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A Spatially Integrated Numerical Model of Inlet Hydraulics

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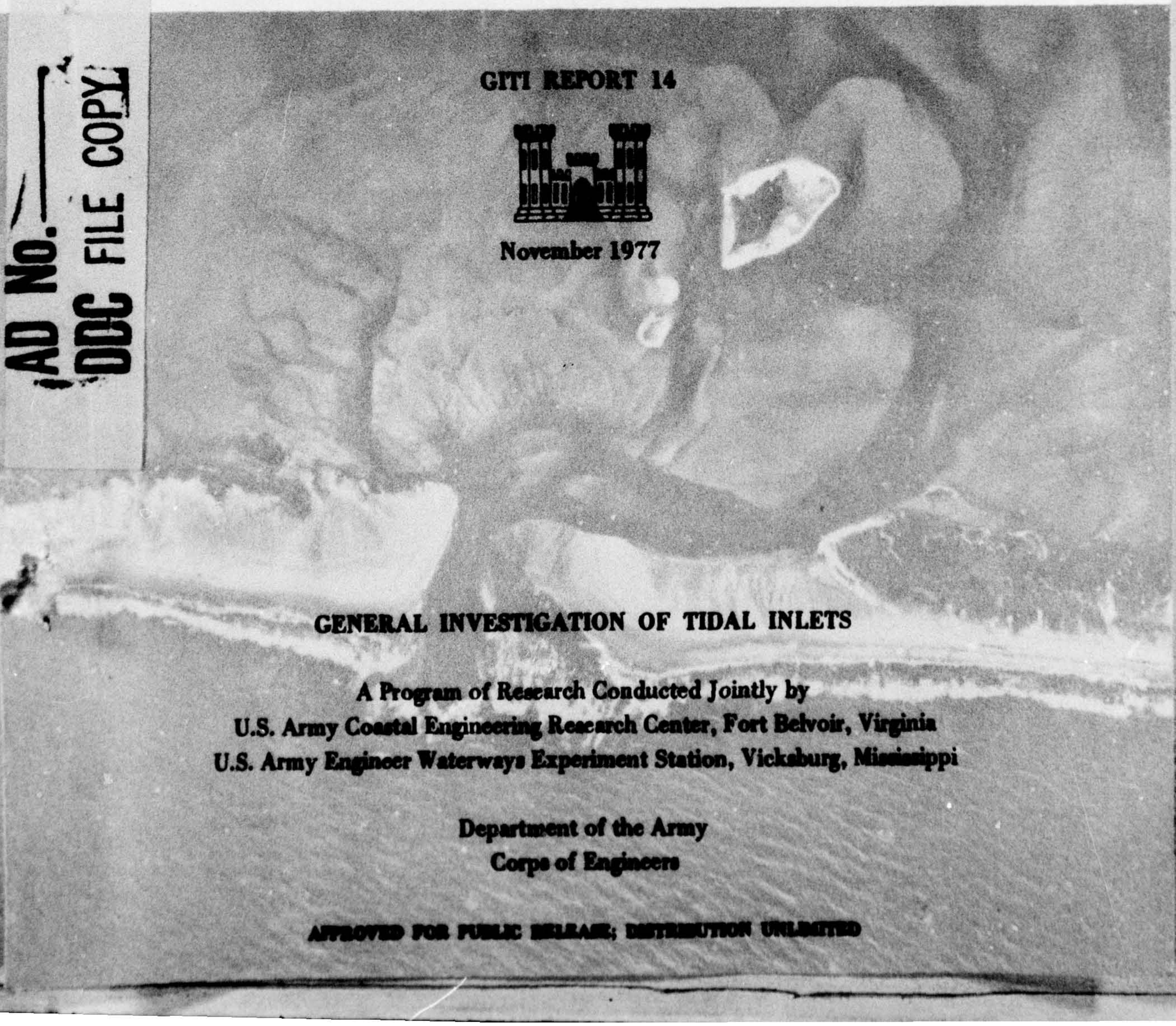
by

William N. Seelig, D. Lee Harris, and Barry E. Herchenroder



GITI REPORT 14

November 1977

GENERAL INVESTIGATION OF TIDAL INLETS

A Program of Research Conducted Jointly by
U.S. Army Coastal Engineering Research Center, Fort Belvoir, Virginia
U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

Department of the Army
Corps of Engineers

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This report discusses the development of a simple numerical model for the prediction of coastal inlet velocities, discharge, and resulting bay level fluctuations. The model is a time-marching model that simultaneously solves the area-averaged momentum equation for the inlet and the continuity equation for the bay. It is assumed that the bay surface elevation remains horizontal as it rises and falls. At each time step the geometric and hydraulic factors describing the inlet-bay system are calculated by evaluating flow conditions → over

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throughout the inlet and by spatially integrating this information to determine coefficients of the first-order differential equations.

This model, which includes the important terms in the equation of motion, is flexible, easy and inexpensive to use, and gives a good estimate of the inlet-bay system hydraulics for various conditions. The model can be used for single or multiple inlets, bays, and seas.

This report includes the model theory and derivation, a FORTRAN computer program for solving the model equations, and instructions for use of the program. Examples are given to illustrate how the model may be used to predict coastal inlet response to astronomical tides, seiching, tsunamis, and storm surges.

FOREWORD

This report was prepared as one of a series of reports from the Corps of Engineers' General Investigation of Tidal Inlets (GITI). The GITI research program is under the technical surveillance of the Coastal Engineering Research Center (CERC), and is conducted by CERC, the U.S. Army Engineer Waterways Experiment Station (WES), other Government agencies, and private organizations. The model described in this report is the latest in a series of developments of numerical inlet hydraulic models beginning with Keulegan in 1967 and continuing with recent work at WES by Huval and others.

The report was prepared by William N. Seelig, Coastal Structures Branch, D. Lee Harris, Chief, Coastal Oceanography Branch, and Barry E. Herchenroder, Coastal Oceanography Branch, CERC. Development of this numerical model and report preparation were supervised by R.M. Sorensen, Chief, Coastal Structures Branch. Technical assistance was provided by C. Mason. Civilian members of the Coastal Engineering Research Board, Dean M.P. O'Brien, Prof. R.G. Dean, and Prof. R.L. Wiegel, reviewed this report.

Technical Directors of CERC and WES were T. Saville, Jr., and F.R. Brown, respectively.

Comments on this publication are invited.

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

JOHN L. CANNON	JOHN H. COUSINS
Colonel, Corps of Engineers	Colonel, Corps of Engineers
Commander and Director	Commander and Director
Waterways Experiment Station	Coastal Engineering Research Center

PREFACE

1. The Corps of Engineers, through its Civil Works program, has sponsored, over the past 23 years, research into the behavior and characteristics of tidal inlets. The Corps' interest in tidal inlet research stems from its responsibilities for navigation, beach erosion prevention and control, and flood control. Tasked with the creation and maintenance of navigable U.S. waterways, the Corps 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, the 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 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, North Carolina, was selected as the prototype inlet which would be used along with hydraulic and numerical models in the evaluation of existing techniques. In September 1969 a complete set of hydraulic and bathymetric data was collected at Masonboro Inlet. Construction of the fixed-bed physical model was initiated in 1969, and extensive tests have been performed since then. In addition, three existing numerical models were applied to predict the inlet's hydraulics. Extensive field data were collected at Masonboro Inlet in August 1974 for use in evaluating the capabilities of the physical and numerical models.

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

c. *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.

4. This report describes a numerical model that can be used to predict inlet channel velocities and discharge as well as the resulting bay surface level oscillations for inlets responding to the tide and other long wave excitation. It has been developed as an easy to use, inexpensive method for a good "first look" analysis of inlet hydraulics. The need for this model arose during preliminary attempts to apply an earlier model developed under the GITI numerical model evaluation (see 3,b,(2) above), and described in Appendix 4 to GITI Report 6, "A Simplified (Lumped Parameter) Numerical Simulation" (Huval and Wintergerst, 1977). Although both models expand upon the Keulegan (1967) concept of a simple one-dimensional analysis, this model supersedes that of Appendix 4 since it provides more accurate results and is applicable to a wider variety of situations and conditions.

5. Included in this report are a derivation of the numerical model, documentation of the FORTRAN computer program used to apply the model, and example applications of the model to evaluate the hydraulic conditions at selected tidal and nontidal inlets.

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TABLE

FIGURES

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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
knots	1.8532	kilometers per hour
acres	0.4047	hectares
foot-pounds	1.3558	newton meters
millibars	1.0197×10^{-3}	kilograms per square centimeter
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]

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[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

Symbol in the report	Symbol in the computer program INLET	Definition
A_c	A(I,J)	cross-sectional area (square feet)
A_b	AB	cross-sectional area at the bay end of the inlet (square feet)
A_s	AS	cross-sectional area at the sea end of the inlet (square feet)
A_{bay}	ABAY	bay surface area (square feet)
A_o	ABY	bay surface area at datum (square feet)
—	AO	ocean forcing amplitude (feet)
B	B(I,J)	width (feet)
C_i	C(I)	flow resistance parameter
C_1,C_2	C1,C2	coefficients to evaluate Manning's bottom-friction factor, n, where $n = C_1 - C_2 * D$
D	D(I,J)	total water depth (feet)
d_{bay}	—	depth of the bay (feet)
d_{max}	—	maximum water depth in the inlet (feet)
F	F	total inlet friction
F_N	—	minimum friction function
F_x	—	friction in the grid cells of a cross section
g	G	acceleration of gravity (feet per second squared)
h	H(I,J)	water level above datum (feet)
h_B	HB	water level at the bay end (feet)
h_s	HS	water level at the sea end (feet)
—	HOURS	model time (hours)

SYMBOLS AND DEFINITIONS--Continued

IC	IC	number of channels in a grid
I_g	—	geometry integral (see text)
IS	IS	number of sections in a grid
i,j	I,J	subscripts indicating grid location
k	—	a constant in Manning's equation to maintain consistent units
L_{bay}	—	length of a bay (feet)
L_{ij}	L(I,J)	length of a grid (feet)
L_{in}	LENGTH	inlet length (feet)
M	NINLETS	number of inlets connecting the bay to the sea
m	NI	subscript identifying the inlet number
n	N(I,J)	Manning's bottom friction coefficient
—	NCYCLES	number of forcing water level cycles used in computation
—	NT	number of time steps used in computations
Q	Y(NI)	discharge of an inlet (cubic feet per second)
Q_{ij}	Q(I,J)	discharge of a grid (cubic feet per second)
Q_{inflow}	QINFLO	net discharge of water into the bay from sources other than the inlet (cubic feet per second)
Q_T	QT	total discharge of all inlets connecting a sea to a bay (cubic feet per second)
—	QINT(NI)	estimated inlet discharge at time the model starts (cubic feet per second)
R	—	remainder terms (neglected)
T_F	T	forcing wave period in the sea (hours or seconds)

SYMBOLS AND DEFINITIONS--Continued

T_H	—	inlet-bay Helmholtz period (hours or seconds)
T_H'	THELM	inlet-bay Helmholtz period estimated by neglecting inlet friction (hours or seconds)
t	X	time of model operation (seconds)
—	THTF	ratio of the Helmholtz to forcing wave period
—	TIME	time (seconds)
u	V(I,J)	water velocity (feet per second)
$\bar{u}$	—	cross-sectional mean water velocity (feet per second)
—	VBAR	mean water velocity across the minimum area section (feet per second)
W_{ij}	W(IJ,)	grid weighting function for distributing flow throughout an inlet grid flow net
x	—	distance along a channel (feet)
x_b	—	bay limit
x_s	—	sea limit
y,y_1,y_2	—	distances perpendicular to the main axis of the inlet channel (feet)
Δt	DELT	variable finite-difference time step (seconds)
β	BETA	bay surface area variation parameter relating bay area to bay water level where: ABAY = ABY (1. + BETA * HB)
—	ZETA	inlet side slope, dZ/dy, where Z is elevation
λ	—	Lagrangian multiplier
$\partial Q/\partial t$	DERBY	derivative of inlet discharge with respect to time (cubic feet per second squared)
$(\tau_{zx})_Z$	—	component of the stress tensor representing the bottom stress

A SPATIALLY INTEGRATED NUMERICAL MODEL OF INLET HYDRAULICS

by
William N. Seelig, D. Lee Harris,
and *Barry E. Herchenroder*

I. INTRODUCTION

Quick, inexpensive estimates of inlet velocities and bay water surface levels for tidal or nontidal sea level fluctuations are needed in planning the design, construction, and maintenance of coastal inlets. Field data are often unavailable, and available data are often incomplete. In addition, hydraulic characteristics for proposed inlets are unavailable and must be predicted.

