-2.24
4.00	1.71	0.00	1.90	-1.48	-25.20
4.50	1.45	0.00	1.67	-2.07	-34.27
5.00	1.09	0.00	1.40	-2.40	-38.19
5.50	0.67	0.00	1.09	-2.78	-42.28
6.00	0.20	0.00	0.73	-3.11	-44.75
6.33	-0.12	0.00	0.47	-3.26	-45.25[1]
6.50	-0.28	0.00	0.34	-3.32	-45.16
7.00	-0.74	0.00	-0.08	-3.40[1]	-43.62
7.50	-1.16	0.00	-0.51	-3.33	-40.35
8.00	-1.50	0.00	-0.93	-3.09	-35.56
8.50	-1.74	0.00	-1.33	-2.67	-29.29
9.00	-1.88	0.00	-1.67	-2.00	-21.29
9.33	-1.90[1]	0.00	-1.84	-1.39	-14.57
9.50	-1.89	0.00	-1.91	-1.01	-10.53
9.83	-1.83	0.00	-1.96[1]	0.02	0.17
10.00	-1.79	0.00	-1.95	0.72	7.53
10.50	-1.57	0.00	-1.74	1.61	17.42
11.00	-1.25	0.00	-1.48	1.87	21.05
11.50	-0.85	0.00	-1.18	2.27	26.79
12.00	-0.40	0.00	-0.83	2.66	33.21
12.50	0.08	0.00	-0.43	2.98	39.46

[1] Critical point value.

Tidal semirange	= 1.900 feet.
Mean bay surface area	= 1.866E + 08 square feet.
Bay side slope parameter beta	= 0.350.
Average bay level	= 0.02 feet.
Inlet properties:	
X-section area below mean tide level	= 1.3560E + 04 square feet.
Inlet width at mean tide level	= 1,790 feet.
Inlet beach slope	= 75:1.
Mean tide level depth	= 13.125 feet.
Inlet length	= 3,792 feet.
Manning's n	= 0.0270.

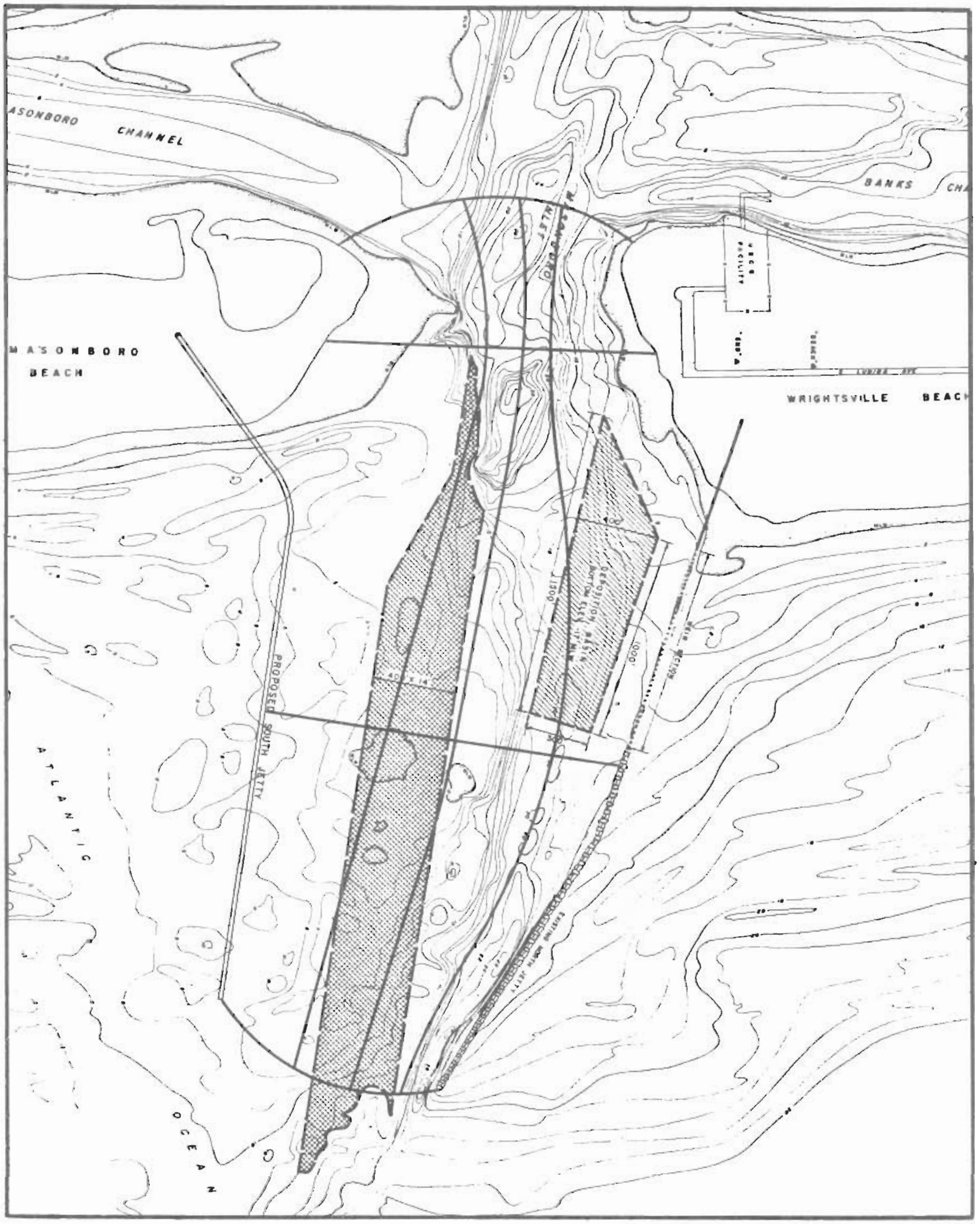

Figure 23. Proposed plan B, 1969.

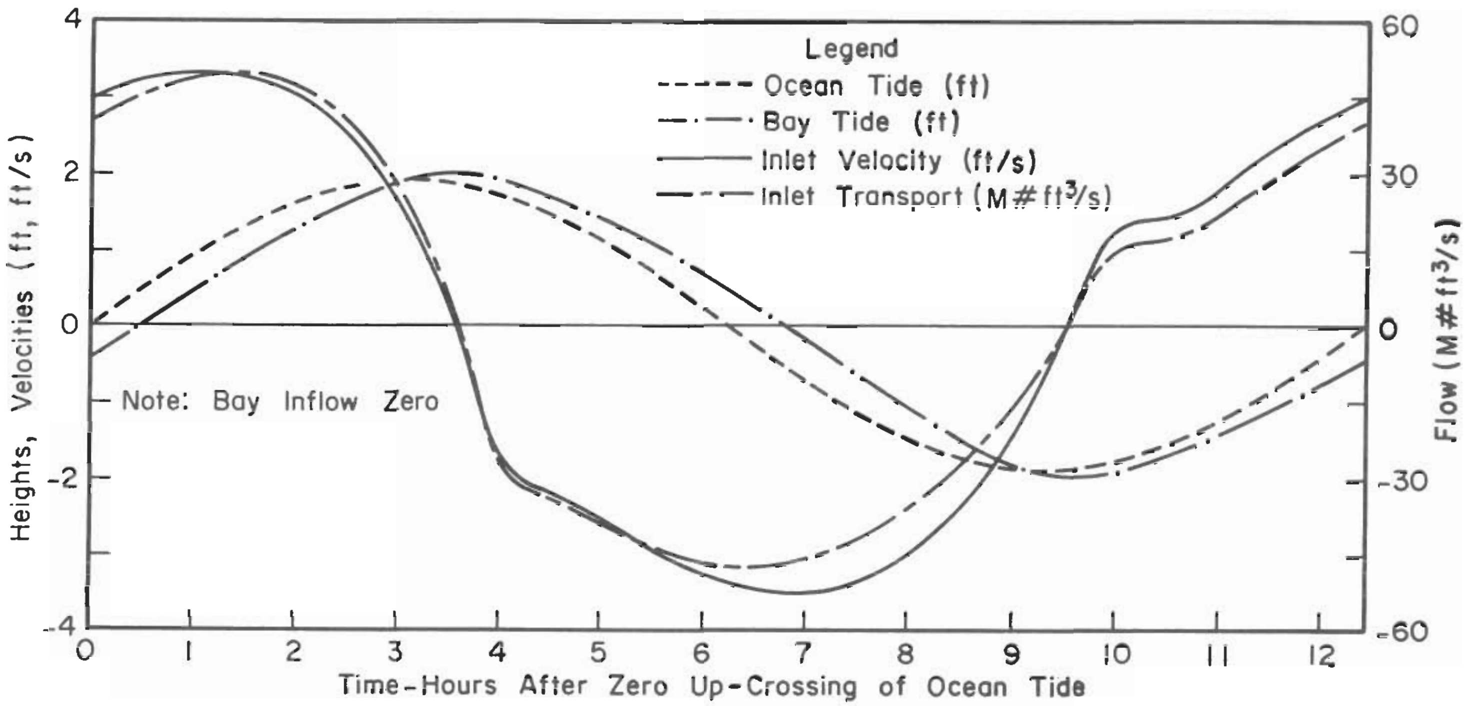

Figure 24. Proposed plan B, 1969.

Table 13. Equivalent coefficient of repletion for nonprismatic inlet, 1969.

Plan B											
Area (ft^2)				Width (ft)				Length (ft)			
3900	3900	3900	3900	485	275	235	180	0	0	0	0
5129	5120	5120	5120	585	320	465	325	1540	1715	1775	900
3430	3430	3430	3430	575	145	145	415	1860	1890	1925	975
4120	4120	4120	4120	570	255	170	385	615	685	680	330
								0	0	0	0

Tidal period = 12.417 hours.
Tidal semirange = 1.900 feet.
Bay area (mean sea level) = 1.86600E + 08 square feet.
Mannings' n = 0.0270.
Coefficient of repletion = 1.802.
Inlet area = 1.37200E + 04 square feet.
Inlet length = 3.72250E + 03 feet.
Inlet depth = 16.703 feet.
Inlet width = 1,280 feet.

Table 14. Computed tide and flow for nonprismatic inlet, 1969.

Plan B					
Time (h)	H2 (ft)	Inflow ($M\#ft^3/s$)	H1 (ft)	Velocity (ft/s)	Discharge ($M\#ft^3/s$)
0.00	0.00	0.00	−0.41	2.98	40.11
0.50	0.48	0.00	0.02	3.22	45.23
1.00	0.92	0.00	0.45	3.33	48.62
1.08	0.99	0.00	0.53	3.33[1]	48.97
1.42	1.25	0.00	0.81	3.29	49.56[1]
1.50	1.31	0.00	0.88	3.27	49.49
2.00	1.61	0.00	1.27	3.00	46.92
2.50	1.81	0.00	1.60	2.50	39.91
3.00	1.90	0.00	1.85	1.67	27.03
3.08	1.90[1]	0.00	1.88	1.49	24.14
3.50	1.86	0.00	1.98	0.30	4.88
3.58	1.84	0.00	1.98[1]	−0.03	−0.43
4.00	1.71	0.00	1.89	−1.67	−26.94
4.50	1.45	0.00	1.66	−2.22	−35.06
5.00	1.09	0.00	1.38	−2.56	−39.33
5.50	0.67	0.00	1.06	−2.97	−44.02
6.00	0.20	0.00	0.68	−3.29	−47.03
6.42	−0.20	0.00	0.33	−3.46	−47.78[1]
6.50	−0.28	0.00	0.26	−3.48	−47.73
6.83	−0.59	0.00	−0.04	−3.52[1]	−46.89
7.00	−0.74	0.00	−1.19	−3.51	−46.09
7.50	−1.16	0.00	−0.66	−3.35	−42.19
8.00	−1.50	0.00	−1.11	−2.98	−36.12
8.50	−1.74	0.00	−1.52	−2.38	−27.85
9.00	−1.88	0.00	−1.84	−1.49	−17.06
9.33	−1.90[1]	0.00	−1.96	−0.70	−7.93
9.50	−1.89	0.00	−1.99	−0.21	−2.42
9.58	−1.88	0.00	−1.99[1]	0.06	0.70
10.00	−1.79	0.00	−1.89	1.21	13.83
10.50	−1.57	0.00	−1.67	1.42	16.61
11.00	−1.25	0.00	−1.42	1.76	21.23
11.50	−0.85	0.00	−1.11	2.26	28.26
12.00	−0.40	0.00	−0.75	2.69	35.01
12.50	0.08	0.00	−0.34	3.03	41.05

[1]Critical point value.

Tidal semirange	= 1.900 feet.
Mean bay surface area	= 1.866E + 08 square feet.
Bay side slope parameter beta	= 0.350.
Average bay level	= 0.02 feet.
Inlet properties:	
X-section area below mean tide level	= 1.3720E + 04 square feet.
Inlet width at mean tide level	= 1,280 feet.
Inlet beach slope	= 30:1.
Mean tide level depth	= 16.703 feet.
Inlet length	= 3,722 feet.
Manning's *n*	= 0.0270.

Table 15. Summary of conditions.

Data	Modeled and major results: Tides, 12 Sept. 1969		Long term			N.S. jetties
	Sinusoidal	Observed	1969	1966	1964	Plan B
H ft	2.15	2.15	1.90	1.90	1.90	1.90
q(t)	-------------	-------------	-------------	-------------	-------------	-------------
A_o M ft^2	192.8	192.8	186.6	186.6	186.6	186.6
β	0.35	0.35	0.35	0.35	0.35	0.35
a_o ft^2	14,640.00	14,640.00	14,100.00	13,560.00	12,570.00	13,720.00
r_o ft	12.4	12.4	11.6	13.1	11.0	16.7
L ft	3,040.00	3,040.00	3,040.00	3,790.00	3,720.00	3,720.00
W_o ft	1,310.00	1,310.00	1,250.00	1,790.00	1,525.00	1,280.00
ζ	75:1	75:1	75:1	75:1	30:1	30:1
Response[1]						
H_1 + ft	2.14	2.21	1.95	1.97	1.94	1.98
H_1 − ft	2.14	2.22	1.97	1.96	1.93	1.99
V + ft/s	3.52	3.58	3.20	3.27	3.50	3.33
V − ft/s	3.56	3.71	3.33	3.40	3.61	3.52
Q + M#ft^3/s	54.6	57.6	49.1	49.9	49.0	49.6
Q − M#ft^3/s	52.6	57.6	46.5	45.2	44.6	47.8
α + h	0.5	0.5	0.5	0.6	0.6	0.5
α − h	0.4	0.3	0.3	0.5	0.5	0.35

[1]Maximum values + floodtide − ebbtide.