This study discusses these needs by developing a numerical model that can be used to estimate inlet velocities, discharge, and bay water levels as functions of time for a given time-dependent sea level fluctuation. The objective of this research was to develop a model that could be used to quantitatively predict hydraulics for as wide a range of conditions as possible, while being easy and inexpensive to use. Inlet hydraulics are predicted in this model by marching through time, simultaneously solving the momentum equation for flow in the inlet and the continuity equation relating the bay level to inlet discharge. The momentum equation is evaluated at each time step by integrating two-dimensional information into coefficients of the equation, using a weighting function (see App. A) and a flow net (see App. B) which systematically distribute flow throughout the inlet.

The advantages of this model are that it requires a minimum amount of input data, and it is easy and inexpensive to use as compared to a full two-dimensional model. Other features of the model are that it includes all potentially important terms developed from the three-dimensional momentum equations, and it allows for special situations. For example, water level fluctuations in the sea can be any function of time, the area of the bay can be a function of water level, and inflow into the bay from sources other than the inlet can be a function of time or water level of the bay. Also, the cross-sectional area of the inlet can be taken as a function of the local water depth. This model can be used to predict hydraulics for tidal or nontidal, single and multiple inlet systems. It assumes that the bay level "pumps" (i.e., rises and falls) at the same rate and phase throughout the bay.

II. INLET HYDRAULICS

An inlet-bay system typically consists of a "sea" (e.g., ocean or lake) connected to a "bay" by one or more inlets (Fig. 1). Long waves in the sea (i.e., astronomical tides, seiches, storm surges, tsunamis, or other water level fluctuations) generate the primary hydraulic response in the inlet-bay system. The difference in water level between the bay and sea, caused by the sea forcing fluctuations, results in reversing

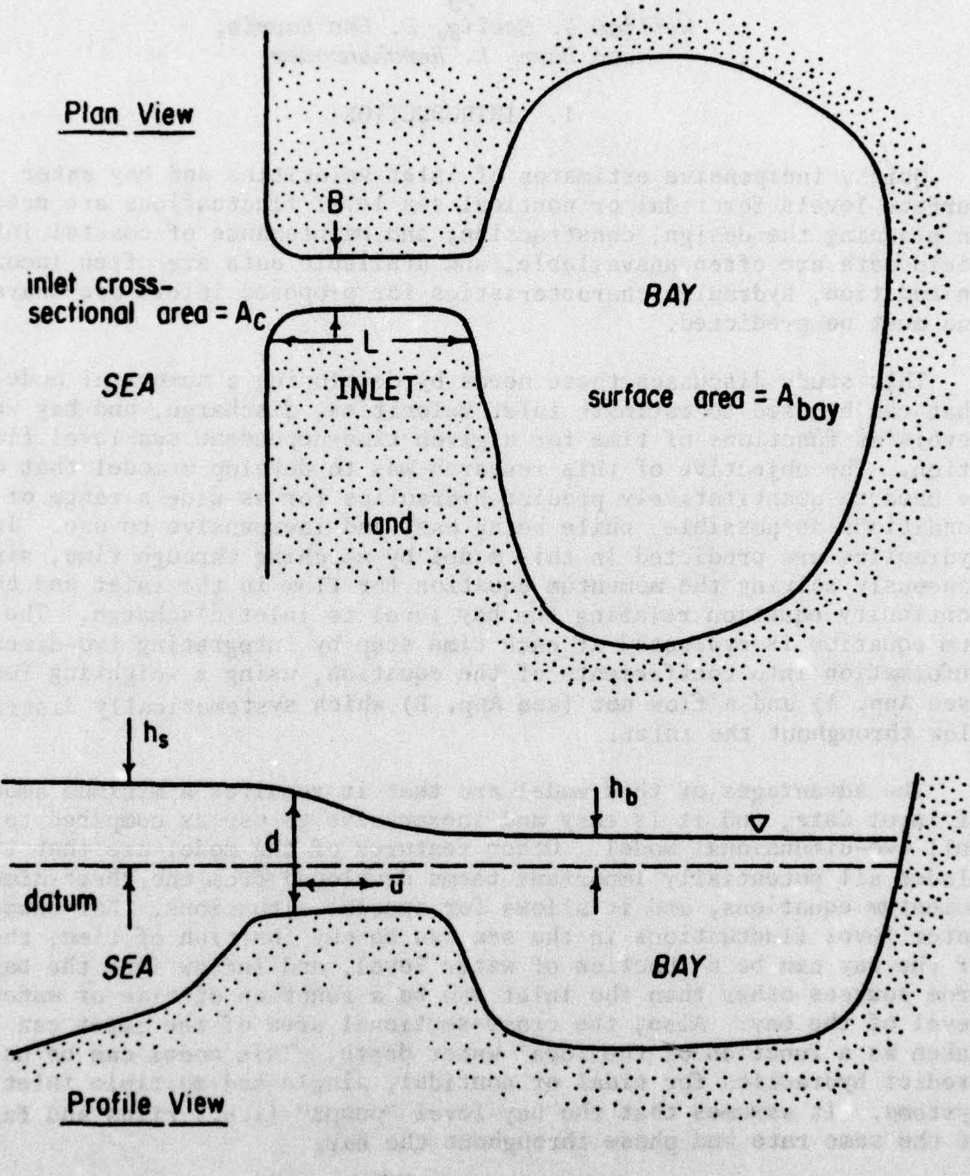


Figure 1. Inlet-bay system.

currents in the inlet which in turn cause the bay level to change. The bay level may also be influenced by inflow from and outflow to other sources (i.e., river discharge or evaporation) which may be a function of time or of the bay level. Additional factors such as wind stress, water density variations, and the earth's rotation may also affect the system.

The prediction of reversing currents in the inlet and bay level fluctuations requires a knowledge of the geometries of the inlets and bay, the water level fluctuations in the sea which force the inlet-bay system, and a model (analytical, numerical, or physical) to predict the system response. For most inlets and bays, the geometries can be measured in the field, obtained from dredging records, or evaluated from hydrographic charts. Water level fluctuations in the sea must be measured in the field, predicted from tide tables or physical or numerical hydrodynamic models.

The complete three-dimensional equations of motion that describe the hydrodynamics of the inlet-bay system (Fig. 1) are complicated. Rather than try to solve the complete equations, various investigators have simplified them and attempted to model only the factors that the investigators considered important in inlet hydraulics. Some models, such as physical distorted scale models and some two-dimensional vertically integrated numerical models, have been used to adequately predict inlet hydraulics for most engineering purposes (Harris and Bodine, 1977). However, operation of these models is relatively expensive, requires expert operators, and usually takes several months of effort to obtain the required results.

Simple analytical models such as those of Brown (1928) and Keulegan (1967), which lump important parameters into a single quantity, require a number of restrictive assumptions. O'Brien and Clark (1974) concluded: "The Keulegan approach and similar analyses of inlet hydraulics provide a useful qualitative framework for ordering data but they apply quantitatively only to small inlets and lagoons with simple inlet channel geometry."

More advanced lumped parameter models, such as those of King (1974) and Huval and Wintergerst (1977), have included additional terms in the equation of motion and have considered other effects to generalize the models. However, many of these more advanced lumped parameter models were based on earlier models and in the processes of expansion some generality was lost. Huval and Wintergerst (1977) and Harris and Bodine (1977) discuss previous models.

III. THE NUMERICAL MODEL

1. Assumptions.

This spatially integrated numerical model is based on the equations derived from the complete equations of motion by Harris and Bodine (1977). Assumptions made in the process of model derivation were:

(a) Sea level is a specified function of time.

(b) The bay water level remains horizontal. This means that the bay water level rises and falls at the same rate throughout the entire bay at each point in time. This occurs when the length of the long wave forcing the system is much longer in the bay than the longest axis of the bay.

(c) The bay is connected to the sea by one or more inlets.

(d) At least one inlet must continuously connect the bay to the sea. Some areas of inlets may go dry during the water level cycle, and one or more inlets may go dry as long as one inlet contains water.

(e) Bay water surface area is a function of bay water level (or a function of time).

(f) Inlet cross-sectional area is a function of local depth (or a function of time).

(g) The local water level slope in the inlet is assumed to be linearly related to the local friction loss along the inlet between the sea and bay levels.

(h) There is a water level drop along the inlet that is proportional to the unrecovered velocity head lost through turbulent eddy diffusion in the bay (floodflow) or sea (ebb flow). (Alternate schemes could be used.)

(i) Storage of water in the inlet is negligible. This means that the flow into the inlet is equal to the flow exiting the inlet at any time. In addition, the volume of water stored in the inlet between high and low water should be small compared to the tidal prism. This is generally the case if the surface area of the bay is much larger than the surface area of the inlet.

(j) Wind stress on the inlet and bay surfaces is negligible. This means that the model is most useful for cases when the wind is light, has a short duration, or has a short fetch over the bay.

(k) Water has constant properties throughout the inlet and bay. No attempt has been made to model saltwater intrusion or other density gradient effects.

(l) Radiation stress (the interaction with wind waves) is neglected.

(m) Coriolis effects are neglected.

If the characteristics of the inlet-bay systems modeled are not consistent with these assumptions, model results may be in error.

2. Derivation.

The derivation of this model begins with the one-dimensional equation of motion as derived by Harris and Bodine (1977):

$$\frac{\partial \bar{u}}{\partial t} + \frac{1}{2}\frac{\partial}{\partial x}\bar{u}^2 + g\frac{\partial h}{\partial x} + \frac{1}{A_c}\int_{y_1}^{y_2} (\tau_{zx})_Z \, dy = R \qquad (1)$$

where

$\bar{u}$ = cross-sectional mean water velocity in the inlet (positive on floodflow)

t = time

x = distance along the main axis of the inlet

h = water level above some datum

g = acceleration due to gravity

A_c = inlet cross-sectional flow area at x

$(\tau_{zx})_Z$ = component of the stress tensor at the bottom of the inlet in the direction of the main axis of the inlet

R = remainder terms, which are neglected in this model (R=0). This means that the water level is taken as constant at each inlet cross section. See Harris and Bodine (1977) for a discussion of these neglected terms.

The first term on the left of equation (1) is the temporal acceleration, the second term is the convective or advective acceleration, the third term is the slope of water surface along the inlet, and the fourth term is the bottom stress.

To obtain a simplified equation, the expressions in equation (1) are integrated over the length of the inlet between the sea and the bay, where x_s and x_b are the respective limits:

$$\int_{x_s}^{x_b} \frac{\partial \bar{u}}{\partial t}\, dx + \int_{x_s}^{x_b} \frac{1}{2}\frac{\partial \bar{u}^2}{\partial x}\, dx + \int_{x_s}^{x_b} g\,\frac{\partial h}{\partial x}\, dx$$

$$+ \int_{x_s}^{x_b} \frac{1}{A_c} \int_{y_1}^{y_2} (\tau_{zx})_Z \; dydx = 0 \;. \qquad (2)$$

Carrying out some of the integrations and rearranging, equation (2) becomes

$$\frac{\partial}{\partial t} \int_{x_s}^{x_b} \bar{u}dx + \frac{1}{2}\left[(\bar{u}_b)^2 - (\bar{u}_s)^2\right]$$

$$+ \; g\left[h_b - h_s\right] + \int_{x_s}^{x_b} \frac{1}{A_c} \int_{y_1}^{y_2} (\tau_{zx})_Z \; dydx = 0 \;. \qquad (3)$$

In equation (3), terms involving $\partial x_b/\partial t$ and $\partial x_s/\partial t$ have been set to zero since x_b and x_s are taken to be independent of time.

From continuity the cross-sectional mean inlet water velocity is equal to the inlet discharge, Q, divided by the inlet cross-sectional area, A_c:

$$\bar{u} = Q/A_c \;. \qquad (4)$$

Substituting equation (4) and using the product rule for integration, the first term on the left of equation (3) can be integrated to yield:

$$\int_{x_s}^{x_b} \frac{\partial\left(\frac{Q}{A_c}\right)}{\partial t}\, dx = \frac{\partial Q}{\partial t} \int_{x_s}^{x_b} \frac{dx}{A_c} + Q\,\frac{\partial}{\partial t}\left(\int_{x_s}^{x_b} \frac{dx}{A_c}\right), \qquad (5)$$

where the second part of the equation,

$$\frac{\partial}{\partial t}\left(\int_{x_s}^{x_b} \frac{dx}{A_c}\right),$$

is taken as zero because channel storage terms are neglected.

After substitution of equation (4), the second and third terms on the left of equation (3) are

$$\frac{1}{2}\left(\frac{1}{A_b^2} - \frac{1}{A_s^2}\right)Q^2 + g(h_b - h_s) \qquad (6)$$

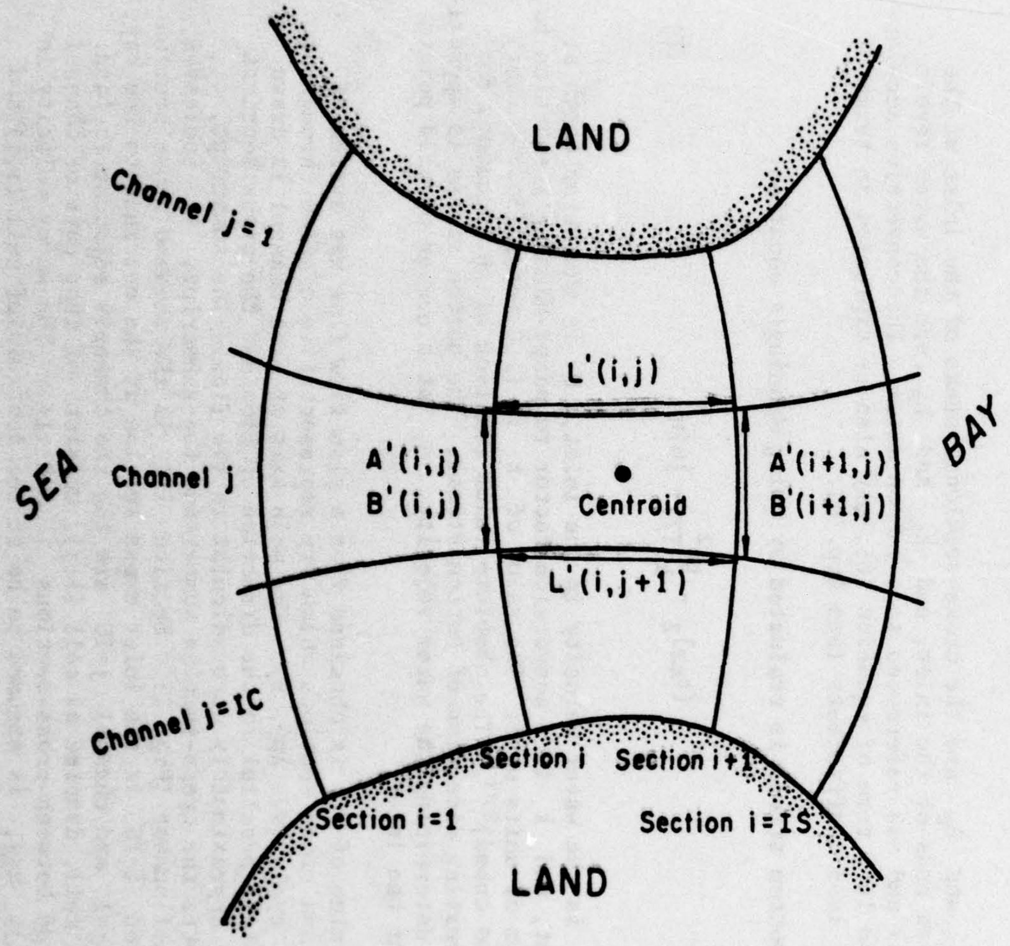
where A_b and A_s are the cross-sectional areas of the inlet at the bay and sea ends of the inlet, and h_b and h_s are the water levels in the bay and sea referenced to a common datum. The convective acceleration, the left term of equation (6), may also be expressed in terms of empirical loss coefficients (see App. C).

The bottom stress is evaluated by using Manning's equation:

$$(\tau_{zx})_Z = \frac{gn^2}{kD^{1/3}} |u|u \qquad (7)$$

where u is the water velocity in the inlet, D is the water depth at that point, and k is a conversion factor to adapt Manning's equation to the system of units used. The value of k is [1.0 meter (3.2808 feet) per second cubed]$^{2/3}$. The absolute value function of u accounts for the alternating direction of bottom stress. The bottom stress is approximated by determining the water velocity, u, at a number of grid points throughout the inlet.

The value of u is obtained from a plan view flow net system of channels and cross sections which are representative of flow throughout the tidal cycle (see App. B). The main axis of each channel is drawn approximately parallel to the direction of flow and the cross sections are drawn approximately perpendicular to the flow. The subscript, i, then denotes the cross-section number and the subscript, j, indicates the channel number (Fig. 2). Section $i=1$ is the seaward cross section and section $i=IS$ is the inlet cross section at the entrance to the bay. Channel $j=1$ and channel $j=IC$ are the two channels adjacent to land. A typical cell, denoted as cell (i,j), consists of that part of channel j situated between cross-sections i and $i+1$. The water velocity in cell (i,j), u_{ij}, is assumed to be at the centroid of cell (i,j) and to act parallel to the axis of channel j (Fig. 2).



Cell characteristics

$$A(i,j) = \frac{A'(i,j) + A'(i+1,j)}{2}$$

$$B(i,j) = \frac{B'(i,j) + B'(i+1,j)}{2}$$

$$D(i,j) = A(i,j) / B(i,j)$$

$$L(i,j) = \frac{L'(i,j) + L'(i,j+1)}{2}$$

are applied at the cell centroid

Figure 2. Inlet grid system.

A weighting function, W_{ij}, is then used to determine what fraction of the total inlet flow, Q, passes through a grid cell (i,j) at an instant in time:

$$Q_{ij} = W_{ij}\, Q \tag{8}$$

where Q_{ij} is the discharge in cell (i,j). Various weighting functions are discussed later in this section.

The mean water velocity in cell (i,j), u_{ij}, is taken equal to the discharge in the cell divided by the mean cross-sectional area of the cell perpendicular to flow, A_{ij}; i.e.,

$$u_{ij} = W_{ij}\, Q/A_{ij} \ . \tag{9}$$

Substituting equations (7) and (9) into the fourth term of equation (3) and integrating over x and y give the total bottom friction, F:

$$F = \sum_{i=1}^{IS-1} \frac{1}{\sum\limits_{j=1}^{IC} (A_{ij})} \sum_{j=1}^{IC} \frac{g(n_{ij})^2 \,|\, W_{ij}\, Q| W_{ij}\, Q\, B_{ij}\, L_{ij}}{k\ (D_{ij})^{1/3}\ A_{ij}{}^2} \tag{10}$$

where n_{ij} is the Manning's coefficient of friction for each grid cell, D_{ij} is the mean instantaneous water depth in a cell, and B_{ij} and L_{ij} are the mean cell width and length, respectively. All of the cell parameters are taken to apply to the centroid of the cell (Fig. 2).

Let I_g be a geometry integral defined for convenience as

$$I_g = \frac{1}{\int_{x_s}^{x_b} \frac{dx}{A_c}} = \frac{1}{\sum\limits_{i=1}^{IS-1} \left(\frac{\sum\limits_{j=1}^{IC} L_{ij}/IC}{\sum\limits_{j=1}^{IC} A_{ij}} \right)} \tag{11}$$

which has units of length.

Substituting equations (5), (6), and (10) into equation (3), multiplying by I_g, and setting dQ/dt equal to the other terms will obtain:

$$\frac{dQ}{dt} = \frac{-I_g}{2}\left(\frac{1}{A_b^2} - \frac{1}{A_g^2}\right) Q^2 - g \quad I_g(h_b - h_g) - I_g F \qquad (12)$$

where F is defined by equation (10).

If M inlets connect the bay to the sea, there will be one equation (eq. 12) for each inlet. Let Q_m be the discharge of the mth inlet, then the total discharge for all inlets, Q_T, is the sum of inlet discharges:

$$Q_T = \sum_{m=1}^{M} Q_m \ . \qquad (13)$$

The rate of change of water level in the bay, dh_b/dt, is related to inlet discharge, Q_T, plus discharge into the bay from other sources, Q_{inflow}, by the continuity equation:

$$\frac{dh_b}{dt} = \frac{Q_T}{A_{bay}} + \frac{Q_{inflow}}{A_{bay}} \qquad (14)$$

where A_{bay} is the instantaneous surface area of the bay.

There are several methods available for solving the simultaneous differential equations (eq. 12 for M inlets, and eq. 14 for a total of M+1 equations). The method selected for this model is a fourth-order Runge-Kutta-Gill technique. Advantages of this method are that it is self-starting, extremely stable, may use a longtime step, has wide application, and converges quickly. The main disadvantage of this technique is that it may cost approximately twice as much as some methods because the Runge-Kutta-Gill technique uses two calculations for each time step to check error bounds and establish the time step (International Business Machine, 1970). On a CDC 6600 computer the total computer cost for computations per inlet for a tidal cycle using the Runge-Kutta-Gill method has been, at most, several dollars (less than $2 per tide cycle) for most test inlets. However, the ease in use of this method justifies its cost.

The computer program based on this model (INLET) is presented in Appendix D.

3. Weighting Functions.

The weighting function, W_{ij} (the fraction of the total flow that passes through a grid cell at a time step), provides a systematic method of distributing flow throughout an inlet for use in evaluating the bottom stress (see App. A). There are three weighting functions developed in this report.

First, a weighting function to distribute flow between channels at each cross section so that total friction in the section is minimized (option IWT=1 in the computer program INLET). This function may allow some water to move perpendicular to the main axis of the flow net at each cross section, but the flow should be small for a well-drawn net.