The method is based on a tidal system composed of a bay connected to the open ocean by an inlet channel. It is presumed that the current velocities can only exist in the inlet channel and those in the ocean and bay are small and may be neglected. Thus, a rise of water elevation in the sea due to a tidal action results in a conversion of potential to kinetic energy in the inlet channel and then part of the kinetic energy is converted to potential energy in the bay and part is lost due to energy dissipation in the channel. In the bay, this means that the water surface varies uniformly over the entire basin.

The lumped parameter mathematical model has been programed for a GE 400 computer. Two digital computer programs, one for the numerical computations of the inlet-basin problem and the other for plotting and computing inlet cross-sectional areas, are provided together with documentation. These programs should be generally adaptable to other inlet-basin problems with a minimum of effort.

The lumped parameter model should be applicable for a variety of inlet problems where ocean tides penetrate a tidal bay or lagoon through a single constricted inlet. The model is sufficiently general to accommodate a variety of inlet shapes. However, care should be exercised in using the model to predict water motions for all inlet-bay problems. Water motions must be restricted to those induced only by ocean tides and the physical characteristics of the system must approximately conform to those inferred by the underlying assumptions used in developing the model.

It is believed that the lumped parameter model, while generally useful for estimating current velocities in inlet channels and water level fluctuations in a connecting basin, could be improved. The introduction of two coefficients of repletion, one for floodtide and one for ebbtide, and a different computational method for the nonprismatic inlets to include the large differences in floodtide and ebbtide flows through the inlet, are possible improvements.

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APPENDIX A

TABLES OF NUMERICAL SOLUTIONS FOR VARIABLE BAY SURFACE AREAS

Table 1. Numerical solution for variable bay surface areas (Beta = 0.10).

Repletion coefficient	Floodtide			Ebbtide			Average
K	H_1[1]	a	U^2	H_1	a	U	H_1
0.20	0.235	76.0	0.987	−0.237	76.0	−0.988	0.001
0.30	0.347	70.0	0.970	−0.351	70.0	−0.974	0.001
0.40	0.451	63.0	0.948	−0.459	63.0	−0.954	0.002
0.50	0.546	58.0	0.920	−0.557	56.0	−0.929	0.003
0.60	0.631	50.0	0.888	−0.646	50.0	−0.900	0.003
0.70	0.706	45.0	0.852	−0.724	43.0	−0.868	0.004
0.80	0.769	40.0	0.815	−0.790	38.0	−0.833	0.005
0.90	0.822	34.0	0.777	−0.844	32.0	−0.797	0.005
1.00	0.864	31.0	0.739	−0.886	28.0	−0.760	0.005
1.10	0.898	26.0	0.702	−0.920	23.0	−0.724	0.005
1.20	0.924	23.0	0.668	−0.945	19.0	−0.689	0.005
1.30	0.945	19.0	0.635	−0.964	15.0	−0.656	0.004
1.40	0.960	16.0	0.604	−0.977	13.0	−0.624	0.004
1.50	0.972	14.0	0.576	−0.986	10.0	−0.595	0.003
1.60	0.981	12.0	0.550	−0.992	7.0	−0.567	0.003
1.70	0.987	9.0	0.526	−0.996	5.0	−0.541	0.002
1.80	0.991	7.0	0.503	−0.998	4.0	−0.518	0.002
1.90	0.995	6.0	0.482	−0.999	3.0	−0.495	0.002
2.00	0.997	5.0	0.463	−1.000	1.0	−0.475	0.001
2.10	0.998	4.0	0.444	−1.000	1.0	−0.456	0.001
2.20	0.999	2.0	0.427	−1.000	0.0	−0.438	0.001
2.30	1.000	2.0	0.411	−1.000	0.0	−0.421	0.001
2.40	1.000	1.0	0.397	−1.000	0.0	−0.406	0.001
2.50	1.000	1.0	0.383	−1.000	0.0	−0.391	0.001
2.60	1.000	1.0	0.369	−1.000	0.0	−0.377	0.001
2.70	1.000	0.0	0.357	−1.000	0.0	−0.364	0.000
2.80	1.000	0.0	0.345	−1.000	0.0	−0.352	0.000
2.90	1.000	0.0	0.334	−1.000	0.0	−0.341	0.000
3.00	1.000	0.0	0.324	−1.000	0.0	−0.330	0.000

[1]Ratio bay amplitude to the sea amplitude.

[2]Dimensionless maximum inlet velocity.

Table 2. Numerical solution for variable bay surface areas (Beta = 0.25).

Repletion coefficient	Floodtide			Ebbtide			Average
K	H_1[1]	a	U[2]	H_1	a	U	H_1
0.20	0.234	76.0	0.985	–0.239	76.0	–0.990	0.001
0.30	0.344	70.0	0.967	–0.355	68.0	–0.977	0.003
0.40	0.446	63.0	0.943	–0.465	63.0	–0.959	0.004
0.50	0.539	58.0	0.913	–0.567	56.0	–0.936	0.007
0.60	0.622	52.0	0.878	–0.659	49.0	–0.910	0.009
0.70	0.694	47.0	0.841	–0.739	43.0	–0.880	0.010
0.80	0.756	41.0	0.802	–0.807	36.0	–0.847	0.012
0.90	0.868	36.0	0.763	–0.862	31.0	–0.813	0.013
1.00	0.849	32.0	0.725	–0.905	25.0	–0.777	0.013
1.10	0.883	28.0	0.689	–0.938	21.0	–0.742	0.012
1.20	0.969	24.0	0.656	–0.961	16.0	–0.708	0.012
1.30	0.931	22.0	0.624	–0.977	13.0	–0.675	0.011
1.40	0.948	19.0	0.595	–0.988	9.0	–0.643	0.010
1.50	0.961	16.0	0.568	–0.994	6.0	–0.613	0.008
1.60	0.971	14.0	0.544	–0.997	4.0	–0.585	0.007
1.70	0.979	12.0	0.520	–0.999	3.0	–0.559	0.006
1.80	0.985	10.0	0.499	–1.000	1.0	–0.535	0.005
1.90	0.989	8.0	0.479	–1.000	0.0	–0.512	0.004
2.00	0.992	7.0	0.461	–1.000	0.0	–0.491	0.004
2.10	0.995	6.0	0.443	–1.000	0.0	–0.471	0.003
2.20	0.997	5.0	0.427	–1.000	0.0	–0.453	0.003
2.30	0.998	4.0	0.411	–1.000	0.0	–0.435	0.002
2.40	0.999	3.0	0.397	–1.000	0.0	–0.419	0.002
2.50	0.999	2.0	0.383	–1.000	0.0	–0.404	0.002
2.60	1.000	2.0	0.371	–1.000	0.0	–0.390	0.001
2.70	1.000	1.0	0.359	–1.000	0.0	–0.376	0.001
2.80	1.000	1.0	0.347	–1.000	0.0	–0.364	0.001
2.90	1.000	1.0	0.337	–1.000	0.0	–0.352	0.001
3.00	1.000	0.0	0.327	–1.000	0.0	–0.341	0.001

[1]Ratio bay amplitude to the sea amplitude.

[2]Dimensionless maximum inlet velocity.

Table 3. Numerical solution for variable bay surface areas (Beta = 0.50).

Repletion coefficient	Floodtide			Ebbtide			Average
K	H_1[1]	a	U[2]	H_1	a	U	H_1
0.20	0.232	77.0	0.983	–0.242	76.0	–0.992	0.003
0.30	0.339	70.0	0.962	–0.362	68.0	–0.981	0.006
0.40	0.439	65.0	0.935	–0.478	61.0	–0.967	0.009
0.50	0.529	58.0	0.901	–0.588	54.0	–0.948	0.014
0.60	0.609	52.0	0.863	–0.687	47.0	–0.925	0.018
0.70	0.679	47.0	0.823	–0.773	40.0	–0.899	0.021
0.80	0.737	43.0	0.783	–0.845	32.0	–0.870	0.024
0.90	0.786	38.0	0.744	–0.900	25.0	–0.838	0.025
1.00	0.826	34.0	0.709	–0.941	20.0	–0.806	0.025
1.10	0.859	31.0	0.676	–0.969	14.0	–0.773	0.024
1.20	0.856	28.0	0.645	–0.986	10.0	–0.740	0.022
1.30	0.908	25.0	0.617	–0.996	5.0	–0.709	0.020
1.40	0.926	23.0	0.590	–0.999	2.0	–0.678	0.018
1.50	0.941	20.0	0.566	–1.000	0.0	–0.649	0.016
1.60	0.953	18.0	0.543	–1.000	0.0	–0.621	0.013
1.70	0.963	15.0	0.522	–1.000	0.0	–0.594	0.012
1.80	0.971	14.0	0.502	–1.000	0.0	–0.569	0.010
1.90	0.977	13.0	0.484	–1.000	0.0	–0.546	0.009
2.00	0.982	11.0	0.467	–1.000	0.0	–0.524	0.007
2.10	0.986	10.0	0.450	–1.000	0.0	–0.504	0.006
2.20	0.990	8.0	0.435	–1.000	0.0	–0.485	0.005
2.30	0.992	7.0	0.420	–1.000	0.0	–0.467	0.005
2.40	0.994	6.0	0.407	–1.000	0.0	–0.450	0.004
2.50	0.996	5.0	0.394	–1.000	0.0	–0.434	0.003
2.60	0.997	4.0	0.382	–1.000	0.0	–0.419	0.003
2.70	0.998	4.0	0.370	–1.000	0.0	–0.404	0.003
2.80	0.999	3.0	0.359	–1.000	1.0	–0.391	0.002
2.90	0.999	2.0	0.349	–1.000	1.0	–0.379	0.002
3.00	0.999	2.0	0.339	–1.000	0.0	–0.367	0.002

[1] Ratio bay amplitude to the sea amplitude.

[2] Dimensionless maximum inlet velocity.

APPENDIX B

APPLICATION OF THE LUMPED PARAMETER TECHNIQUE

The fundamental equations of the lumped parameter approach to the study of tidal inlet hydraulics are summarized below:

$$\frac{dV}{dt} = \frac{g}{L}(H_2 - H_1 - C_v|V|V) \ , \qquad (25b)$$

$$\frac{dH}{dt} = \frac{1}{A}(aV + q) \ , \qquad (26b)$$

$$A = A_o\,(1 + \beta h_1) \ , \qquad (4b)$$

$$C_v = \frac{1}{2g}\left\{1 + FL\left[r_o + \frac{1}{2}(H_1 + H_2)\right]^{-4/3}\right\} \ , \qquad (23b)$$

$$F = \frac{2gn^2}{(1.486)^2}$$

$$= \frac{gn^2}{1.104}$$

$$r_o = \left[\frac{1}{FL}\left[\frac{g}{2H}\left(\frac{Ta_o}{\pi K_1 A_o}\right)^2 - 1\right]\right]^{-3/4} \ , \qquad (44b)$$

$$K_1 = \frac{T}{2\pi H}\,\frac{a_m}{A_o}\sqrt{2gh}\ \sum_{i=1}^{i_m}\left[\left(\frac{a_m}{a_{mi}}\right)^2 + F\,\frac{a_m^2}{2}\sum_{j=1}^{j_m}\frac{r_{ij}^{-4/3}}{a_j^2}\,(x_j - x_{j-1})\right]^{-1/2} \ . \qquad (43b)$$

Numerical constants have been simplified and auxiliary values introduced to simplify programing, but each equation is algebraically equivalent to an equation already identified in the text by the same arabic numeral.

Note that F is changed only by changes in Manning's n; K_1 depends only on changes in F and changes in the manner of partitioning the inlet to account for irregular cross sections. Since the friction term, which involves F, is generally smaller than the other terms in square brackets in the definition of K_1; K_1, itself, is not very sensitive to changes in the manner of partitioning the inlet or to changes in n. The effective hydraulic radius, r_o, is a function of both F and K_1. Since F modifies all terms in r_o, not just the smaller term, as for K_1, r_o is more sensitive than K_1 to changes in Manning's n. F, K_1, and r_o are all constant for any one value of Manning's n and one partitioning system.

The calculation of C_v requires F and r_o, both of which depend on Manning's n, and the tide levels in both bay and ocean, H_1 and H_2. The tide levels, H_1 and H_2 are both functions of time. Thus C_v must be constantly updated throughout the calculation.

The differential equation (25b) is nonlinear because C_v is a function of both H_1 and H_2 and because a quadratic term in V appears. The differential equation (26b) is nonlinear because the bay area, A, is a function of H_1.

The first step in applying this technique is to partition the inlet into channels and sections of channels to obtain reasonably uniform values of r_{ij} in each segment and uniform cross sections. The procedure is illustrated in Section VI by application to Masonboro Inlet. The next step is to select a tentative value for Manning's n. The values of β, F, K_1 and r_o are then evaluated. At time equals zero, V and H may both be taken as zero. By repeated use of equation (23b) to define C_v, equation (4b) to define A and integrating equations (25b) and (26b) for one time step values of V(t) and $H_1(t)$ are generated from prescribed values of the open side tide $H_2(t)$.

Calculations for the tide in the bay are rarely satisfactory for the first few tidal cycles because the proper initial conditions are unknown and the assumption that H_1 and V are initially zero is not very accurate. However, friction causes the influence of the initial conditions to decay with time, and the computed bay tide becomes periodic after a few cycles. When the agreement between computed and observed bay tide becomes acceptable, the model is said to be calibrated. It is rare to obtain satisfactory agreement with the first value of Manning's n selected.

If the first calculations are not satisfactory, a new value of n is selected and the procedure is repeated. Several values of n may have to be tried before satisfactory agreement is obtained.

APPENDIX C

DOCUMENTATION OF SECTION PLOTTING PROGRAM *SECPLT*

Program *SECPLT* is used to plot and compute areas for inlet cross sections from digitized hydrographic data. Section data are read from prepared data cards and the program produces a listing of input data, a listing of accumulated cross-sectional areas at specified width increments, and a tape of plotter data for CALCOMP drum plotting of the section(s).

The program allows variation of the water level datum for area calculations by allowing the user to specify the number of the data point which should be used as the vertical datum. Widths tabulated with corresponding areas are then referenced to the specified point. The final tabulation table is useful in determining input data for the INLET program.

Description of input and output follows; the program is coded to operate on the WES Honeywell 437.

1. Input Data.

Card Type A.

A1–This card contains the number of sections to be plotted, the number of parallel inlet channels, and an overall scale factor. The scale factor allows the plot size to be reduced by the factor indicated and should be a number not exceeding 1.0. FORMAT (2I5, F5.2).

A2–This record consists of up to 32 contiguous alphameric characters which will be printed out to identify all output. FORMAT (4A8).

2. Section Data.

A blank card is entered to indicate the end of a data set for a section; an additional blank card is added at the end of all data sets.

Card Type B.