Second, a weighting function is developed by assuming that all flow is parallel to the streamlines of the flow net and distributes the discharge in each channel of the inlet to minimize overall friction (option IWT=2 in the computer program INLET). This method is consistent with the equations of motion used in the model derivation and assumes that the grid system permits an accurate representation of the inlet streamline patterns.

In practice both of the minimum friction weighting functions (IWT=1 and IWT=2) produce similar results for many inlets. Comparisons with prototype measurements show that either minimum friction weighting function adequately predicts the flow distribution across inlet cross sections tested. For example, at Brown Cedar Cut, Texas, minimum friction weighting predicted the fraction of flow at any point at a cross section to within several percent of the measured total flow (Fig. 3). At times in the tidal cycle, minimum friction weighting slightly over or under predicts flow in parts of the section, but on the average this difference will have little effect on the final result.

Differences between prototype and minimum friction weighting distributions may occur for several reasons. First, Manning's uniform flow friction relation, as used in this model, may not completely describe friction losses for unsteady inlet flow. For example, Manning's equation may overestimate friction when discharge is increasing because turbulence has not developed to the point that would be reached for steady flow of the same discharge. As the magnitude of discharge decreases, the opposite effect occurs. Turbulence is higher than for the same steady-state discharge, so Manning's equation underestimates actual friction. Changes in bed forms throughout the tide cycle may also change frictional resistance.

Jet formation in flow exiting the inlet throat, not accounted for in these weighting functions, may also cause differences between observed and predicted flow patterns. However, an empirical coefficient may be used to account for losses caused by jets (discussed in App. C).

See Appendix B for a detailed discussion of drawing flow nets based on the minimum friction weighting function (IWT=1).

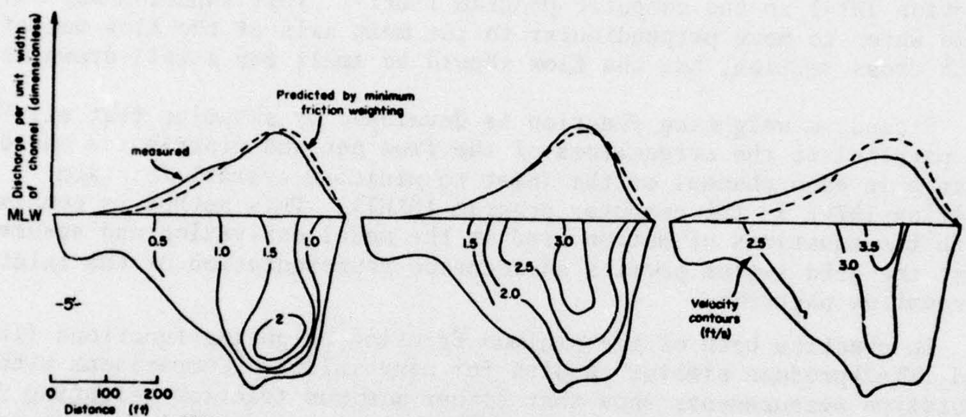


Figure 3. Discharge of Brown Cedar Cut, Texas (after Mason and Sorensen, 1971).

The third weighting function (IWT=3) is the same as that used in lumped parameter models (Huval and Wintergerst, 1977). It assumes that discharge is the same in all grid cells throughout the inlet at any instant in time. This means that the flow in each grid is equal to the total flow for the inlet divided by the number of channels, IC. The weighting function, W_{ij} is evaluated by:

$$W_{ij} = 1.0/IC \tag{15}$$

Generally, this function will not accurately reproduce prototype conditions because it is almost impossible to visually draw the grid that corresponds to this condition. In addition, the function does not consider changes in flow distribution that occur during the tidal cycle. However, this weighting function is useful in obtaining an upper limit for frictional effects because it overemphasizes friction in most cases. By producing high friction the function tends to give a lower limit for bay level fluctuations, mean inlet velocity, and inlet discharge.

Weighting functions are organized as subroutines in the computer program INLET, so that other weighting functions may easily be added to this numerical model as they are developed.

IV. USE OF THE COMPUTER PROGRAM

1. General Conditions for Model Use.

The computer program INLET (App. D) estimates inlet hydraulics by solving equations (12), (13), and (14) with the use of appropriate geometric and hydraulic inputs. This section summarizes the conditions that can be modeled consistent with assumptions discussed in Section III. Details of the application of the computer program are discussed in Appendix D.

The conditions required when using the model are:

(a) The sea is much larger than the inlets and bay.

(b) The bay is much larger than the inlets.

(c) The bay and at least one of the inlets must contain water throughout the water level cycle.

(d) The forcing seawater level fluctuations must be specified as a function of time. Start the model when the sea level is zero.

(e) The inflow or outflow from sources other than the inlet must be a specified function of time, a function of bay water level, or constant (the computer model is programed for a constant inflow).

(f) The bay surface area must be constant, a function of bay water level, or a function of time (the model is now programed for bay area as a linear function of bay level).

(g) The inlet cross-sectional area at a section is a function of local water level or time (the model is programed for linear channel side slopes).

(h) The model assumes that the bay level remains horizontal. This means that the forcing wavelength in the bay should be much longer than the bay:

$$T_F \sqrt{g d_{bay}} >> L_{bay} , \tag{16}$$

where L_{bay} is the length of the longest axis of the bay, d_{bay} is the depth of the bay, and T_F is the forcing wave period.

(i) This model uses a lower limit of the time step, Δt, which is the time required for a shallow-water wave to travel the length of the inlet channel:

$$\Delta t = \frac{L_{in}}{\sqrt{g d_{max}}} \tag{17}$$

where L_{in} is the length of the inlet, and d_{max} is the maximum water depth in the inlet. In practice, a much longer time step may be used in some situations; the Runge-Kutta-Gill technique used in INLET will automatically adjust the time step. A suggested upper limit for the time step input to INLET is one-hundredth of the forcing wave period, T_F.

(j) Recommended techniques for drawing inlet grid flow nets, which are used in the evaluation of bottom friction, are presented in Appendix B.

(k) The weighting function for distributing the flow throughout the inlet must be selected (Sec. II). The minimum friction weighting functions (option IWT=1 or IWT=2) are recommended for most cases.

(l) If the seawater level fluctuation is of constant period and amplitude, generally one to four cycles are required to eliminate transient terms so that an equilibrium response is reached in the inlet and bay. If friction is high, as in many tidal inlets, the first cycle will give a good estimate of water motions and levels. Four cycles are recommended for inlets with high temporal acceleration, such as inlets on the Great Lakes.

(m) The program INLET is designed so that the sea forcing is sinusoidal or is described by water levels sampled at a uniform rate, Q_{inflow} is constant, A_{bay} is a linear function of the bay water level, and the inlet side slope is linearly related to the local water depth. For more general conditions, appropriate programing changes should be made to the computer program. For example, if the surface area of the bay is a nonlinear function of bay water level, the program statement that evaluates bay surface area should be changed to incorporate the given function.

(n) The recommended method of using this model is similar to that for other inlet models. Obtain prototype geometries, sea and bay water levels, and inlet velocities for the system. Using this prototype information, calibrate the model so that the predicted bay levels and inlet velocities accurately reproduce the prototype data. The suggested method of calibration is to vary the Manning's bottom friction factor, n, or ebb and flood entrance and exit-loss coefficients (App. C) until good agreement is obtained between observed and predicted hydraulics. For short records of field data it is recommended that the model first be calibrated so that predicted inlet velocities or discharges reproduce prototype conditions, because velocities are most sensitive to changes in model parameters. Bay levels are a form of integrated inlet discharge, so levels are less sensitive to variation in model parameters. After the model is calibrated for velocities, check bay level predictions.

If additional prototype data are available, the calibrated model should be run with the additional data to verify that the model produces adequate results.

If no prototype data are available for calibration, use values of n and loss coefficients previously calibrated on the model for similar inlets. The examples presented later in this section provide estimates of values that apply to various types of inlets. Specific applications of the model are also presented.

A preliminary estimate of n can be obtained from the linear relation recommended by Masch, Brandes, and Reagan (1977) for grid cells of tidal inlet models. They reported that n is weakly dependent on water depth by the relation:

$$n = C_1 - C_2 D \tag{18}$$

where D is the stillwater depth, because the probability of vegetation decreases with depth. For water depths less than 9.1 meters (30 feet) and greater than 1.2 meters (4 feet) they recommend $C_1 = 0.0377$ and $C_2 = 0.000667$. This condition is assumed if a relation for n is not specified in input data. For depths less than 1.2 meters they recommend $C_1 = 0.055$ and $C_2 = 0.005$.

(o) Note that asymmetry of the inlet and bay geometries throughout the forcing cycle will result in asymmetrical inlet hydraulics. For example, a sinusoidal ocean tide may produce a nonsinusoidal bay tide due to effects such as the change in inlet cross-sectional area with water depth (Keulegan, 1967).

2. Examples.

The model was applied to a variety of tidal and nontidal inlets. Five examples were selected to illustrate the range of conditions that can be modeled: Pentwater Inlet, Michigan, to show the response of a simple geometry, nontidal inlet to forcing at different wave periods due to seiching of Lake Michigan; a hypothetical harbor, which illustrates the application of the model to predict tsunami-induced hydraulics at a harbor; Masonboro Inlet, North Carolina, to illustrate the evaluation of tidal inlet hydraulics; Indian River, Delaware, to show how the model can predict the effect of storm surge at a tidal inlet; and Cabin Point Creek, Virginia, to show the effect of adding a second inlet to a one-inlet tidal system.

a. Pentwater Inlet, Michigan. Pentwater Inlet, located on the east coast of Lake Michigan, is an example of a nontidal Great Lakes inlet (Fig. 4). Like many Great Lakes inlets, Pentwater is controlled by parallel jetties and retaining walls, and is periodically dredged to maintain the channel.

(1) Geometry. The channel is 610 meters (2,000 feet) long with a width of 44 meters (145 feet) and a minimum depth of 3.6 meters (12 feet). A survey of the channel at six cross sections with a spacing of 122 meters (400 feet) was used to calculate the cross-sectional flow area along the inlet (Fig. 5). Since the inlet cross-sectional area and depth are approximately uniform, the inlet was modeled using a one-channel flow net. The area of the bay, Pentwater Lake (1.68×10^6 square meters, 1.812×10^7 square feet), was measured from Lake Survey Chart 77.

Figure 6 summarizes geometric measurements used in the Pentwater Inlet model.

(2) Forcing Hydraulics. Spectral analysis of water levels in Pentwater Lake indicates that astronomical tides are not important and that Pentwater is being forced by some higher seiching modes of Lake Michigan (Fig. 7). For example, the 5.3-hour peak in the spectra corresponds to the second longitudinal mode of oscillation of Lake Michigan; the 3.5-hour peak is the third mode, etc. (Seelig and Sorensen, 1977).