B1–The first data card for each section contains the number of the data point to be used as the datum for the section, the horizontal increments at which areas are to be computed and tabulated (maximum of 200 increments per section), the horizontal scale to be used in plotting (feet per inch), and the vertical scale to be used in plotting. The length of the y-axis below the datum is fixed at 6 inches and the scale should be chosen accordingly. This length corresponds to a scale factor of 1.0 (card A1) and will be reduced if a reduction factor is specified. FORMAT (I5, F6.0, 2F6.1).

B2–This record is a 24-character label and is annotated on the associated section plot. FORMAT (3A8).

B3–Data records are entered for each data point in this section, and contains: (a) A point number which provides a notation for convenience in identifying the point. A number must be entered but its value is ignored to allow for introduction of additional intermediate data points if required, (b) horizontal coordinate of the point in feet, and (c) elevation of the point in feet; positive values are below the zero elevation and negative values are above. FORMAT (I5, F6.0, F6.1).

3. Output.

As each x-section set is processed, several diagnostic notes are printed to help in locating data errors should a run prove unsuccessful. After a group of up to six sections has been processed, the output routine prints out the output tables for the group. These tables include a listing of the input data, a listing of the x-section areas as functions of the distance along the section length, and a table of flow grid data. The flow grid data may be useful in establishing the INLET program data for determining the equivalent prismatic properties of an irregular inlet.

To produce the grid data, the program divides the total section area into as many equal parts as the number of parallel channel segments specified. Then, the cumulative and incremental widths at which those area increments occur are determined and printed.

This program can be useful but must be used carefully. The user should review the plots to verify that they are reasonable interpretations of the data points. In plotting the cross section, the program uses a cubic spline curve-fitting technique which may introduce unnatural humps in the section. If unusual perturbations occur, they can usually be eliminated by introducing additional data points in the given region. This problem is mostly encountered in regions where the slope changes rapidly. When a reasonable plot is obtained, the user should plot the flow grid over the inlet plan view to assure that the grid as determined by the program allows for a reasonable flow pattern. If the pattern is unacceptable, it will be necessary to adjust the grid and associated data before using the INLET program. It may be found that the x-sections selected cannot produce a reasonable flow pattern and that they must be revised.

The manual plotting, planimetering, and data calculations for the x-sections are very tedious; however, initial use of manual techniques may be helpful in developing an appreciation for the limitations of the program.

THIS FORM IS DESIGNED FOR ELITE TYPEWRITER OR MANUAL ENTRIES

Input for section plotting program

No. Plots | No. Chan | Scale

Label

Origin Pt. | Width Inc. | Horiz Scale | Vert Scale

Section Label

Pt. No. | Horiz | Elev

ENG FORM 2900
MAY 60
(Local reproduction of this form is authorized after desired information is filled-in.)

80 COLUMN KEY PUNCH TRANSCRIPT LAYOUT SHEET

SHEET OF SHEETS

SAMPLE INPUT FOR SECTION PLOTTING PROGRAM

```
        .JOB,WINTERGE , RO HM    803-G9R0-181    10   H52961HV11
        .OPTIONS,,,,,F
        .SODA,V300,PRNT
        .PERIPH,T04C4
        .LOAD

            (INSERT   OBJECT PROGRAM HERE)

        .DATA
   1     4  050
MASONBORO  INLET  JULY-AUG 1966
   2     20  2000    50
SECTION 4--BAY END
   1     -50    -38
   2      00    -19
   3      50     00
  31     200     15
  32     400     18
  36     800     20
  38    1000     35
   4    1300     70
   5    1360    100
  55    1600    175
   6    1800    200
  65    2000    170
   7    2250    100
   8    2350     50
   9    2410     00
  10    2470    -38
```

SAMPLE OUTPUT FROM SECTION PLOTTING PROGRAM

```
MASONBORO INLET   JULY-AUG 1966

READ SECTION DATA
X(1) =  -50.00   Y(1) = -3.80
X(N) = 2470.00   Y(N) = -3.80

SECTION DATA READ  16 POINTS, ORIGIN = POINT  2
WIDTH INCREMENT = 20.0
SCALE:   200.0 HORIZ
           5.0 VERT
CALL SPLINE
SPLINE COMPLETED
INITIALIZATION AND AXES COMPLETED
K = 122, KMAX = 123

MASONBORO INLET  JULY-AUG 1966       L =  1   NUM =  1
KMAX = 123   NUMWR =  1

OUTPUT ROUTINE REACHED
```

SAMPLE OUTPUT

PAGE 1 MASONBORO INLET JULY-AUG 1966

INPUT DATA--FT

	1							
X	Y	X	Y	X	Y	X	Y	X
-50.	-3.80							
0.	-1.90							
50.	0.00							
200.	1.50							
400.	1.80							
800.	2.00							
1000.	3.50							
1300.	7.00							
1360.	10.00							
1600.	17.50							
1800.	20.00							
2000.	17.00							
2250.	10.00							
2350.	5.00							
2410.	0.00							
2470.	-3.80							

SAMPLE OUTPUT

PAGE 3 MASONBORO INLET JULY-AUG 1966

SECTION NUMBERS, AREAS-KSF

	1							
W	A	W	A	W	A	W	A	W
2010.	18.487							
2030.	18.855							
2050.	19.214							
2070.	19.564							
2090.	19.903							
2110.	20.232							
2130.	20.551							
2150.	20.858							
2170.	21.154							
2190.	21.438							
2210.	21.709							
2230.	21.968							
2250.	22.213							
2270.	22.443							
2290.	22.659							
2310.	22.856							
2330.	23.033							
2350.	23.185							
2370.	23.307							
2390.	23.395							
2410.	23.449							
2430.	23.473							
2450.	23.478							

SAMPLE OUTPUT

INLET FLOW GRID MASONBORO INLET JULY-AUG 1966

CUMULATIVE AREAS

		CHANNEL NUMBER		
SECTION	1	2	3	4
1	5869.	11739.	17608.	23478.

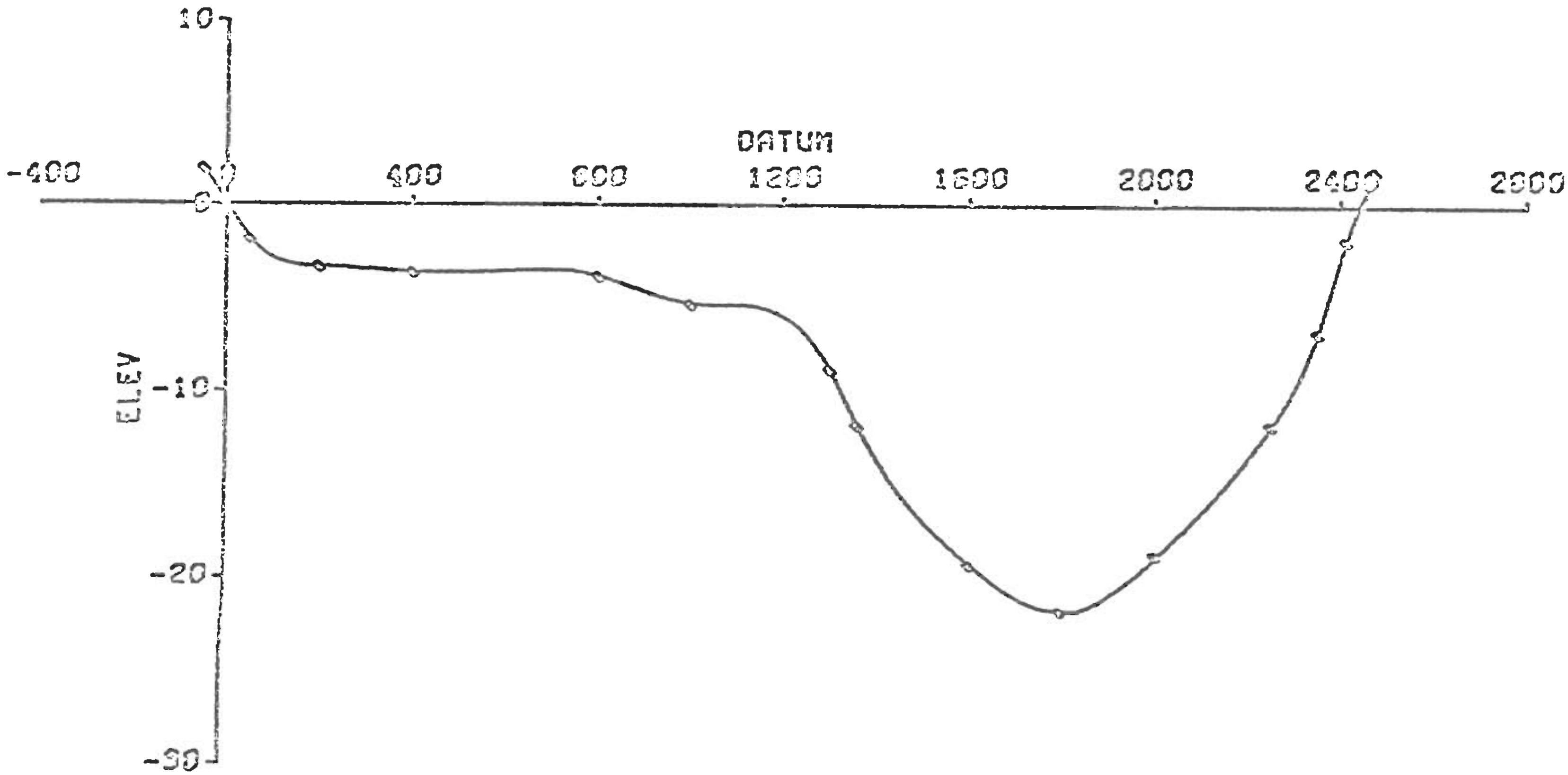
CUMULATIVE WIDTHS

		CHANNEL NUMBER		
SECTION	1	2	3	4
1	1344.	1689.	1964.	2450.

WIDTHS

		CHANNEL NUMBER		
SECTION	1	2	3	4
1	1344.	345.	276.	486.