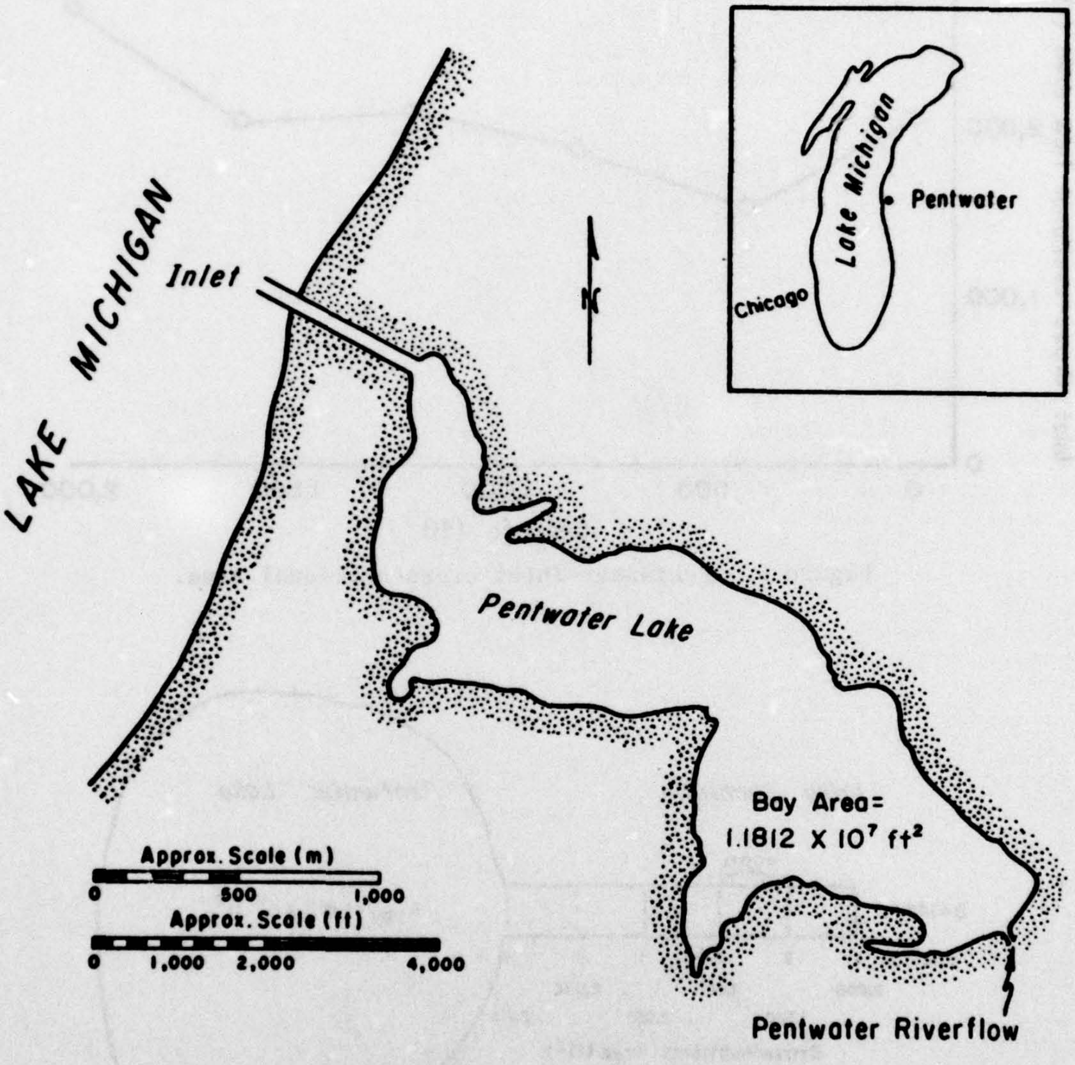


Figure 4. Pentwater, Michigan.

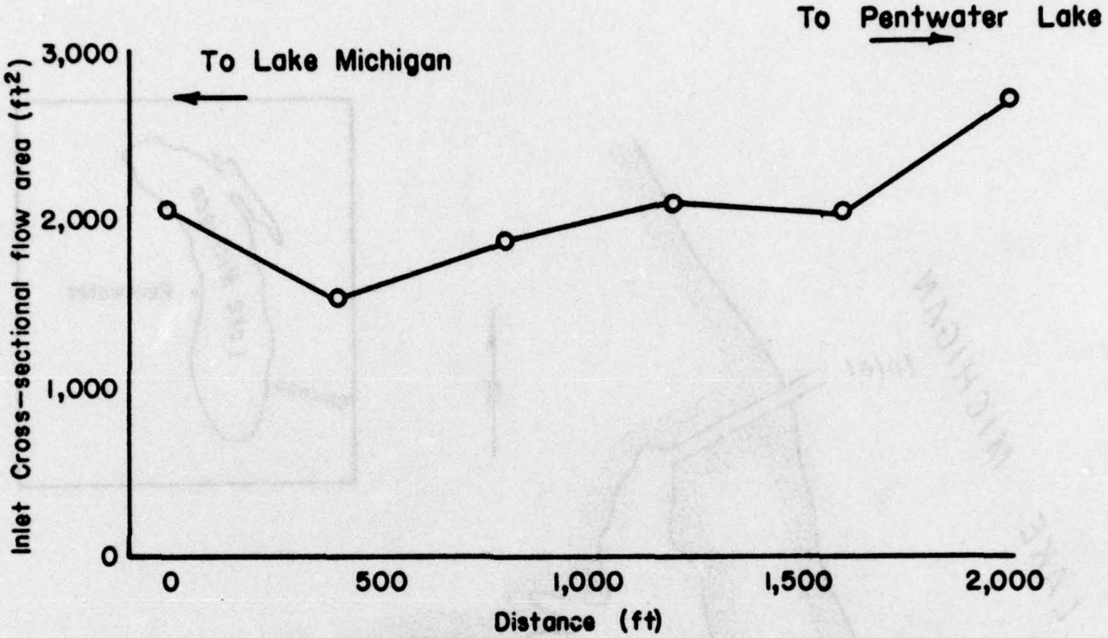


Figure 5. Pentwater Inlet cross-sectional area.

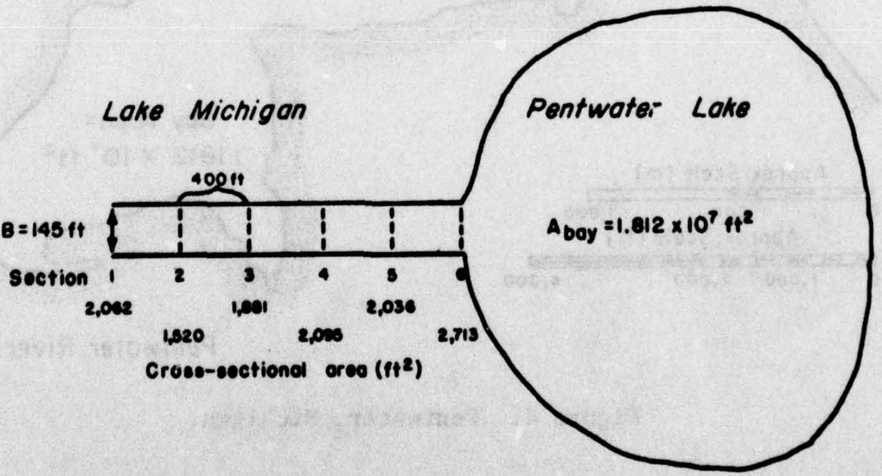


Figure 6. Pentwater geometry used in the numerical model.

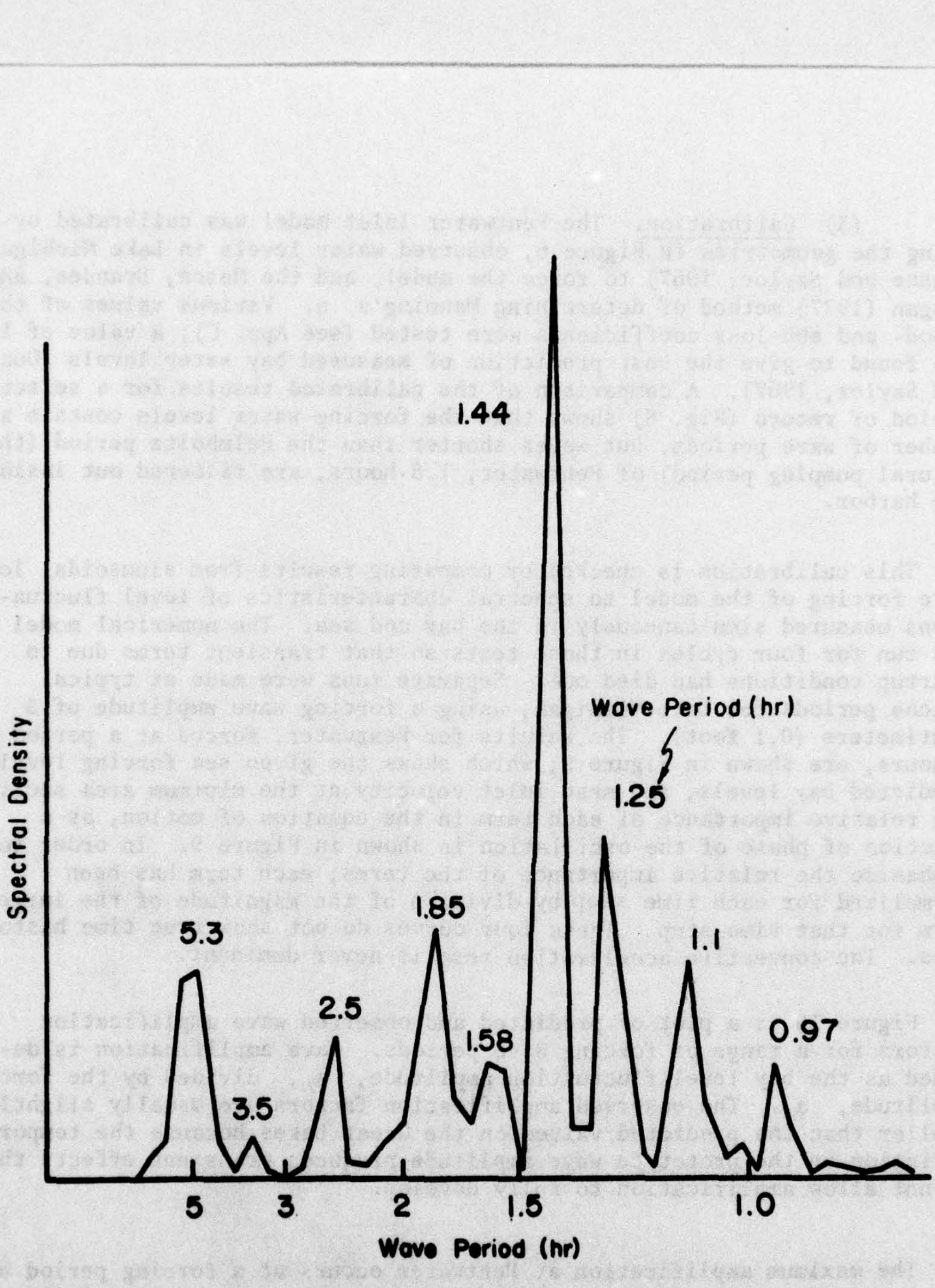


Figure 7. Spectral analysis of Pentwater Lake water levels (3, 4, and 5 November 1974).

(3) Calibration. The Pentwater Inlet model was calibrated by using the geometries in Figure 6, observed water levels in Lake Michigan (Duane and Saylor, 1967) to force the model, and the Masch, Brandes, and Reagan (1977) method of determining Manning's n. Various values of the flood- and ebb-loss coefficients were tested (see App. C); a value of 1.0 was found to give the best prediction of measured bay water levels (Duane and Saylor, 1967). A comparison of the calibrated results for a selected period of record (Fig. 8) shows that the forcing water levels contain a number of wave periods, but waves shorter than the Helmholtz period (the natural pumping period) of Pentwater, 1.8 hours, are filtered out inside the harbor.