SAMPLE X-SECTION FROM SECTION PLOTTING PROGRAM



MASONBORO INLET JULY-AUG 1966
SECTION 4--BAY END

SECTION PLOTTING PROGRAM (SECPLT)

```
QSTES,  SIMS  500 CARDS
TASK(TN0072434,PWCERC1,TRTS)SIMS
FTN.
ATTACH(PLOT,PLOTTT,ID=0072440,MR=1,CY=1)
LOAD(PLOT)
LGO.
REWIND(TAPE3)
COPYSBF(TAPE3,OUTPUT)

      PROGRAM SECPLT(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT, TAPE3,PUNCH=
     1TAPE3)
C     SECTION PLOTTING PROGRAM
C     DAPS VERSION--OCT 71
C
C
      DIMENSION IBUFF(1000)
      DIMENSION X(100), Y(100), A(100), TITL1(4),
     2TITL2(3), WRTARY(2,6,200), DATA(2,6,100)
      DIMENSION DA(10), W(6,10), DAA(10)
      DATA AXSLBL/5HDATUM/, IRD1,IWR1/5,6/
      DATA YLBL/4HELEV/
      DATA IPLTPE/ 3/
      REWIND IPLTPE
      CALL PLOTS (IBUFF, 1000,IPLTPE)
      CALL PLOT(0.,0.,-3)
C  READ CARD TYPE A1 CONTAINING
C     NPLTS (I5)= NUMBER OF SECTIONS TO BE PLOTTED
C     NCHNL (I5)= NUMBER OF PARALLEL INLET CHANNELS
C     SCALE (F5.2)= OVERALL SCALE FACTOR
4     READ (IRD1,2001) NPLTS, NCHNL, SCALE
      IF(EOF(IRD1))99,8
8     IF (NPLTS) 99, 99, 9
9     NCH1 = NCHNL - 1
C
C     N = PLOTTER SECTION INDEX
C
      N = 0
      CALL FACTOR (SCALE)
      YPO = 10.
C  READ CARD TYPE A2 CONTAINING
C     TITL1 (4A8)= 32 CHARACTER OUTPUT IDENTIFICATION
      READ (IRD1,1001) TITL1
      WRITE (IWR1,1028) TITL1
      XPO = 2.
C
C     NUM = ABSOLUTE INDEX
C
      NUM = 0
      XMAX = 0.
      DO 95 L = 1, NPLTS, 6
      DO 2 I = 1, 6
      DO 1 J = 1, 100
      DATA(1,I,J) = 0.
1     DATA(2,I,J) = 0.
      DO 2 J = 1, 200
      WRTARY(1,I,J) = 0.
2     WRTARY(2,I,J) = 0.
C
C     CLEAR ARRAY AFTER EACH SIX SECTIONS
C
      NMAX = 0
```

```
      KMAX = 0
      NUMWR = 0
C
C     NUMWR = WRITE SET INDEX
C
5     WRITE (IWR1,1011)
C  READ CARD TYPE B1 CONTAINING
C    NZER (I5)= NUMBER OF DATA POINT TO BE USED
C     AS THE DATUM FOR THE SECTION
C    DX (F6.0)= HORIZONTAL INCREMENTS AT WHICH
C      AREAS ARE TO BE COMPUTED AND TABULATED
C    SCALEX (F6.1)= HORIZONTAL SCALE TO BE USED IN
C       PLOTTING (FEET PER INCH)
C    SCALY (F6.1)= VERTICAL SCALE TO BE USED IN
C       PLOTTING (FEET PER INCH)
      READ (IRD1,2004) NZER, DX, SCALX, SCALY
C  READ CARD TYPE B2 CONTAINING
C    TITL2 (3A8)= 24 CHARACTER LABEL ANNOTATED ON THE
C       ASSOCIATED SECTION PLOT.
      READ (IRD1,1001) TITL2
      NPTS = 1
C   READ CARD TYPE B3 CONTAINING
C    J (I5)= POINT NUMBER
C    X(NPTS) (F6.0)= HORIZONTAL CO-ORDINATE OF POINT IN FEET
C    Y(NPTS) (F6.1)= ELEVATION OF POINT IN FEET
C  READ ONE CARD FOR EACH DATA POINT
C  LAST CARD OF DATA SET FOR A SECTION IS BLANK
C   ONE ADDITIONAL BLANK CARD AT END OF ALL DATA SETS.
10    READ (IRD1,2004) J, X(NPTS), Y(NPTS)
      IF (J) 15, 15, 12
12    NPTS = NPTS + 1
      GO TO 10
15    NPTS = NPTS - 1
      WRITE (IWR1,1020) X(1), Y(1), X(NPTS), Y(NPTS)
      WRITE (IWR1,1008) NPTS, NZER, DX, SCALX, SCALY
      KCHK = 0
      DO 25 J = 2, NPTS
      IF (X(J) - X(J - 1)) 24, 24, 25
   24 WRITE (IWR1,1030) J-1, X(J-1), X(J)
      KCHK = KCHK + 1
   25 CONTINUE
      Y00 = 0.
      XTRN = X(NZER) - X(1)
      WRITE (IWR1,1012)
      IF (KCHK) 27, 27, 28
C
C     DETERMINE SPLINE CONSTANTS
C
   27 CALL SPLINE (X, Y, NPTS, A)
      WRITE (IWR1,1013)
C
C     SPLINE COMPLETED
C
   28 XT = X(1)
      DX5 = 0.5*DX
      AREA = 0.
      SCAL2X = SCALX + SCALX
      SCXINV = 1./SCALX
      SCYINV = -1./SCALY
      XP = X(1)*SCXINV
      YP = Y(1)*SCYINV
```

```
      YA0 = Y(NZER)*SCYINV
      YTRN = Y(NZER)
      YY1 = YA0 - 6.0
      X1 = X(NZER)*SCXINV
      XX1 = -2*IFIX(0.5*SCXINV*XTRN + 1.0)
      XNOTE = SCALX*XX1
      XX1 = X1 + XX1
      XA0 = 2. - SCXINV*X(1)
      XL = SCXINV*(X(NPTS) - X(1)) + 4.0
      CALL PLOT(XP0,0.,-3)
      CALL PLOT (XA0, YP0,-3)
C
C     PLOT X AXIS
C
      CALL AXIS13(XX1,YA0,AXSLBL,5,0.21,XL,-1.0,XNOTE,SCAL2X,
     &2.0,-1.0)
C
C     PLOT DATA POINTS
C
      DO 30 I = 1, NPTS
      DATA(1,NUMWR+1,I) = X(I)
      DATA(2,NUMWR+1,I) = Y(I)
      ISUB = NPTS - I + 1
      XP = SCXINV*X(ISUB)
      YP = SCYINV*Y(ISUB)
      IF (XP - 100.) 31, 32, 32
   31 IF (YP - 30.) 33, 32, 32
   32 WRITE (IWR1,1032) ISUB, X(ISUB), Y(ISUB)
      KCHK = KCHK + 1
      GO TO 30
33    CALL SYMBOL (XP,YP,0.12,5,0.,-1)
30    CONTINUE
C
C     PLOT TITLES
C
      CALL SYMBOL (0.,-7.,0.28,TITL1,0.,32)
      CALL SYMBOL (0.,-7.5,0.28,TITL2,0.,24)
      SCAL2Y = SCALY + SCALY
      YNOTE = -6.*SCALY
C
C     PLOT Y AXIS
C
      CALL AXIS13 (X1,YY1,YLBL,4,0.21,8.0,-1.1,YNOTE,
     1SCAL2Y,2.0,-1.0)
      IF (KCHK) 35, 35, 72
C
C     MOVE TO FIRST POINT
C
35    CALL PLOT (XP,YP,3)
      NUM = NUM + 1
      NUMWR = NUMWR + 1
      K = 0
      WRITE (IWR1,1014)
C
C     AXES COMPLETED
C
      JPT = 1
50    XT = XT + DX
C
C     INTERPOLATE FOR Y(X)
C
```

```
      CALL SPLINT(XT,Y0,Y1,X,Y,A,NPTS,JPT)
C
C     COMPUTE AREA IF Y BELOW AXIS
C
      IF (Y0 - YTRN) 60, 60, 55
55    AREA = AREA + DX5*(Y00 + Y0 - YTRN)
      K = K + 1
      WRTARY(1,NUMWR,K) = XT - X(NZER)
      WRTARY(2,NUMWR,K) = AREA
      Y00 = Y0 - YTRN
60    XP = SCXINV*XT
      YP = SCYINV*Y0
C
C     PLOT SECTION
C
      CALL PLOT (XP,YP,2)
      IF (XT - X(NPTS) + DX) 50, 50, 70
70    WRTARY(2,NUMWR,K+1) = AREA + DX5*Y00
      WRTARY(1,NUMWR,K+1) = WRTARY(1,NUMWR,K) + DX
      DA(NUMWR) = WRTARY(2,NUMWR,K+1)/NCHNL
      W(NUMWR,NCHNL) = WRTARY(1,NUMWR,K+1)
C
C     CLOSE ON LAST DATA POINT
C
      XP = SCXINV*X(NPTS)
      YP = SCYINV*Y(NPTS)
      CALL PLOT (XP,YP,2)
   72 IF (NMAX.LT.NPTS) NMAX = NPTS
      IF (KMAX - K - 1) 71, 74, 74
71    KMAX = K + 1
      WRITE (IWR1,1016) K, KMAX
74    N = N + 1
      IF (NUM - NPLTS) 75, 90, 90
75    IF (N - 2) 80, 85, 85
80    XP0 = -XA0
      XMAX = XP
      YP0 = 24.
      GO TO 5
85    IF (XMAX - XP) 86, 88, 88
86    XMAX = XP
88    XP0 = XMAX + 5.0
      YP0 = 10.
      N = 0
      IF (NUMWR - 6) 5, 90, 90
90    WRITE (IWR1,1010) TITL1,L,NUM,KMAX,NUMWR
      WRITE (IWR1,1015)
      IPG = NMAX/50 + 1
      DO 92 J3 = 1, IPG
C
C     OUTPUT ROUTINE
C
      WRITE (IWR1,1017) J3,TITL1,(J,J=L,NUM)
      WRITE (IWR1,1018)
      IMAX = 50*J3
      IMIN = IMAX - 49
      IF (J3.EQ.IPG) IMAX = NMAX
      DO 92 J2 = IMIN, IMAX
92    WRITE (IWR1,1019)(DATA(1,J1,J2),DATA(2,J1,J2),J1=1,NUMWR)
      IPG = KMAX/50 + 1
      DO 195 J4 = 1, IPG
      WRITE (IWR1,1005) J4,TITL1,(J,J=L,NUM)
```

```
      WRITE (IWR1,1004)
      IMAX = 50*J4
      IMIN = IMAX - 49
      IF (J4.EQ.IPG) IMAX = KMAX
      DO 195 J2 = IMIN, IMAX
      IF (NCHNL - 1) 195,195,91
91    DO 94 J3 = 1, NCH1
      DO 94 J1 = 1, NUMWR
      DDA = FLOAT(J3)*DA(J1)
      IF (WRTARY(2,J1,J2) - DDA) 93, 93, 94
93    IF (WRTARY(2,J1,J2+1) - DDA) 94, 94, 193
193   DX = WRTARY(1,J1,J2+1) - WRTARY(1,J1,J2)
      DEL = DX*(DDA - WRTARY(2,J1,J2))/(WRTARY(2,J1,J2+1) -
     1WRTARY(2,J1,J2))
      W(J1,J3) = WRTARY(1,J1,J2) + DEL
94    CONTINUE
      WRITE (IWR1,1006) (WRTARY(1,J1,J2),WRTARY(2,J1,J2),J1=1,NUMWR)
195   CONTINUE
C
      IF (NCHNL - 1) 95, 95, 105
105   WRITE (IWR1,1021) TITL1,(J1, J1=1, NCHNL)
      DO 110 J1 = 1, NCHNL
110   DAA(J1) = 0.
      DO 130 J1 = 1, NUMWR
      DO 115 J2 = 1, NCHNL
115   DAA(J2) = J2*DA(J1)
130   WRITE (IWR1,1025) J1,(DAA(J2), J2 = 1, NCHNL)
      WRITE (IWR1,1022) (J1,J1=1,NCHNL)
      DO 135 J1 = 1, NUMWR
135   WRITE (IWR1,1025) J1, (W(J1,J2), J2 = 1, NCHNL)
      WRITE (IWR1,1024) (J1,J1 = 1, NCHNL)
      DO 145 J1 = 1, NUMWR
      DAA(1) = W(J1,1)
      DO 140 J2 = 2, NCHNL
140   DAA(J2) = W(J1,J2) - W(J1,J2-1)
145   WRITE (IWR1,1025) J1, (DAA(J2), J2 = 1, NCHNL)
95    CONTINUE
      GO TO 4
C
99    XMAX = XMAX + 5.
      CALL PLOT(XMAX,0.,999)
      REWIND IPLTPE
      STOP
C
1001  FORMAT(3A10,A2)
1004  FORMAT (6(7X, 1HW, 9X, 1HA, 2X)/)
1005  FORMAT (5H1PAGE,I3,40X,4A8//27H SECTION NUMBERS, AREAS-KSF,/
     &6(12X, I3, 5X))
1006  FORMAT (6(0PF10.0, -3PF10.3))
1008  FORMAT (/18H SECTION DATA READ I4, 9H POINTS, ,
     &14HORIGIN = POINT, I4/18H WIDTH INCREMENT =, F5.1/
     &7H SCALE, F8.1, 6H HORIZ/ 7X, F8.1, 5H VERT)
1010  FORMAT (/1X, 4A8, 5X, 5HL =, I3, 8H    NUM =, I4/
     &7H KMAX =, I4, 10H    NUMWR =, I4/)
1011  FORMAT (18H READ SECTION DATA )
1012  FORMAT (12H CALL SPLINE)
1013  FORMAT (17H SPLINE COMPLETED)
1014  FORMAT (34H INITIALIZATION AND AXES COMPLETED)
1015  FORMAT (23H OUTPUT ROUTINE REACHED/)
1016  FORMAT (4H K =, I4, 8H, KMAX =, I4)
1017  FORMAT (5H1PAGE,I3,40X,4A8//15H INPUT DATA--FT,
```

```
     &/6(12X, I3, 5X))
1018  FORMAT (6(7X, 1HX, 9X, 1HY, 2X)/)
1019  FORMAT (6(F10.0, F10.2))
1020  FORMAT(7H X(1) =, F8.2, 9H    Y(1) =, F8.2/
     &7H X(N) =, F8.2, 9H    Y(N) =, F8.2)
1021  FORMAT (16H1INLET FLOW GRID, 10X, 4A8//
     &17H CUMULATIVE AREAS/
     &40X, 15H CHANNEL NUMBER/ 8H SECTION, I6, 10I12)
1022  FORMAT (/18H CUMULATIVE WIDTHS/ 40X,
     &14HCHANNEL NUMBER/ 8H SECTION, I6, 10I12)
1024  FORMAT (/7H WIDTHS/40X, 14HCHANNEL NUMBER/
     &8H SECTION, I6, 10I12)
1025  FORMAT (I5, 11F12.0)
1028  FORMAT (1H1, 4A8/)
1030  FORMAT (/40H * * * * * * * * * * * * * * * * * * * * * * * * * //
     2  16H ERROR, ABSISSCA, I4, 1H., F6.0,
     3  28H EXCEEDS SUCCEEDING VALUE OF, F6.0//
     4  40H * * * * * * * * * * * * * * * * * * * * * * * /)
1032  FORMAT (/40H * * * * * * * * * * * * * * * * * * * * * * * * * //
     26H POINT, I4, 2F8.2, 21H OUT OF PLOTTER RANGE//
     340H * * * * * * * * * * * * * * * * * * * * * * * /)
C
2001  FORMAT (2I5,F5.2)
2004  FORMAT (I5, F6.0, 2F6.1)
      END
      SUBROUTINE SPLINE(X,Y,N,Y1)
C
      REAL L
C
C     N = NUMBER OF POINTS, EQUATIONS
C     Y1 = CALCULATED FIRST DERIVATIVES OF Y
C
      DIMENSION X(N), Y(N), Y1(N), A(100), B(100)
      N1 = N - 1
      L = 1./ABS(X(2) - X(1))
      D1 = 3.*(Y(2) - Y(1))*L*L
      B(1) = L
      A(1) = B(1) + B(1)
      Y1(1) = D1
C
C     A = VECTOR OF PRINCIPAL DIAGONAL ELEMENTS
C     B = VECTOR OF 1ST OFF DIAGONALS
C     STORE CONSTANTS IN Y1
C
      DO 50 I = 2, N1
      L = 1./ABS(X(I+1) - X(I))
      D2 = 3.*(Y(I+1) - Y(I))*L*L
      B(I) = L
      A(I) = 2.*(B(I) + B(I-1))
      Y1(I) = D1 + D2
50    D1 = D2
      A(N) = B(N1) + B(N1)
      Y1(N) = D1
C
C     EQUATIONS SET, SYMMETRIC AND TRIDIAGONAL, NOW TRIANGULATE
C
      DO 60 I = 2, N
      F = B(I-1)/A(I-1)
      A(I) = A(I) - B(I-1)*F
60    Y1(I) = Y1(I) - Y1(I-1)*F
      Y1(N) = Y1(N)/A(N)
```

```
C
C     SOLVE BY BACK SUBSTITUTION
C
      DO 70 I = 1, N1
      J = N - I
70    Y1(J) = (Y1(J) - B(J)*Y1(J+1))/A(J)
      RETURN
      END
      SUBROUTINE SPLINT (X0,Y0,Y10,X,Y,Y1,N,J)
C
      DIMENSION X(N), Y(N), Y1(N)
C
C     J INDICATES SPAN OF LAST CALL TO ROUTINE
C     IF X .LT. X(J), START AT BEGINNING
C
      IF (X0 - X(J)) 10, 20, 20
10    J = 1
20    DO 25 I = J, N
      IF (X0 - X(I)) 40, 60, 25
25    CONTINUE
C
C     X0 .GT. X(N), EXTRAPOLATE FROM X(N)
C
      J = N
      Y0 = Y(N) + (X0 - X(N))*Y1(N)
      Y10 = Y1(N)
      RETURN
40    IF (I - 1) 45, 45, 50
C
C     X0 .LT. X(1), EXTRAPOLATE FROM X(1)
C
45    Y10 = Y1(1)
      Y0 = Y(1) + (X0 - X(1))*Y10
      RETURN
C
C     INTERPOLATE ON SPAN J
C
50    J = I - 1
      TL = 1./(X(J+1) - X(J))
      X00 = X0 - X(J)
      C = Y1(J)
      D = Y(J)
      B = (Y(J+1) - Y(J))*TL*TL
      A = TL*(TL*(Y1(J) + Y1(J+1)) - B - B)
      B = 3.*B - TL*(Y1(J) + Y1(J) + Y1(J+1))
      Y0 = A*X00**3 + B*X00*X00 + C*X00 + D
      Y10 = 3.*A*X00*X00 + 2.*B*X00 + C
      RETURN
C
C     X0 IS AT A DATA POINT
C
60    Y0 = Y(I)
      Y10 = Y1(I)
      J=I
      RETURN
      END

    1     4   050
MASONBORO INLET  JULY-AUG 1966
    2    20  2000     50
SECTION 4--BAY END
```

1	-50	-38			
2	00	-19			
3	50	00			
31	200	15			
32	400	18			
36	800	20			
38	1000	35			
4	1300	70			
5	1360	100			
55	1600	175			
6	1800	200			
65	2000	170			
7	2250	100			
8	2350	50			
9	2410	10	10	2470	-38
-9					

APPENDIX D

DOCUMENTATION OF PROGRAM *INLET*

INLET is a digital computer program which performs various numerical computations and equation solutions required in the lumped parameter analysis of an inlet bay system. The program operation can be divided into three principle functions: (a) Analysis of inlet grid data for nonprismatic inlets to determine equivalent prismatic inlet properties according to the method described in section III. This function may be deleted if not applicable; (b) numerical solution of the simultaneous nonlinear differential equation (25) based on input data and results of function (a); and (c) generation of a solution plot for function (b). This feature may also be deleted if only a tabular solution is desired.

1. Input Data.

Input for INLET should be on punchcards in the formats shown for A and B. Descriptions of individual card requirements follow.

Card Type A.

A1—This card indicates whether solution plots are desired at any point in the program execution. A1 in cc2 of this card indicates that plots are desired; if no plots are desired, the card should be left blank.

A2—This card defines grid and system data for the chosen flow grid, inlet, bay, and tidal conditions for the area. The first value indicates the number of flow channels in the assumed flow grid; the second value similarly indicates the number of x-sections which have been selected across the inlet. If the number of x-sections is entered as zero, the inlet is assumed as prismatic and all parameters are entered on A4. The next two values are the tidal period in hours and the tidal semirange in feet. Manning's n for the inlet is specified next; however, if it is desired to specify distinct values of n for each channel and x-section, zero should be entered here; the distinct values will then be read later. The MTL surface area of the bay in square feet is input in scientific notation with the mantissa entered to the left of the "E" and the power of 10 to the right. The dimensionless surface area variation parameter β follows and is determined as previously described. The final value for the card is the beach slope ζ defined as horizontal to vertical differences.

A3—These two cards are title cards and each may contain up to 32 characters of numerical or alphabetical information to identify the resulting output. These titles will also appear on the solution plots if any are generated.

A4—This card is omitted if equivalent prismatic properties are to be computed from data on card type B. This card should be used only if the number of sections on card A2 is specified as zero, otherwise the B cards should be used in its place. For an inlet of known prismatic properties, the data values on this card include the MTL cross-sectional inlet area (square feet), inlet width (feet), inlet depth or hydraulic radius (feet), and the inlet length (feet).

A5—This card sets up the equation solution parameters. The first value is the time at which the calculation is initialized and the second value is the time at which output is to begin. If it is desired to start output at time zero, the beginning time should usually be some negative multiple of the tidal cycle in hours, thus allowing a transient solution stage during which the effects of inexact initial conditions may be dissipated. The third data value is the time in hours at which the solution is to be terminated.

The next two values are the initial conditions for bay surface elevation and inlet velocity. For sinusoidal ocean tides, the initial bay level (negative) may generally be taken as one-fourth of the tidal semirange and the initial velocity will likely approximate 3 feet per second. While the initial values chosen should not usually be critical, the closer they approximate the steady-state conditions, the shorter may be the transient stage of the solution. The next value specifies the time step in minutes to be used in the numerical solution method. A 5-minute time step has been used successfully for sinusoidal tides but may be varied if desired. All time steps need not be output as the seventh data value specifies which values are to be printed. For example, if a 5-minute time step is entered and a 12 is entered for the number of steps between output, output will be printed every 60 minutes. Critical values of all functions will always be printed.

The final value is a plot indicator and is set equal to one if a solution plot is desired. If left blank, no plot is generated and this card terminates the data set.

A6—This card describes the data which establish the limits and scales for plotting the computed solution if such a plot is desired. The first two values define the starting and ending times for the plot and should not exceed the range of the tabulated output specified on card A5.

The time-axis scale (hours per inch) is specified next and should be chosen to result in a plot length of at least 10 inches to complement the legend and title format. For the vertical axis, the minimum value of tidal heights (feet) or velocities (foot per second), overall height of plot (inches), scale of tidal heights (foot per inch), and velocities (foot per second), minimum value of flows (thousand cubic feet per second), and scale of flow (thousand cubic feet per second per inch) are specified.

The final data value on the card allows adjustment of the total plot size by the value selected. For instance, if a single sheet plot size is desired, the above data should be selected to produce a plot of approximately 5 by 10 inches. Specifying a size factor of 0.75 will then produce a plot 3.75 by 7.5 inches which will fit on a standard sheet size with axes and annotations. The size factor could also be used to increase the plot size if desired.

2. Irregular Inlet Grid Data.

Card Type B.

B1—Label card to indicate that data following are cross-sectional areas.

B2—Area cards; each card contains the cross-sectional area of each assumed flow channel. One record should be used for each cross section.

B3–Label card for widths.

B4–Width cards; each card contains the width of each assumed flow channel for the corresponding section.

B5–Label card for lengths.

B6–Length cards; each card contains the length between cross sections along the boundaries of the assumed flow channels. The number of lengths per card is one greater than the number of channels and the number of cards is one less than the number of sections.

B7–Label card for Manning's n.

B8–Values of Manning's n for each channel of each cross section. A value should correspond to each of the B2 and B4 data values.

Cards B7 and B8 must be omitted if a value of Manning's n other than zero is specified on card A2.

Cards A2 through B8 may be repeated if several problems are to be solved in a single run.

THIS FORM IS DESIGNED FOR ELITE TYPEWRITER OR MANUAL ENTRIES

"A" Cards for Inlet Analysis

Card

A1 — 1 For Plots

A2 — No. of Channels | No. of Sections | Tidal Period (h) | Tide Amplitude | Manning's n | Bay Surface Area (Scientific Notation) Exponent + | β | ζ

A3 — Title Cards

Inlet Grid Data Cards Here If Number Of Sections > 0

A4 — Cross-sectional Area | Width | Depth | Length | (measurements at MTL) — Omit card if "B" cards are used

Solution Parameters

A5 — Start Time | Time | Stop Time | Initial Bay Level | Initial Velocity | Time Step (min) | Steps Per Print Line | 1 for Plot

Plot Controls

A6 — Start Time | Stop Time | Time Scale (h/in) | Least Value of H or V | Plot Height (in) | Scale ft/in, FPS/in | Least Value of Flow (KCFS) | Flow Scale (KCFS/in) | Factor Size

ENG FORM 2900 MAY 68 (Local reproduction of this form is authorized after desired information is filled-in.) 80 COLUMN KEY PUNCH TRANSCRIPT LAYOUT SHEET SHEET OF SHEETS

THIS FORM IS DESIGNED FOR ELITE TYPEWRITER OR MANUAL ENTRIES

"B" Cards of grid data for equivalent K analysis

Areas

Widths

Lengths

Manning's N (enter n value for each section if 0 input on first card. Omit if n is uniform.)

ENG FORM 2900 MAY 60 (Local reproduction of this form is authorized af er desired information is filled-in.) 80 COLUMN KEY PUNCH TRANSCRIPT LAYOUT SHEET SHEET OF SHEETS

SAMPLE INPUT FOR INLET PROGRAM

```
        .JOB,WINTERGE       RO  HM  803-G9RO-182  10  H52962HV11       15
        .OPTIONS,,,,,F
        .SODA,0300,COMP
        .PERIPH,T0404
        .DFAREA,00,AM,ANY,2000,48
        .LOAD

      (PROGRAM OBJECT DECK INSERTED HERE)

        .DATA
 1
   4    5 124166667  1900 00270    1866&8 03500   7500
    MASONBORO INLET   1969
   MEAN SEA LEVEL CONDITION
AREAS
   8350     8290     8460     8280
   4990     4240     6710     3950
   3090     6600     4770     4820
   4010     4400     3370     2320
   4550     3220     4510     3280
WIDTHS
   1080      870     1050      725
    905      995      475      330
    550      190      150      360
    500      130      180      345
LENGTHS
    960     1100     1200     1440     1500
    650     1070     1290     1510     1640
    190      540      630      700      870
    350      525      540      550      500
-1241666  000000 1250000 -0500   3000      5      6    1
  000000 1242050  125000 -4000   4800   1667-60000 25000     0833
```

SAMPLE OUTPUT FOR INLET PROGRAM

EQUIVALENT COEFFICIENT OF REPLETION
FOR NON-PRISMATIC INLET

MASONBORO INLET 1969
MEAN SEA LEVEL CONDITION

AREAS

8350.	8290.	8460.	8280.
4990.	4240.	6710.	3950.
3090.	6600.	4770.	4820.
4010.	4400.	3370.	2320.
4550.	3220.	4510.	3280.

WIDTHS

1080.	870.	1050.	725.
905.	995.	475.	330.
750.	255.	250.	625.
550.	190.	150.	360.
500.	130.	180.	345.

LENGTHS

0.	0.	0.	0.
1030.	1150.	1320.	720.
860.	1180.	1400.	755.
365.	585.	665.	350.
437.	532.	545.	275.
0.	0.	0.	0.

TIDAL PERIOD = 12.417 HR
TIDAL SEMIRANGE = 1.900 FT
BAY AREA (MSL) = 1.86600E+08 SQ FT
MANNING''S N = 0.0270

COEF OF REPL = 1.681
INLET AREA = 1.41000E+04 SQ FT
INLET LENGTH = 3.04250E+03 FT
INLET DEPTH = 11.591 FT
INLET WIDTH = 1250. FT

SAMPLE OUTPUT FOR INLET PROGRAM

INLET ANALYSIS

MASONBORO INLET 1969
MEAN SEA LEVEL CONDITION

TIDAL SEMIRANGE = 1.900 FT
MEAN BAY SURFACE AREA = 1.866E+08 SQ FT
BAY SIDE SLOPE PARAMETER BETA = 0.350

INLET PROPERTIES:
X-SECTION AREA BELOW MTL = 1.4100E+04 SQ FT
INLET WIDTH AT MTL = 1250. FT
INLET BEACH SLOPE = 75:1
MTL DEPTH = 11.591 FT
INLET LENGTH = 3042. FT
MANNING"S N = 0.0270

TIME HRS	H2 FT	INFLOW KCFS	H1 FT	VEL FPS	Q KCFS
0.00	0.00	0.00	-.44	2.82	39.04
0.50	0.48	0.00	-.02	3.07	44.22
1.00	0.92	0.00	0.41	3.20	47.83
1.17	1.06	0.00	0.55	3.20*	48.54
1.50	1.31	0.00	0.83	3.16	49.05*
2.00	1.61	0.00	1.22	2.93	46.97
2.50	1.81	0.00	1.56	2.47	40.50
3.00	1.90	0.00	1.82	1.69	28.18
3.08	1.90*	0.00	1.85	1.52	25.38
3.50	1.86	0.00	1.95	0.38	6.36
3.58	1.84	0.00	1.95*	0.06	0.96
4.00	1.71	0.00	1.87	-1.58	-26.16
4.50	1.45	0.00	1.65	-2.03	-32.87
5.00	1.09	0.00	1.39	-2.41	-37.93
5.50	0.67	0.00	1.07	-2.80	-42.75
6.00	0.20	0.00	0.71	-3.11	-45.70
6.42	-.20	0.00	0.37	-3.27	-46.50*
6.50	-.28	0.00	0.30	-3.29	-46.48
6.83	-.59	0.00	0.01	-3.33*	-45.80
7.00	-.74	0.00	-.14	-3.33	-45.11
7.50	-1.16	0.00	-.58	-3.19	-41.71
8.00	-1.50	0.00	-1.03	-2.87	-36.33
8.50	-1.74	0.00	-1.44	-2.35	-28.91
9.00	-1.88	0.00	-1.77	-1.58	-19.03
9.33	-1.90*	0.00	-1.92	-.87	-10.48
9.50	-1.89	0.00	-1.96	-.43	-5.20
9.67	-1.87	0.00	-1.97*	0.11	1.31
10.00	-1.79	0.00	-1.89	1.08	12.96
10.50	-1.57	0.00	-1.68	1.30	15.92
11.00	-1.25	0.00	-1.44	1.67	20.96
11.50	-.85	0.00	-1.13	2.13	27.55
12.00	-.40	0.00	-.77	2.54	34.01
12.50	0.08	0.00	-.37	2.87	39.98