This calibration is checked by comparing results from sinusoidal long wave forcing of the model to spectral characteristics of level fluctuations measured simultaneously in the bay and sea. The numerical model was run for four cycles in these tests so that transient terms due to startup conditions had died out. Separate runs were made at typical seiche periods for Lake Michigan, using a forcing wave amplitude of 3 centimeters (0.1 foot). The results for Pentwater, forced at a period of 2 hours, are shown in Figure 9, which shows the given sea forcing levels, predicted bay levels, and mean inlet velocity at the minimum area section. The relative importance of each term in the equation of motion, as a function of phase of the oscillation is shown in Figure 9. In order to emphasize the relative importance of the terms, each term has been normalized for each time step by division of the magnitude of the largest term for that time step. These four curves do not show true time histories. The convective acceleration term is never dominant.

Figure 10 is a plot of predicted and observed wave amplification factors for a range of forcing wave periods. Wave amplification is defined as the bay level fluctuation amplitude, a_b, divided by the forcing amplitude, a_o. The observed amplification factors are usually slightly smaller than the predicted values on the Great Lakes because the temporal variation in the prototype wave amplitude produces transient effects that do not allow amplification to fully develop.

The maximum amplification at Pentwater occurs at a forcing period of 1.8 hours (Fig. 10) and the maximum velocity occurs at a period of 1.4 hours, assuming a constant forcing amplitude of 3 centimeters. The relatively high amplification of the forcing wave, the short Helmholtz period, and the large ratio between surface area of the bay and inlet cross-sectional area (10^4) cause relatively large inlet velocities at Pentwater (0.6 meter (2 feet) per second).

b. Tsunami Effects in a Planned Inlet. This model may also be used to predict the effects of a tsunami at some inlets. This example analyzes the response of a hypothetical inlet-harbor system to an assumed tsunami.

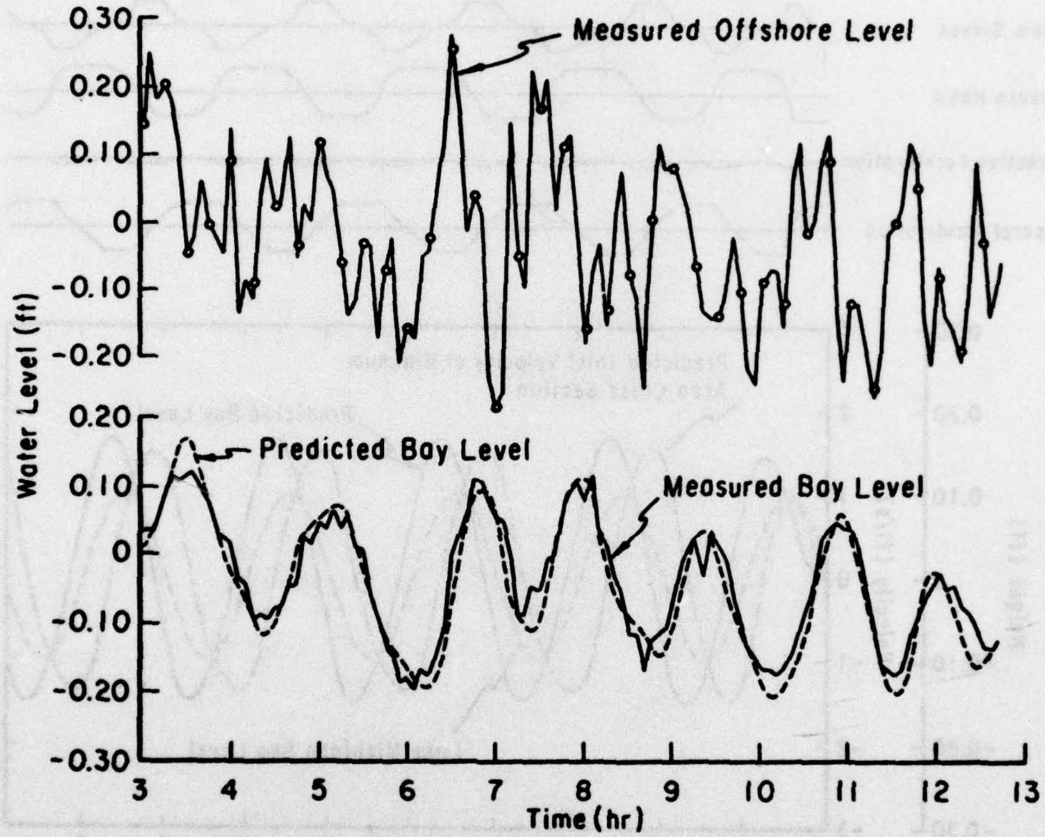


Figure 8. Comparison of results from the Pentwater model application, 17 and 18 August 1967.

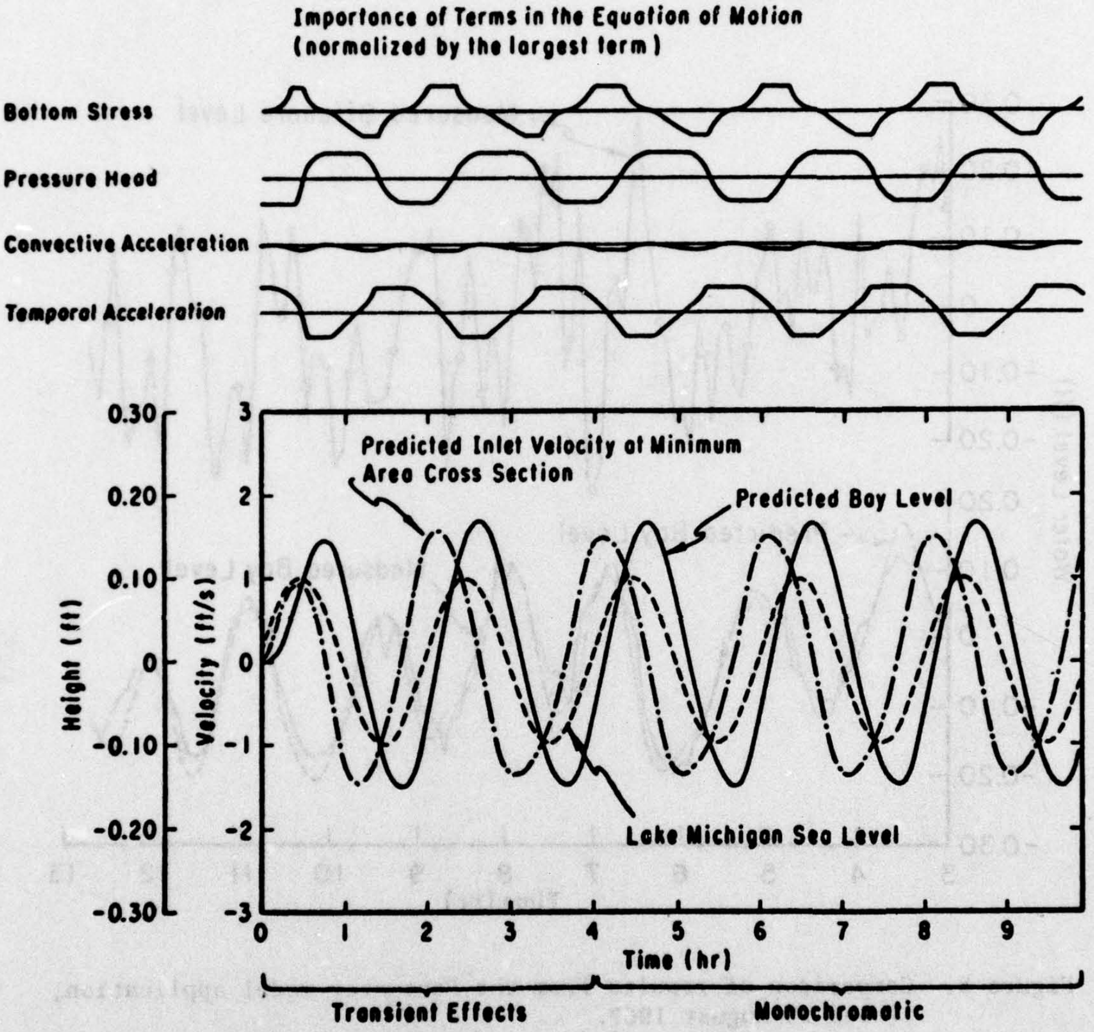


Figure 9. Pentwater model prediction of monochromatic forcing, T_F = 2.0 hours and a_o = 3 centimeters (0.1 foot).

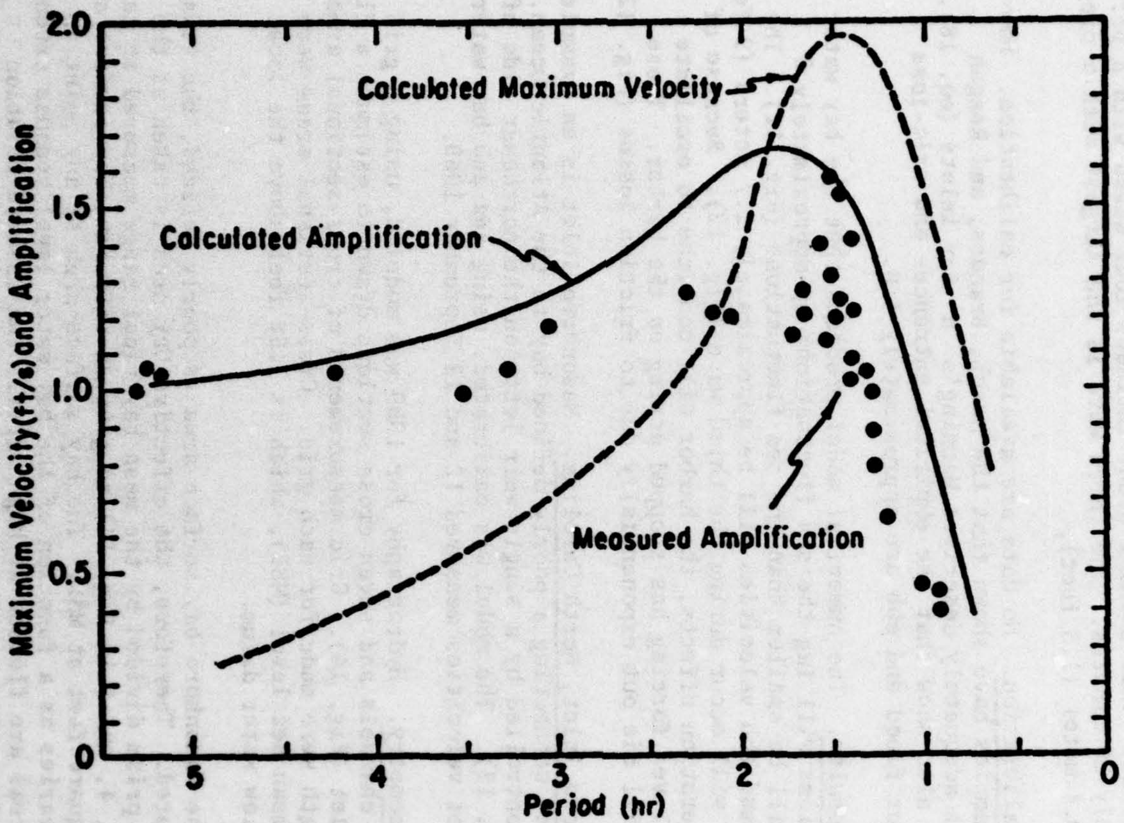


Figure 10. Response to long wave excitation at Pentwater, Michigan (wave amplitude = 0.1 foot).