AVG BAY LEVEL = 0.02 FT

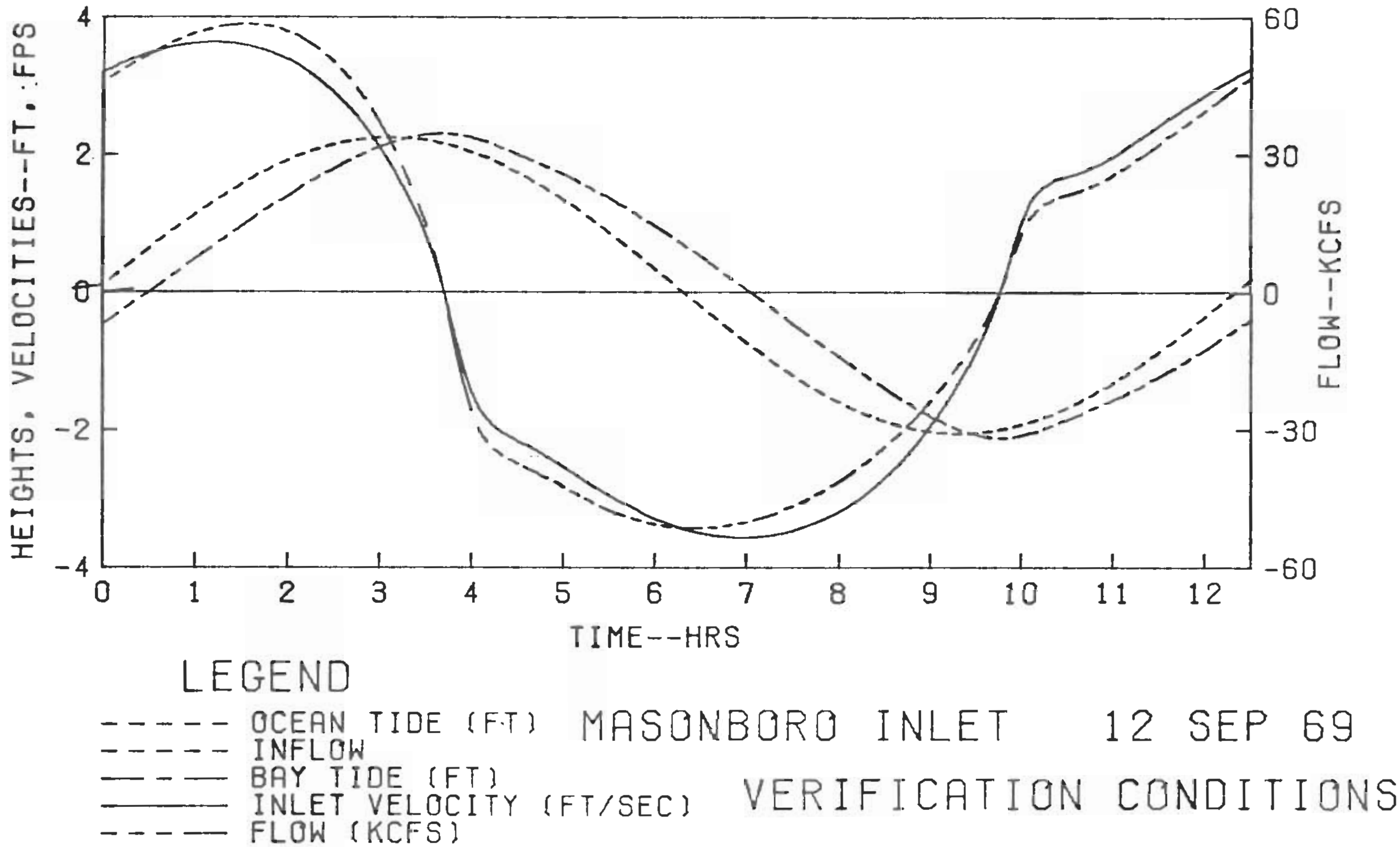
* CRITICAL POINT VALUE

SAMPLE OUTPUT FOR INLET PROGRAM

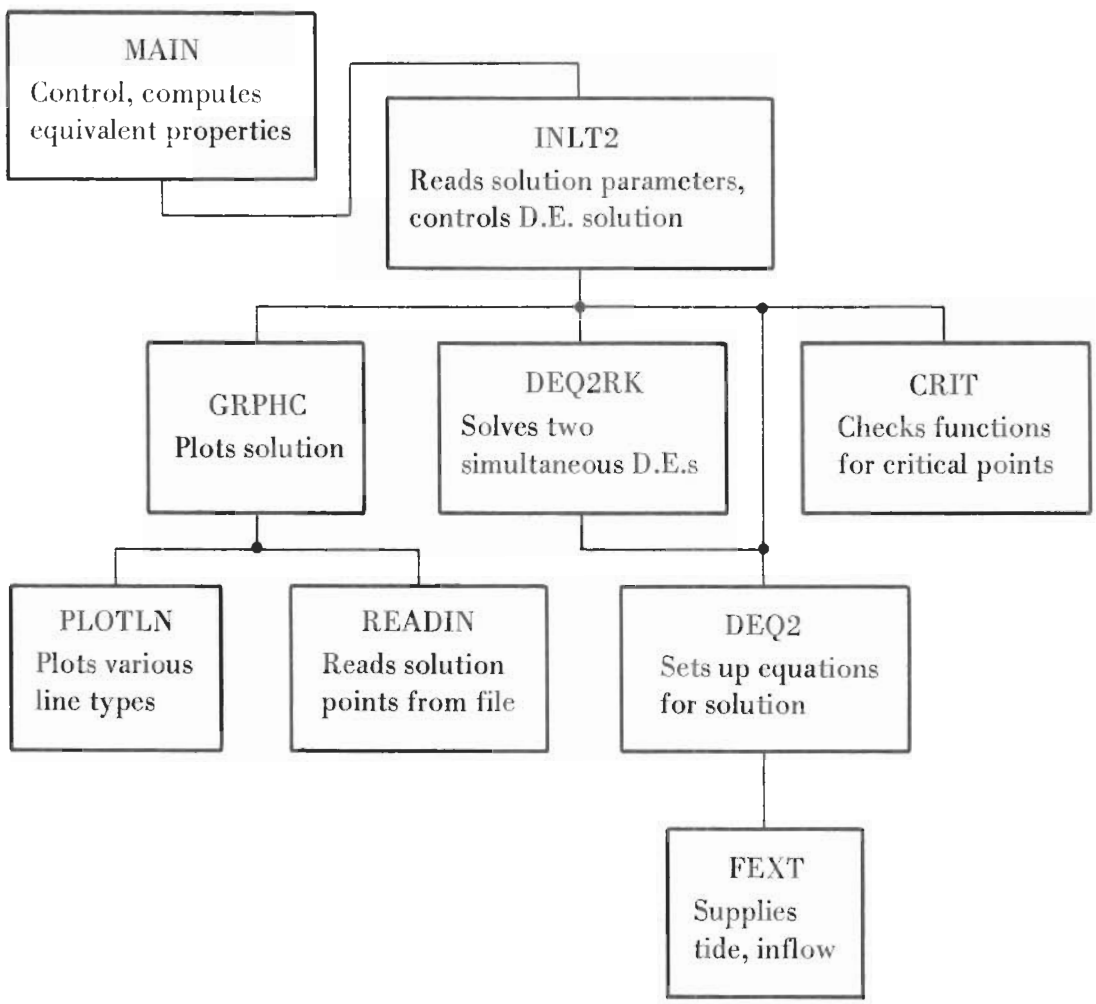
```
*** TABULATION COMPLETED ***

ST 20
ST 30
PLOT X AXIS
PLOT RIGHT AXIS
PLOT LEFT AXIS
BORDER COMPLETE
DO 50 I = 1
DO 80 I = 1
DO 80 I = 2
DO 80 I = 3
ST 80
```

INLET PROGRAM SAMPLE GRAPHIC OUTPUT



INLET Program – Subroutine Control Structure



PROGRAM INLET ROUTINE TO CALCULATE

EQUIVALENT K + R FOR NONPRISMATIC INLET CHANNELS

```
Q=TES,   SEELIG  TEST
TASK(TNQQ72434,PWCERC1,TRTS)SIMS
FTN(R=2)
ATTACH(PLOT,PLOTTT,ID=QQ72440,MR=1,CY=1)
LOAD(PLOT)
REWIND(TAPE3)
COPYSBF(TAPE3,OUTPUT)

      PROGRAM INLET(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE9,TAPE10,
     1TAPE3,PUNCH=TAPE3)
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     ROUTINE TO CALCULATE EQUIVALENT K + R FOR
C     NON-PRISMATIC INLET CHANNELS.
C
      INTEGER P, CH, P1, CH1, PM1
      REAL N, K, KF
      COMMON IDUMMY(1000),BETA,HO,ZETA,A0,BAY,D1,TL,N,RO,H,
     1D2,DT,DT5,Q,AX,HOURS,F(3,5),H1H,QINO,IOUT,IPLTS,XT
      DIMENSION A(8,8), R(8,8), DL(9,8), DDL(9)
      DIMENSION TITL1(4), TITL2(4), EN(8,8)
      DATA I50/5/
      DATA IPLTPE/ 3/
C
C  THE FOLLOWING 2 CARDS APPLY ONLY TO CDC6600 - COPE 1200 CARD OUTPUT
C        AT REMOTE BATCH TERMINAL
      PUNCH 1
    1 FORMAT(*89C*)
C
C  READ CARD TYPE A1 CONTAINING
C    IP (I2)= 1 IN CC 2 INDICATES IF PLOTS ARE DESIRED
C             BLANK INDICATES NO PLOTS DESIRED
      READ (I50,2001) IP
C
C     CH = NO. OF CHANNELS
C     P = NO. OF X-SECTIONS
C
      IOUT=6
      IPLTS = 0
C
      IF (IP) 10, 10, 5
5     REWIND IPLTPE
      CALL PLOTS(IDUMMY,1000,IPLTPE)
10    A0 = 1.E+25
      WRITE (IOUT,127)
C
C  READ CARD TYPE A2 CONTAINING
C    CH (I5)- NUMBER OF FLOW CHANNELS IN ASSUMED FLOW GRID
C     P (I5)- NUMBER OF X-SECTIONS SELECTED ACROSS INLET.
C     T (F10.7)- TIDAL PERIOD IN HOURS
C     H (F6.- TIDAL SEMI-RANGE IN FEET
C     N (F6.4)- MANNINGIS N FOR THE INLET OR 0
C         IF DISTINCT VALUES OF N FOR EACH CHANNEL
C         AND X-SECTION ARE TO BE SPECIFIED
C    BAY (F8.3)- MTL SURFACE AREA OF THE BAY IN SQUARE FEET (ENTER IN
C       E NOTATION WITH MANTISSA TO LEFT AND POWER OF 10 TO THE RIGHT)
C    BETA (F6.4)- DIMENSIONLESS SURFACE AREA VARIATION PARAMETER
C    ZETA (F6.2)- BEACH SLOPE
C
C
      READ (I50,2002) CH, P, T, H, N, BAY, BETA, ZETA
C
```

```
      IF(EOF(5))99,15
C     0 FOR NO. OF CHNLS OR EOF MARK INDICATES END OF DATA.
C
   15 IF(CH.EQ.0) GO TO 99
C  READ CARD TYPE A3 (2 CARDS) CONTAINING
C     TITL1, TITL2 = (3A10,A2/3A10,A2) = 2 LINES OF 32 CHARACTERS EACH
C      OUTPUT IDENTIFICATION.  ALSO USED AS TITLE ON PLOTS.
C       NOTE*** CDC6600 WORD SIZE IS 10 CHARACTERS
      READ (I50,2003) TITL1,TITL2
C
C     FOR P = 0, DELETE CALCULATION FOR EQUIVALENT K
C
      IF (P.EQ.0) GO TO 98
      WRITE (IOUT,125) TITL1, TITL2
C  READ CARD TYPE B1 CONTAINING
C    LABEL TO INDICATE DATA FOLLOWING ARE
C    CROSS-SECTIONAL AREAS (NO DATA- READ)
C     FORMAT(80X)
      READ (I50,2004)
      P1 = P + 1
      PM1 = P - 1
      CH1 = CH + 1
C
C    KF=G/(1.486**2)
C
      KF = 14.582
C
C     READ + PRINT INPUT DATA.
C
C     AREAS
C  READ CARD TYPE B2 CONTAINING
C    A(J,I) - (8F8.0) - CROSS-SECTIONAL AREA EACH ASSUMED FLOW CHANNEL
C         (I). ONE CARD FOR EACH CROSS-SECTION(J).
C
C
      DO 40 J = 1, P
      READ (I50,101) (A(J,I), I = 1, CH)
      WRITE (IOUT,101) (A(J,I), I = 1, CH)
      AMIN = 0.
      DO 30 I = 1, CH
30    AMIN = AMIN + A(J,I)
      IF (AMIN - A0) 35, 40, 40
35    MIN = J
      A0 = AMIN
C
C     RETAIN SMALLEST X-SECTION FOUND (THROAT).
C
40    CONTINUE
C  READ CARD TYPE B3 CONTAINING
C    LABEL FOR WIDTHS (NO DATA READ) FORMAT(80X)
      READ (I50,2004)
      WRITE (IOUT,111)
      W0 = 0.
      DO 45 J = 1, P
C
C     WIDTHS
C  READ CARD TYPE B4 CONTAINING
C    R(J,I) - (8F8.0) - WIDTHS OF EACH ASSUMED FLOW CHANNEL (I), ONE
C         CARD FOR EACH CROSS-SECTION(J).
C
      READ (I50,101) (R(J,I), I = 1, CH)
```

```
      WRITE (IOUT,101) (R(J,I), I = 1, CH)
      DO 45 I = 1, CH
      IF (J - MIN) 44, 42, 44
C
C     COMPUTE MSL WIDTH AT THROAT
C
42    WO = WO + R(J,I)
C
C     CONVERT WIDTHS TO HYDR. RADII.
C
44    R(J,I) = A(J,I)/R(J,I)
45    CONTINUE
      DO 50 J = 1, P1, P
      DO 50 I = 1, CH
      DL(J,I) = 0.
50    CONTINUE
      TL = 0.
C  READ CARD TYPE B5 CONTAINING
C    LABEL FOR LENGTHS (NO DATA READ) FORMAT(80X)
      READ (I50,2004)
      DO 52 J = 1, PM1
C
C     LENGTHS
C
C  READ CARD TYPE B6 CONTAINING
C    DDL(I) (8F8.0)= LENGTHS BETWEEN CROSS-SECTIONS ALONG THE
C        BOUNDARIES OF THE ASSUMED FLOW CHANNELS(I). THE NUMBER OF
C        LENGTHS PER CARD IS ONE GREATER THAN THE NUMBER OF CHANNELS
C        AND THE NUMBER OF CARDS IS ONE LESS THAN THE NUMBER OF SECTIONS
      READ (I50,101) (DDL(I), I = 1, CH1)
      DO 52 I = 1, CH
      DL(J+1,I) = 0.5*(DDL(I) + DDL(I+1))
      TL = TL + DL(J+1,I)
52    CONTINUE
      WRITE (IOUT,115)
      DO 54 J = 1, P1
54    WRITE (IOUT,101) (DL(J,I), I = 1, CH)
      TL = TL/CH
C
C     FOR N ZERO, READ DIFFERENT N'S FOR EACH X-SECTION.
C
      IF (N) 156, 156, 154
154   DO 155 I = 1, CH
      DO 155 J = 1, P
      EN(J,I) = N
155   CONTINUE
      GO TO 158
C  READ CARD TYPE B7 CONTAINING
C    LABEL FOR MANINGS N (NO DATA READ) FORMAT(80X)
C    NOT USED IF VALUE OF N ON CARD TYPE A2 IS NOT ZERO.
156   READ (I50,2004)
      WRITE (IOUT,121)
      DO 157 J = 1, P
C  READ CARD TYPE B8 CONTAINING
C    EN (J,I) = MANNINGS N FOR EACH CHANNEL OF EACH CROSS-SECTION.
C  NOT USED IF VALUE OF N ON CARD TYPE A2 IS NOT ZERO
      READ (I50,123) (EN(J,I), I = 1, CH)
      WRITE (IOUT,123) (EN(J,I), I = 1, CH)
157   CONTINUE
158   ROOT = 0.
      DO 60 I = 1, CH
```

```
      ROOTI = 0.
      DO 55 J = 1, P
      ROOTI = ROOTI + (DL(J,I) + DL(J+1,I))*R(J,I)**(-1.333333)
     &*(EN(J,I)/A(J,I))**2
55    CONTINUE
      ROOTI = 1./(SQRT(1./(A(MIN,I)**2) + KF*ROOTI))
      ROOT = ROOT + ROOTI
60    CONTINUE
C
C     CALCULATE EQUIVALENT K
C
      K = 572.96*T*ROOT*SQRT(64.3*H)/(H*BAY)
C
C     CALCULATE EQUIVALENT R
C
      RO = 1145.9*T*AO/(K*BAY)
      RO = 16.075*RO*RO/H - 1.
      RO = (0.034338*RO/(N*N*TL))**(-0.75)
C
C     OUTPUT DATA + RESULTS
C
      WRITE (IOUT,103) T, H, BAY, N
      WRITE (IOUT,105) K, AO, TL, RO, WO
C     CALL ROUTINE TO SOLVE EQUATION SET
      CALL INLT2(TITL1,TITL2)
      GO TO 10
C  READ CARD TYPE A4 CONTAINING
C    AO (F8.0)- MTL CROSS-SECTIONAL INLET AREA IN SQUARE FEET
C    WO (F8.0)- INLET WIDTH IN FEET
C    RO (F8.4)- INLET DEPTH OR HYDRAULIC RADIUS IN FEET
C    TL (F8.0)- INLET LENGTH IN FEET
98    READ (I50,2005) AO, WO, RO, TL
      CALL INLT2(TITL1,TITL2)
      GO TO 10
99    IF(IPLTS.GT.0) CALL PLOT(XT,0.,999)
C
C  THE FOLLOWING 2 CARDS APPLY ONLY TO CDC6600 - COPE 1200 CARD OUTPUT
C        AT REMOTE BATCH TERMINAL
      PUNCH 999
  999 FORMAT(*EOL*)
      STOP
C
101   FORMAT (8F8.0)
103   FORMAT (/ 15H TIDAL PERIOD =, F7.3, 3H HR/
     118H TIDAL SEMIRANGE =, F7.3, 3H FT/
     217H BAY AREA (MSL) =, 1PE12.6, 6H SQ FT/
     314H MANNING'S N =, 0PF7.4/)
C
105   FORMAT (15H COEF OF REPL =, F7.3/
     113H INLET AREA =, 1PE12.6, 6H SQ FT/
     215H INLET LENGTH =, E12.6, 3H FT/
     314H INLET DEPTH =, 0PF7.3, 3H FT/
     414H INLET WIDTH =, F7.0, 3H FT/)
C
107   FORMAT (5(1PE11.5, 1H,)/ 3(E11.5, 1H,), F11.5////)
111   FORMAT (/7H WIDTHS)
115   FORMAT (/8H LENGTHS)
121   FORMAT (/ 14H MANNING'S N'S)
123   FORMAT (8F8.4)
125   FORMAT (/5X, 35HEQUIVALENT COEFFICIENT OF REPLETION/
     111X, 23HFOR NON-PRISMATIC INLET //
```

```
     2 2(6X, 3A10,A2/)/ 6H AREAS)
C
127    FORMAT (/40H1* * * * * * * * * * * * * * * * * * * * * * * * /)
2001   FORMAT (I2)
2002   FORMAT (2I5, F10.7, F6.3, F6.4, F8.3, F6.4, F6.2)
 2003  FORMAT(3A10,A2/3A10,A2)
2004   FORMAT (80X)
2005   FORMAT (2F8.0, F8.4, F8.0)
       END
       SUBROUTINE INLT2(A1,A2)
C
C      *****
C      PROGRAM INLET2 - ANALYSES INLET-BAY SYSTEM
C      BY LUMPED PARAMETER APPROACH.  INCLUDES
C      INERTIA OF FLOW, ALLOWS FRESH WATER INFLOW.
C
C      DEFINE OCEAN TIDE AND INFLOW AS FUNCTIONS OF TIME IN
C      SUBROUTINE FEXT(T,H2)
C      T = TIME IN SEC.
C      H2 = OCEAN TIDE IN FEET
C
       REAL KF, N, L
       DIMENSION A1(4), A2(4), DUMMY(6)
       COMMON IDUMMY(1000),BETA,W0,ZETA,AX0,AB0,GL,L,N,R0,
      1H,KF,DT,DTS,Q,AX,HOURS,F(3,5),H1H,QIN0,IFL1,IPLTS,
      2YT
       DATA IFL2, IFL3/5,9/,     DUMMY/6*1.E+75/
C
C   READ CARD TYPE A5 CONTAINING
C     T (F8.5)- TIME AT WHICH CALCULATION IS INITIALIZED
C     TO F8.5)- TIME AT WHICH OUTPUT IS TO BEGIN
C     TF F8.5)- TIME IN HOURS AT WHICH SOLUTION IS TO BE TERMINATED
C     H10 (F6.3)- INITIAL CONDITION FOR BAY SURFACE ELEVATION
C       V (F6.3)- INITIAL CONDITION FOR INLET VELOCITY
C      DT (F6.0)- TIME STEP IN MINUTES TO BE USED IN NUMERICAL
C                SOLUTION METHOD
C     NDT (I6)- SPECIFIES NUMBER OF TIMES STEPS TO BE PRINTED
C     IPLT (I4)- SET EQUAL TO 1 IF SOLUTION PLOT IS DESIRED
        READ (IFL2,2010) T,TO,TF,H10,V,DT,NDT,IPLT
        IF (IPLT.NE.0) REWIND 9
        WRITE (IFL1,1004) A1, A2
        WRITE (IFL1,1005) H, AB0, BETA
        IZETA = ZETA
        WRITE (IFL1,1006) AX0, W0, IZETA, R0, L, N
        WRITE (IFL1,1009)
        DT = 60.*DT
        GL = 32.15/L
        KF = 29.122*N*N*L
        BETA = BETA/H
        T = 3600.*T
        TO = 3600.*TO
        TF = 3600.*TF
        DTS = 0.5*DT
        CALL DEQ2(T,H10,H11,V,V1,H20)
        KOUNT = 0
 230    IF (T - TO + DT + DTS) 240, 240, 250
 240    CALL DEQ2RK(T,H10,H11,V,V1,H20)
        KOUNT = KOUNT + 1
 C
 C      SAFETY VALVE - ABORT IF KOUNT EXCEEDS 5000
 C
```

```
      IF (KOUNT - 5000) 230, 230, 245
245   WRITE (IFL1,1007)
      RETURN
C
C     BEGIN SOLUTION CYCLE WITH OUTPUT
C
250   F(1,1) = H20
      F(1,2) = QINO
      F(1,3) = H10
      F(1,4) = V
      F(1,5) = Q
      CALL DEQ2RK(T,H10,H11,V,V1,H20)
      F(2,1) = H20
      F(2,2) = QINO
      F(2,3) = H10
      F(2,4) = V
      F(2,5) = Q
      H1SUM = 0.
      CALL DEQ2RK(T,H10,H11,V,V1,H20)
      IOUT = 0
      CALL CRIT (H20,H10,V,IPRNT,IOUT)
      IF (IPLT) 271, 271, 256
256   WRITE (IFL3) HOURS, (F(1,IA), IA = 1, 5)
      GO TO  271
260   DO 270 I = 1, NOT
      IOUT = 0
      H1SUM = H1SUM + H10
      CALL DEQ2RK(T,H10,H11,V,V1,H20)
      CALL CRIT (H20,H10,V,IPRNT,IOUT)
      IF (IPLT) 270, 270, 265
265   WRITE (IFL3) HOURS, (F(1,IA), IA = 1, 5)
270   CONTINUE
      IF (IOUT) 271, 271, 280
271   WRITE (IFL1,1010) HOURS, (F(1,IA), IA = 1, 5)
280   IF (T - TF - DT) 260, 290, 290
290   H1SUM = H1SUM*DT/(TF - T0)
      IF (IPLT.GT.0) WRITE (IFL3) DUMMY
      WRITE (IFL1,1011) H1SUM
C
C     END OF SOLUTION ROUTINE, GO TO PLOT ROUTINE OR
C     READ NEXT DATA SET.
C
      IF (IPLT.GT.0) CALL GRPHC(A1,A2)
      RETURN
C
1001  FORMAT (3(5A6/))
1004  FORMAT (1H1, 20X,14HINLET ANALYSIS//2(12X,4A8/)/)
1005  FORMAT (5X, 17HTIDAL SEMIRANGE =, F7.3, 3H FT/
     15X, 23HMEAN BAY SURFACE AREA =, 1PE10.4, 6H SQ FT/
     25X, 31HBAY SIDE SLOPE PARAMETER BETA =, 0PF6.3/)
C
1006  FORMAT (5X, 17HINLET PROPERTIES:/ 8X,
     126HX-SECTION AREA BELOW MTL =, 1PE11.5, 6H SQ FT/
     28X,20HINLET WIDTH AT MTL =, 0PF7.0, 3H FT/ 8X,
     319HINLET BEACH SLOPE =, I4, 2H:1/ 8X,
     411HMTL DEPTH =, F7.3, 3H FT/8X, 14HINLET LENGTH =,
     5F7.0, 3H FT/ 8X, 13HMANNING'S N =, F7.4//)
C
1007  FORMAT (29H EXECUTION ABORTED, TRANSIENT/
     126H STAGE EXCEEDS 5000 STEPS./)
C
```

```
1009  FORMAT (4X, 4HTIME, 5X, 2HH2, 4X, 6HINFLOW, 5X, 2HH1,
     15X, 3HVEL, 7X, 1HQ/ 5X, 3HHRS, 5X, 2HFT, 5X, 4HKCFS,
     16X, 2HFT, 5X, 3HFPS, 6X, 4HKCFS/)
C
1010  FORMAT (2F8.2, -3PF9.2, 0P2F8.2, -3PF10.2, 2F9.3)
1011  FORMAT (/ 16H AVG BAY LEVEL =, F6.2, 3H FT//
     123H * CRITICAL POINT VALUE// 10X,
     228H*** TABULATION COMPLETED ***/)
C
2010  FORMAT (3F8.5, 2F6.3, F6.0, I6, I4)
      END
      SUBROUTINE DEQ2 (T,H10,H11,V,V1,H2)
C
C     SUBROUTINE DEQ2 ASSEMBLES AND EVALUATES THE NON-LINEAR
C     SIMULTANEOUS D.E.'S CHARACTERIZING THE INLET
C
      REAL KF, L, N
      COMMON IDUMMY(1000),BETA,W0,ZETA,AXO,ABO,GL,L,N,RO,H,KF,
C
     1DT,DT5,Q,AX,HOURS,F(3,5),H1H,QINO,IFL1,IPLTS,XT
C     CALL FEXT FOR TIDE AND INFLOW
C
      CALL FEXT(T,H2)
      ETAO = 0.5*(H10 + H2)
C