(1) Geometry. The inlet is 122 meters long, and 24 meters (80 feet) wide with a design depth of 7.3 meters (24 feet). The bay area is 4.6×10^5 square meters (5×10^6 square feet).

(2) Forcing. The assumed tsunami seawater level fluctuation is shown in Figure 11. This tsunami event includes four waves with a period of approximately 20 minutes. The third wave is the largest with a crest elevation of 0.4 meter (1.3 feet).

(3) Calibration. No data are available for calibration. However, other examples have shown that the Masch, Brandes, and Reagan (1977) relation adequately describes Manning's n for inlets (eq. 18). These examples also show that the empirical entrance- and exit-loss coefficients for flood and ebb are approximately 1.0.

(4) Results. The numerical model predicts that the bay water level fluctuations will lag the sea fluctuations by approximately 5 minutes, and will be smaller than the sea fluctuations (Fig. 12). The maximum flood and ebb velocities will be approximately 2.7 meters (9 feet) per second and will occur during the third wave (Fig. 12). Because of temporal acceleration effects, the harbor will continue to oscillate after the sea level forcing has stopped acting on the harbor. These oscillations will die out exponentially due to friction losses (Fig. 12).

c. Masonboro Inlet, North Carolina. Masonboro Inlet is an example of a tidal inlet connecting a poorly defined bay to the Atlantic Ocean. The inlet is controlled by a single weir jetty on the northeast side of the inlet (Fig. 13). The model was calibrated, using sea and bay water levels and inlet velocities measured 12 and 13 September 1969.

(1) Geometry. Hydrography for 1969 was modeled, using a grid system of four channels and seven cross sections drawn to estimate a flow net for the inlet (Fig. 14). Grid measurements of cross-sectional area, width, and length were made for each grid. Cross-sectional areas were referenced to mean sea level (MSL), which is 1.88 feet above the local Beaufort mean low water datum.

Although the Masonboro bay surface area is poorly defined, the tidal prism was measured. Therefore, the effective bay area is taken as the measured tidal prism divided by the mean bay tidal range measured at three gages (gages 3, 4, and 5 in Fig. 14) to give an effective bay surface area of 1.8×10^6 square feet at MSL. The bay surface area at any point in time, A_{bay}, varies as a function of the bay water level because extensive lowland areas are flooded at high water. The assumed relation between bay surface area and bay level is

$$A_{bay} = A_o(1 + \beta h_b) \tag{19}$$

with $\beta = 0.2$ estimated from hydrographic charts.

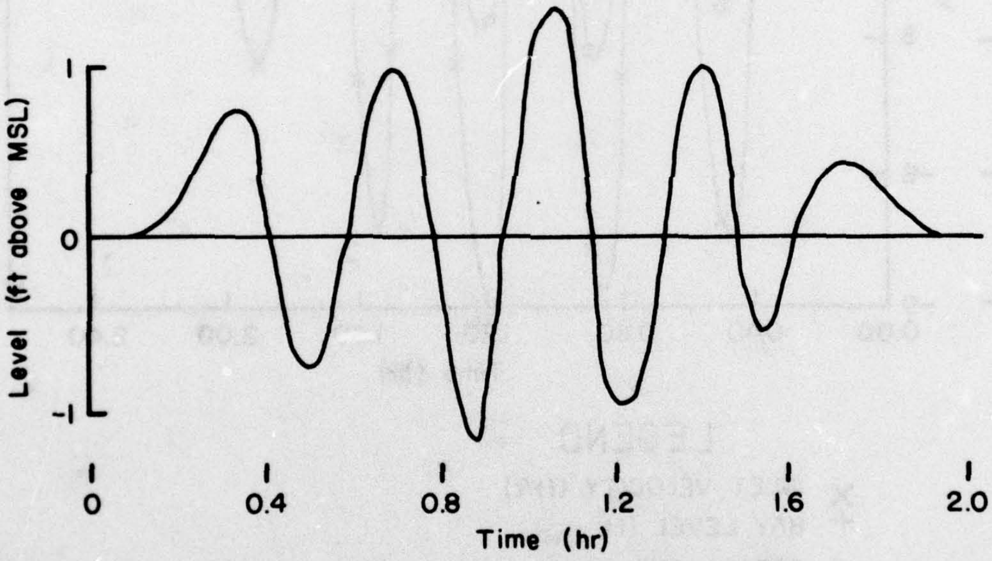


Figure 11. Tsunami water level fluctuations in the sea.

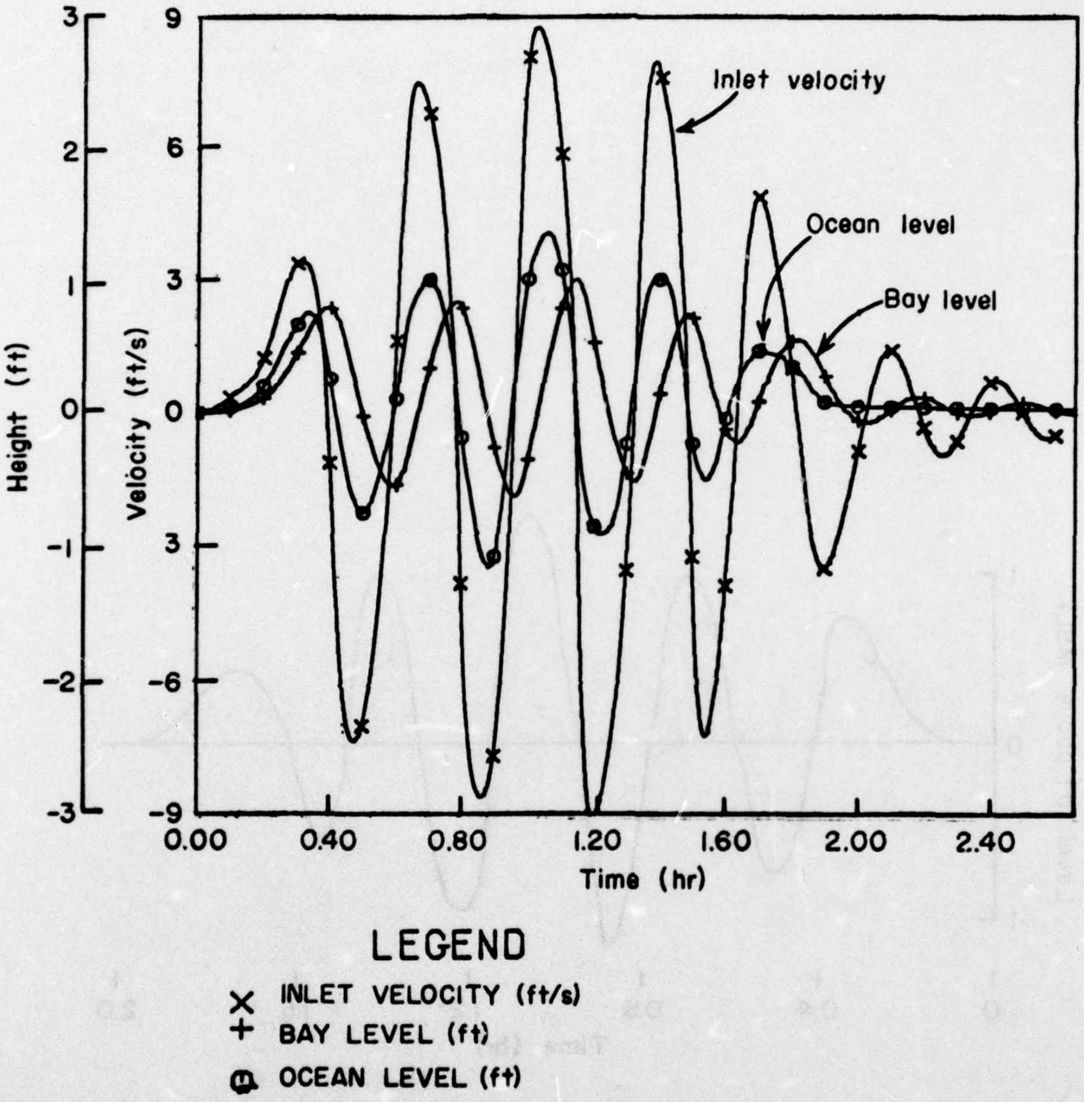


Figure 12. Predicted inlet-bay system response to tsunami-generated seawater level fluctuations.

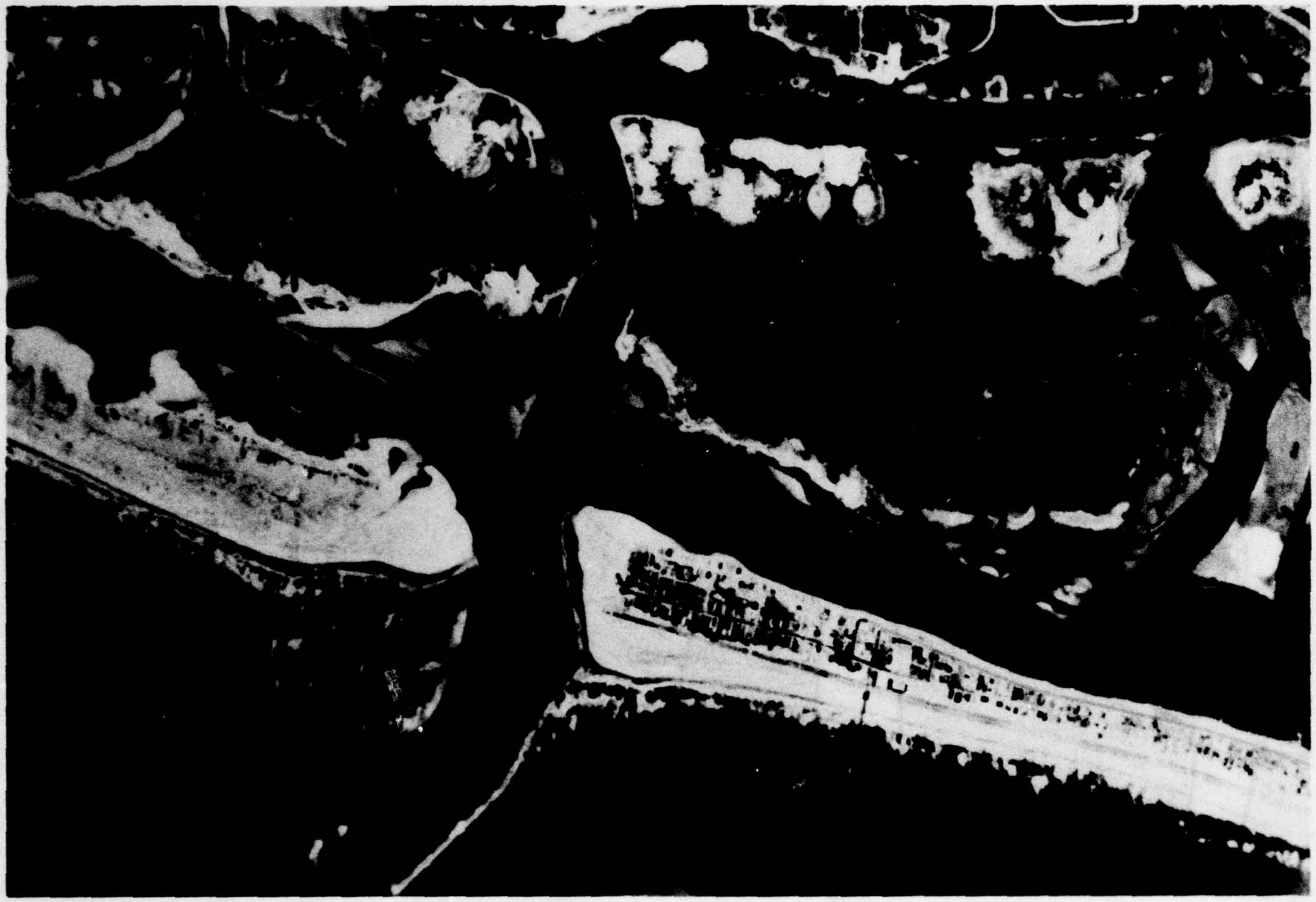


Figure 13. Masonboro Inlet, North Carolina, April 1968.