C     VELOCITY COEFFICIENT
C
      CV = 0.01555*(1. + KF*(RO+ETAO)**(-1.33333))
C
C     SURFACE AREA OF BAY
C
      AB = ABO*(1. + BETA*H10)
C
C     INLET CROSS-SECTIONAL AREA
C
      AX = AXO + (W0 + ZETA*ETAO)*ETAO
      V1 = GL*(H2 - H10 - CV*V*ABS(V))
C     COMPUTE DV/DT FROM ENERGY EQUATION
C
      Q = AX*V
C
C     COMPUTE DH1/DT FROM CONTINUITY EQUATION
C
      H11 = (Q + QINO)/AB
      HOURS = (2.7777777E-04)*(T - DT)
      H1H = 3.6E+06*H11
      RETURN
      END
      SUBROUTINE FEXT(T,H2)
C
C     SUBROUTINE TO DEFINE OCEAN TIDE H2 AND INFLOW QINO AS
C     FUNCTIONS OF TIME T IN SECONDS
C
      REAL KF, L, N
      COMMON IDUMMY(1000),BETA,W0,ZETA,AXO,ABO,GL,L,N,RO,H,KF,
     1DT,DT5,Q,AX,HOURS,F(3,5),H1H,QINO,IFL1,IPLTS,XT
C
C     CONVERT SECONDS TO RADIANS
C
      X = 1.405634E-04*T
C
```

```
C       SINUSOIDAL TIDE OF AMPLITUDE H
C
        H2 = H*SIN(X)
C
C       INFLOW NEGLIGIBLE
C
        QINO = 0
        RETURN
        END
        SUBROUTINE CRIT(H20,H10,V,IPRNT,IOUT)
C
C       SUBROUTINE CRIT COMPARES 3 CONSECUTIVE FUNCTION POINTS
C       AND WRITES MIDDLE POINT IF IT IS A CRITICAL POINT
C
        REAL KF, L, N
        COMMON IDUMMY(1000),BETA,AO,ZETA,AXO,ARO,GL,L,N,RO,H,KF,
       1DT,DT5,Q,AX,HOURS,F(3,5),H1H,QINO,IFL1,IPLTS,XT
        DIMENSION MARK(5)
        DATA MARKA/1H /, MARKB/1H*/
        F(3,1) = H20
        F(3,2) = QINO
        F(3,3) = H10
        F(3,4) = V
        F(3,5) = Q
        DO 2020 IA = 1, 5
        MARK(IA) = MARKA
        IF (F(2,IA) - F(1,IA)) 2012, 2020, 2014
2012    IF (F(3,IA) - F(2,IA)) 2020, 2015, 2015
2014    IF (F(3,IA) - F(2,IA)) 2015, 2015, 2020
2015    IOUT = 1
        MARK(IA) = MARKB
2020    CONTINUE
        DO 2025 IA = 1, 5
        F(1,IA) = F(2,IA)
2025    F(2,IA) = F(3,IA)
        IF (IOUT.EQ.0) RETURN
        WRITE (IFL1,2101) HOURS,(F(1,IA),MARK(IA),IA=1,5)
        RETURN
2101    FORMAT (2F8.2,A1,-3PF8.2,A1,2(0PF7.2,A1),
       &-3PF9.2, A1, 2(F8.3, A1))
        END
        SUBROUTINE DEQ2RK(X,Y,Y1,Z,Z1,S)
C
C       RUNGE-KUTTA-GILL SUBROUTINE TO SOLVE 2ND ORDER D.E.
C       OR 2 SIMULTANEOUS FIRST ORDER D.E.'S
C
        REAL KF, L, N
        COMMON IDUMMY(1000),BETA,AO,ZETA,AXO,ARO,GL,L,N,RO,H,KF,
       1DT,DT5,Q,AX,HOURS,F(3,5),H1H,QINO,IFL1,IPLTS,XT
        CALL DEQ2(X,Y,Y1,Z,Z1,S)
        P1 = Y1*DT5
        Q1 = Z1*DT5
        X = X + DT5
        Y01 = Y + P1
        Z01 = Z + Q1
        CALL DEQ2(X,Y01,Y1,Z01,Z1,S)
        P2 = Y1*DT5
        Q2 = Z1*DT5
        Y01 = Y + P2
        Z01 = Z + Q2
        CALL DEQ2(X,Y01,Y1,Z01,Z1,S)
```

```
      P3 = Y1*DT5
      Q3 = Z1*DT5
      X = X + DT5
      Y01 = Y + P3
      Z01 = Z + Q3
      CALL DEQ2(X,Y01,Y1,Z01,Z1,S)
      P4 = Y1*DT5
      Q4 = Z1*DT5
      D1 = 0.33333333*(P1+P4+P2+P2+P3+P3)
      D2 = 0.33333333*(Q1+Q4+Q2+Q2+Q3+Q3)
      Y = Y + D1
      Z = Z + D2
      CALL DEQ2(X,Y,Y1,Z,Z1,S)
      RETURN
      END

      SUBROUTINE PLOTLN(X,Y,LN,INDX)
C
C     SUBROUTINE TO PLOT VARIOUS LINE TYPES
C
      IPEN = 2
      INDX = INDX + 1
      GO TO (20,40,30,10), LN
C     - - - - - - - -    LN = 4
10    GO TO (40, 15), INDX
15    INDX = 0
      GO TO 35
C     --- - --- - ---    LN = 1
20    GO TO (40,40,40,35,40,25), INDX
25    INDX = 0
      GO TO 35
C     - - - --- - - - ---    LN = 3
30    GO TO (40,35,40,35,40,35,40,40,40,32), INDX
32    INDX = 0
35    IPEN = 3
C     --------------- LN = 2
40    CALL PLOT (X,Y,IPEN)
      RETURN
      END
      SUBROUTINE AXIS13(X,Y,IBCD,NC,H,SIZE,NN,IXY,XMIN,DX,SPACE,ITIC,
     1NP10)
      DIMENSION LBL(3),MESAGE(5)
      DATA LBL/7H(X10   )/
      DATA MESAGE/13HAXIS TOO LONG/
      XY=IXY
      ANGLE=XY*90.
      TIC=ITIC
      SPAC=SPACE
      G=H
      P10=NP10
      XT=X
      YT=Y
      LINE=2
      SIZ=SIZE
      IF(SIZ)1,16,100
    1 LINE=3
      SIZ=-SIZE
  100 ND=NA=NN
      IF(ND)3,2,2
    2 NDIG=ND+1
```

```
      GO TO 30
 3    ND=NDIG=0
 30   NSPACE=SIZ/SPAC+.5
      TL=NSPACE*SPAC
      IF(YT+TL*XY-29.) 4,4,50
 50   CALL SYMBOL(XT,YT+.1,.14,MESAGE,90.,13)
      RETURN
 4    HO2=G*.5
      HO7=HO2/3.5
      HO7T24=4.*G
      POWER=10.**(-NP10)
      DELX=POWER*DX
      XMEN=POWER*XMIN
      ANG=1.-XY
      NB=NC
      ALAB=1.
      IF(NB)5,6,6
 5    NB=-NB
      ALAB=-1.
 6    TICXY=(2.*XY-1.)*ALAB*TIC*.1
      XTIC=TICXY*XY
      YTIC=TICXY*ANG
      AK=NB
      IF(P10)60,65,60
 60   AK=AK+8.
 65   STITLE=TL*.5-(7.*AK-3.)*HO7*.5
      TICM1=.16-TIC*.05
      ANOMIN=24.
      XNUMB=XMEN
      LIN=3
      NMAX=0
      IRA=0
      DO 12 I=IRA,NSPACE
      NDIGIT=NDIG
      CALL PLOT(XT,YT,LIN)
      LIN=LINE
      CALL PLOT(XT+XTIC,YT+YTIC,2)
      IF(G) 7,11,7
 7    ITEMP=.434294482*ALOG(ABS(XNUMB)+.5*10.**(-ND))+1.
      IF(ITEMP)75,75,51
 51   CONTINUE
      NDIGIT=NDIGIT+ITEMP
 75   IF(XNUMB)9,8,10
 8    NDIGIT=0
 9    NDIGIT=NDIGIT+1
 10   IF(NDIGIT-NMAX)  77,77,52
52    CONTINUE
      NMAX=NDIGIT
 77   CENTER=HO7*(7.*NDIGIT-3.)*.5
      XANO=-ALAB*XY*(TICM1+CENTER)-CENTER
      YANO=ALAB*ANG*(TICM1+HO2)-HO2
      CALL NUMBER(XT+XANO,YT+YANO,G,XNUMB,0.,NA)
      XNUMB=XNUMB+DELX
      IF(ANOMIN-XANO)11,11,53
 53   ANOMIN=XANO
 11   CALL PLOT(XT,YT,3)
      XT=XT+SPAC*ANG
      YT=YT+SPAC*XY
 12   CONTINUE
      IF(G)13,16,13
 13   ANOWID=(7.*NMAX-3.)*HO7*0.5
```

```
      XTITLE=X+XY*(ANOMIN+ANOWID-ALAB*(ANOWID+.18))+ANG*STITLE
      YTITLE=Y+ANG*(YANO+ALAB*(G+.18))+XY*STITLE
      CALL SYMBOL(XTITLE,YTITLE,G,IBCD,ANGLE,NB)
      IF(P10)14,16,14
   14 BN=(NB+1)*G
      XTITLE=XTITLE+ANG*BN
      YTITLE=YTITLE+XY*BN
      CALL SYMBOL(XTITLE,YTITLE,G,LBL(1),ANGLE,7)
      XTITLE=XTITLE+ANG*H07T24-XY*H02
      YTITLE=YTITLE +XY*H07T24+ANG*H02
      CALL NUMBER(XTITLE,YTITLE,5,*H07,P10,ANGLE,-1)
   16 RETURN
      END
      SUBROUTINE READIN (X,Y,YFAC,XFAC,X0,XF,INDC,KK,LN)
C
C     SUBROUTINE TO READ SOLUTION TABULATION FROM FILE
C
      REAL KF, L, N
      COMMON IDUMMY(1000), BETA, H0, ZETA,AX0,AB0,GL,L,N,R0,H,KF,
     1DT,DT5,G,AK,HOURS,F(3,5),H1H,QIN0,IFL1,IPLTS,XT
      DIMENSION Y(5), YFAC(5)
      READ (9)  X, Y
      IF (X.GE.1.E+75) KK = 2
      INDC = 0
      IF (KK - 1) 10, 10, 50
10    IF (X0 - X - DT5) 20, 50, 50
20    IF (X - XF - DT5) 30, 25, 25
25    KK = 2
      GO TO 50
30    INDC = 1
      X = XFAC*(X - X0)
      Y(LN) = YFAC(LN)*Y(LN)
50    RETURN
      END
      SUBROUTINE GRPHC(ALABL1,ALABL2)
C
C     SUBROUTINE GRPHC WRITES PLOTTER TAPE FOR GRAPHICAL
C     OUTPUT OF SOLUTION
C
      COMMON IDUMMY(1000),RDUMMY(12),DT5,SDUMMY(20),IFL1,IPLTS,XT
      DIMENSION YLABLL(3)
      DIMENSION ALEGN(3,6), ALAB1(4),ALABL2(4)
      DIMENSION SYM(3), Y(5), YFAC(5)
      DATA XLABL/ 9HTIME--HRS/,YLABLR/10HFLOW--KCFS/
      DATA YLABLL/10HHEIGHTS, V,10HELOCITIES-,8H-FT, FPS/
      DATA ALEGN/10HFLOW (KCFS,10H)          ,3H   ,10HINLET VELO,10HCITY
     1 (FT/S,3HEC),10HBAY TIDE (,10HFT)       ,3H   ,10HINFLOW    ,10H
     2          ,3H   ,10HOCEAN TIDE,10H (FT)     ,3H   ,10HLEGEND    ,10H
     3          ,3H   /
      IPLTS = IPLTS + 1
      DT5 = DT5/3600.
C  READ CARD TYPE A6 CONTAINING
C    X0 (F8.5)- STARTING TIME OF PLOT
C    XF (F8.5)- ENDING TIME OF PLOT
C SCALX (F8.5)- TIME-AXIS SCALE IN HOURS PER INCH
C   YL0 (6.3)- MINIMUM VALUE OF TIDAL HEIGHTS IN FEET OR VELOCITIES
C            IN FEET PER SECOND
C    YL (F6.3) - OVERALL HEIGHT OF PLOT IN INCHES
C    YLSCAL (F6.3)- SCALE OF TIDAL HEIGHTS IN FEET PER INCH OR
C                 VELOCITIES IN FEET PER SECOND
C    YR0 (F6.3)- MINIMUM VALUE OF FLOWS IN THOUSAND CUBIC
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C              FEET PER SECOND
C     YRSCAL (F6.3) - SCALE OF FLOW IN THOUSAND CUBIC FEET PER SECOND
C     SCALE (F6.3) - SCALE FACTOR FOR TOTAL PLOT SIZE
      READ ( 5,2001) X0,XF,SCALX,YL0,YL,YLSCAL,YR0,
     1YRSCAL, SCALE
      CALL FACTOR(SCALE)
      CALL PLOT(0.,0.,-3)
C
C     PLOT LEGEND
C
      DO 20 LN = 1, 3
      INDX = 0
      YP = 0.8 + 0.2*LN
      CALL PLOT (0.,YP+0.06,3)
      DO 15 I = 1, 9
      XP = 0.1*I
      LINE = 4 - LN
15    CALL PLOTLN(XP, YP+0.06, LINE, INDX)
      SYM(1) = ALEGN(1,LN)
      SYM(2) = ALEGN(2,LN)
      SYM(3)= ALEGN(3,LN)
      CALL SYMBOL(1.1,YP,0.14,SYM,0.,23)
20    CONTINUE
C
C     PRINT, 'IST 20'
C
      WRITE (IFL1,1002)
      DO 30 LN = 4, 5
      INDX = 0
      YP = 0.8 + 0.2*LN
      CALL PLOT (0.,YP+0.06,3)
      DO 25 I = 1, 9
      XP = 0.1*I
25    CALL PLOTLN(XP,YP+0.06,4,INDX)
      SYM(1) = ALEGN(1,LN)
      SYM(2) = ALEGN(2,LN)
      SYM(3)= ALEGN(3,LN)
   30 CALL SYMBOL(1.1,YP,0.14,SYM,0.,23)
C
C     PRINT, 'ST 30'
C
      WRITE (IFL1,1003)
      CALL SYMBOL (0.6,2.1,0.21,ALEGN(1,6),0.,6)
      CALL SYMBOL (3.5,1.75,0.21,ALABL1,0.,32)
      YMID = 3.0 + 0.5*YL
      TOP = 3. + YL
      XL = (XF - X0)/SCALX
      CALL SYMBOL(4.25,1.25,0.21,ALABL2,0.,32)
C
C     PRINT, 'PLOT X AXIS'
C
      WRITE (IFL1,1004)
      XTIC = 1./SCALX
      XL13 = -XTIC*FLOAT(IFIX(XF - X0))
33    CALL AXIS13 (0.,3.0,XLABL,-9,0.14,XL13,-1,0,X0,
     11.0,XTIC,1.0)
C
C     PRINT, 'PLOT RIGHT AXIS'
C
      WRITE (IFL1,1005)
      DYR = -0.5*YR0
```

```
      YRTIC = DYR/YRSCAL
      CALL AXIS13(XL,3.0,YLABLR,-10,0.14,YL,-1,1,YR0,
     1DYR, YRTIC,1,0)
      CALL PLOT (XL,TOP,3)
      CALL PLOT (0.,TOP,2)
C
C     PRINT, 'PLOT LEFT AXIS'
C
      WRITE (IFL1,1006)
      DYL = -0.5*YL0
      YLTIC = DYL/YLSCAL
      CALL AXIS13 (0.,3.0,YLABLL,28,0.14,YL,-1,1,YL0,
     1DYL, YLTIC, 1, 0)
      CALL PLOT (0.,3.0,3)
      CALL PLOT (XL,3.0,2)
      CALL PLOT (XL,YMID,3)
      CALL PLOT (0.,YMID,-2)
C
C     PRINT, 'BORDER COMPLETE'
C
      CALL PLOT(-.22,0.,-3)
      WRITE (IFL1,1007)
      YFAC(1) = 1./YLSCAL
      YFAC(2) = 0.001/YRSCAL
      YFAC(3) = YFAC(1)
      YFAC(4) = YFAC(1)
      YFAC(5) = YFAC(2)
      INF = 0
      XFAC = 1./SCALX
C
C     PLOT OCEAN TIDE AND INFLOW
C
      DO 50 I = 1, 2
C
C     PRINT, 'DO 50 I =', I
C
      WRITE (IFL1,1009) I
      CALL PLOT (0.,0.,3)
      KK = 1
      REWIND 9
      INDX = 0
35    CALL READIN(X,Y,YFAC,XFAC,X0,XF,INDC,KK,I)
      GO TO (40,45), KK
40    IF (INDC) 35, 35, 41
41    CALL PLOTLN(X,Y(I),4,INDX)
      IF (Y(2)) 42, 35, 42
42    INF = 1
      GO TO 35
45    IF (INF) 60, 60, 50
50    CONTINUE
C
C     PLOT BAY RESPONSE, VELOCITY, FLOW
C
60    DO 80 I = 1, 3
C
C     PRINT, 'DO 80 I =', I
C
      WRITE (IFL1,1010) I
      CALL PLOT (0., 0., 3)
      KK = 1
      REWIND 9
```

```
      INDX = 0
65    CALL READIN (X,Y,YFAC,XFAC,X0,XF,INDC,KK,I+2)
      GO TO (70, 80), KK
70    IF (INDC) 65, 65, 72
72    CALL PLOTLN(X,Y(I+2),I,INDX)
      GO TO 65
80    CONTINUE
C
C     PRINT, 'ST 80'
C
      WRITE (IFL1,1008)
      XT = XL+4.
      CALL PLOT(XT,0.,-3)
      RETURN
C
1001  FORMAT (6A6)
1002  FORMAT (6H1ST 20)
1003  FORMAT (6H ST 30)
1004  FORMAT (12H PLOT X AXIS)
1005  FORMAT (16H PLOT RIGHT AXIS)
1006  FORMAT (15H PLOT LEFT AXIS)
1007  FORMAT (16H BORDER COMPLETE)
1008  FORMAT (6H ST 80)
1009  FORMAT (10H DO 50 I =, I2)
1010  FORMAT (10H DO 80 I =, I2)
2001  FORMAT (3F8.5, 6F6.3)
      END
  EOR
  EOR
  EOI
```

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

Huval, Carl John

Comparison of numerical and physical hydraulic models, Masonboro Inlet, North Carolina; Appendix 4: Simplified numerical (lumped parameter) simulation / by C. J. Huval and G. L. Wintergerst. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : Available from National Technical Information Service, 1977.

115 p. : ill. ; 27 cm. (GITI report - U. S. Army. Corps of Engineers ; 6, Appendix 4)

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

1. Hydraulic models. 2. Lumped parameter approach. 3. Masonboro Inlet, N. C. 4. Mathematical models. 5. Numerical simulation. 6. Tidal inlets. I. Wintergerst, G. L., joint author. II. United States. Coastal Engineering Research Center. III. United States. Waterways Experiment Station, Vicksburg, Miss. IV. Series: United States. Army. Corps of Engineers. GITI report ; 6, Appendix 4.

GB454.T5.U5 no.6 Appendix 4