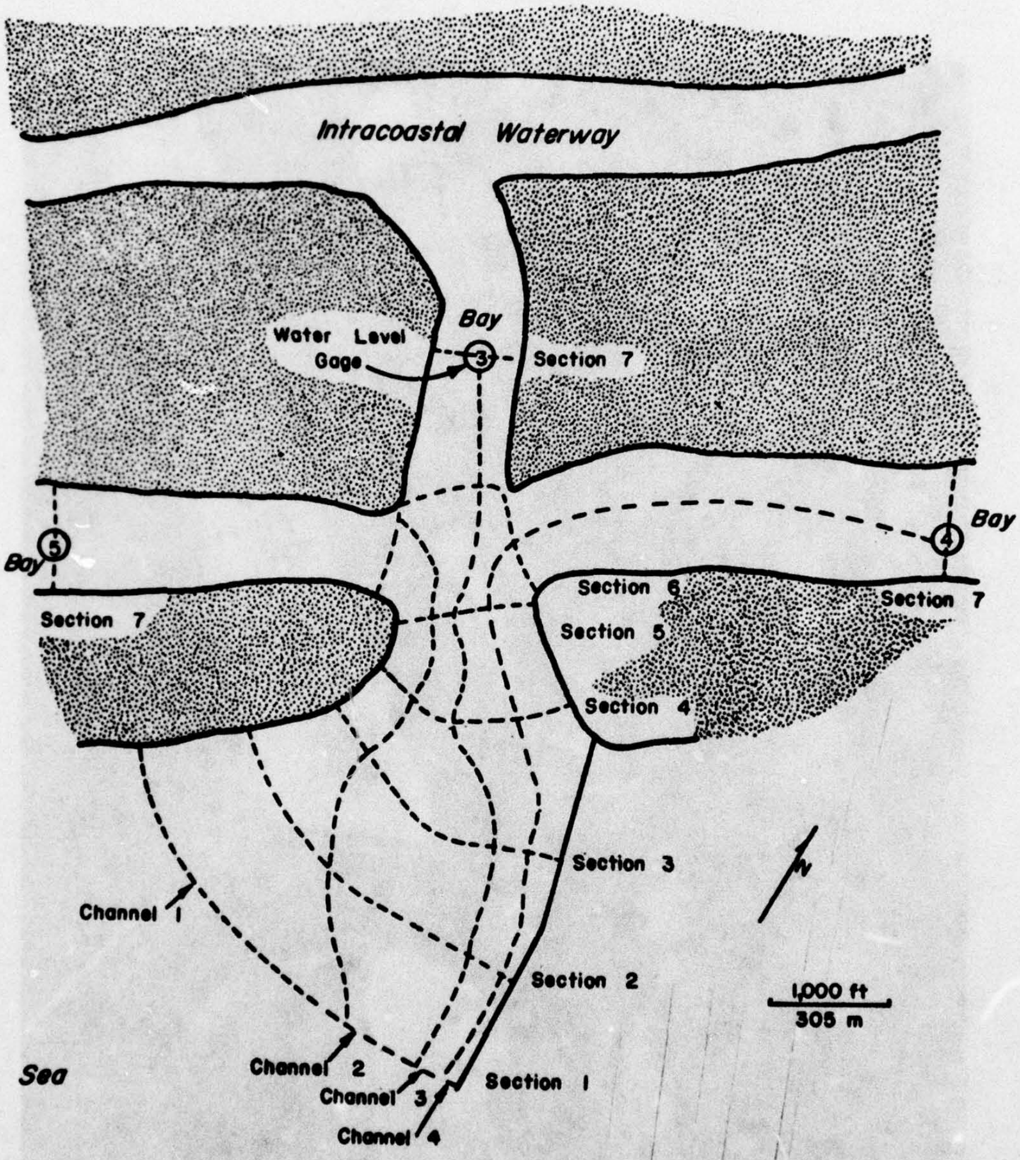


Figure 14. Grid system for Masonboro Inlet, 1969.

The slopes of Masonboro Inlet are estimated to be 0.0133 from the hydrographic survey.

(2) Forcing. Tidewater levels measured outside the inlet at 0.5-hour intervals for a period of 25 hours, 12 and 13 September 1969, were used as the input to the model.

(3) Calibration. The prototype inlet velocities measured 12 September 1969 were used to calibrate the Masonboro model. Values of Manning's n throughout the inlet grid system are assumed to be a function of the water depth below datum in each grid, D_{ij}, using the relation recommended by Masch, Brandes, and Reagan (1977):

$$n = 0.0377 - 0.000667\, D_{ij} \tag{20}$$

Flow is distributed throughout the inlet so that friction is minimized in each channel (IWT=2).

Figure 15 shows the forcing tide, predicted bay levels, inlet velocity at the throat, and discharge. The plot of the importance of terms in the equation of motion shows that the Masonboro Inlet flow is predominantly controlled by head and frictional effects. Temporal acceleration becomes important only for a short time near slack water.

Comparisons between observed and calibrated inlet velocities show that this is a good model for predicting mean velocity in the throat at Masonboro (Fig. 16). The standard deviation between observed and predicted is 0.62.

This model was also used to estimate flow distribution throughout the inlet using output from the subroutine TABLE in the computer program. Predicted maximum ebb and flood velocities are illustrated in Figures 17 and 18. This calibration shows that highest velocities occur in the deep gorge of the inlet adjacent to the jetty.

d. Indian River Inlet, Delaware. Indian River is an example of a single-jettied inlet which connects an open bay to the Atlantic Ocean (Fig. 19). This example illustrates the effects of a storm surge on water motions in the inlet and bay.

(1) Geometry. The inlet, approximately 1,650 meters (5,400 feet) long, is comparatively straight and uniform throughout its length, so the inlet is modeled using one channel and five cross sections (four grids long). The channel dimensions of 1943 (Keulegan, 1967) were used to model the inlet geometries (Fig. 20). The bay area is taken as 4.2×10^8 square feet (Keulegan, 1967) and as a first approximation the effect of "The Ditches" is neglected because flow through "The Ditches" is small compared to the inlet discharge (Keulegan, 1967).

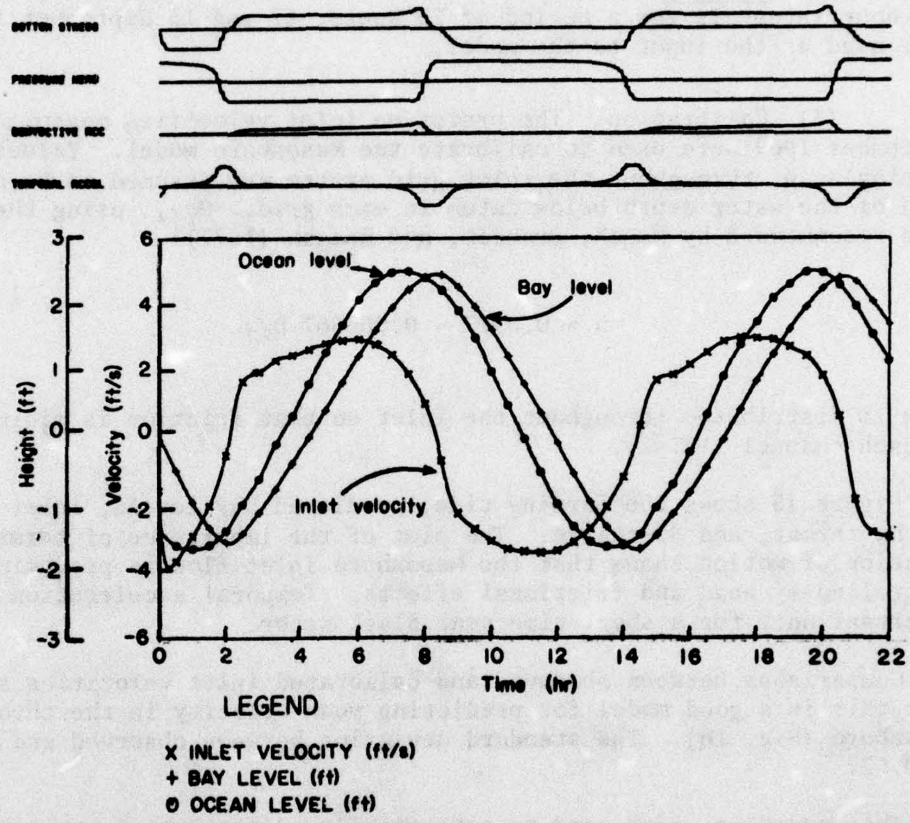


Figure 15. Predicted Masonboro Inlet hydraulics (12 September 1969), CDF = 2.

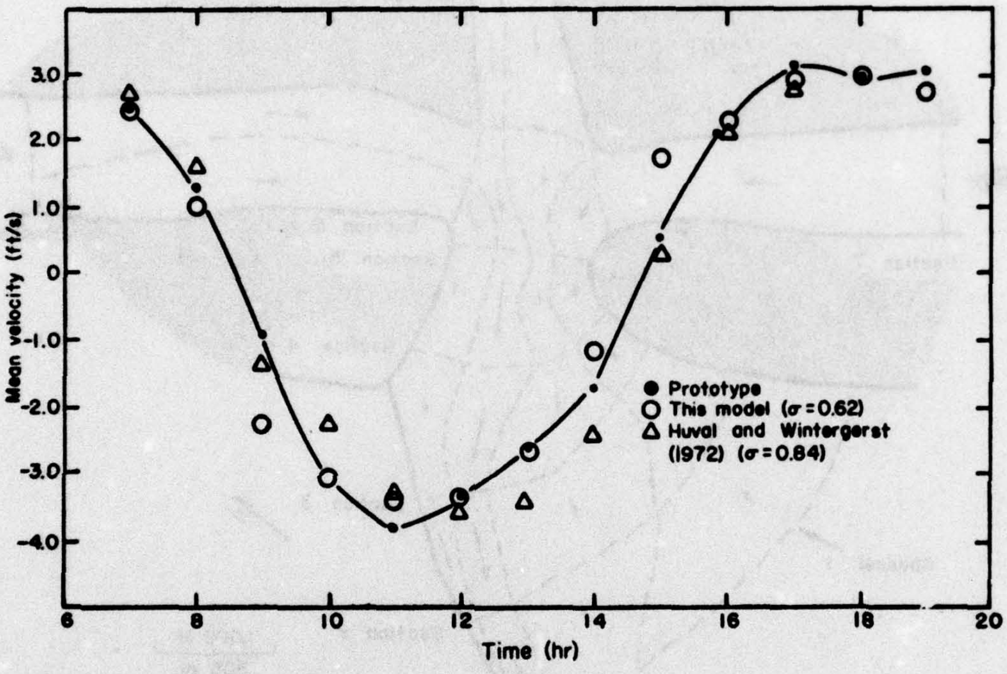


Figure 16. Prototype and predicted mean velocity in the throat of Masonboro Inlet, 12 September 1969.

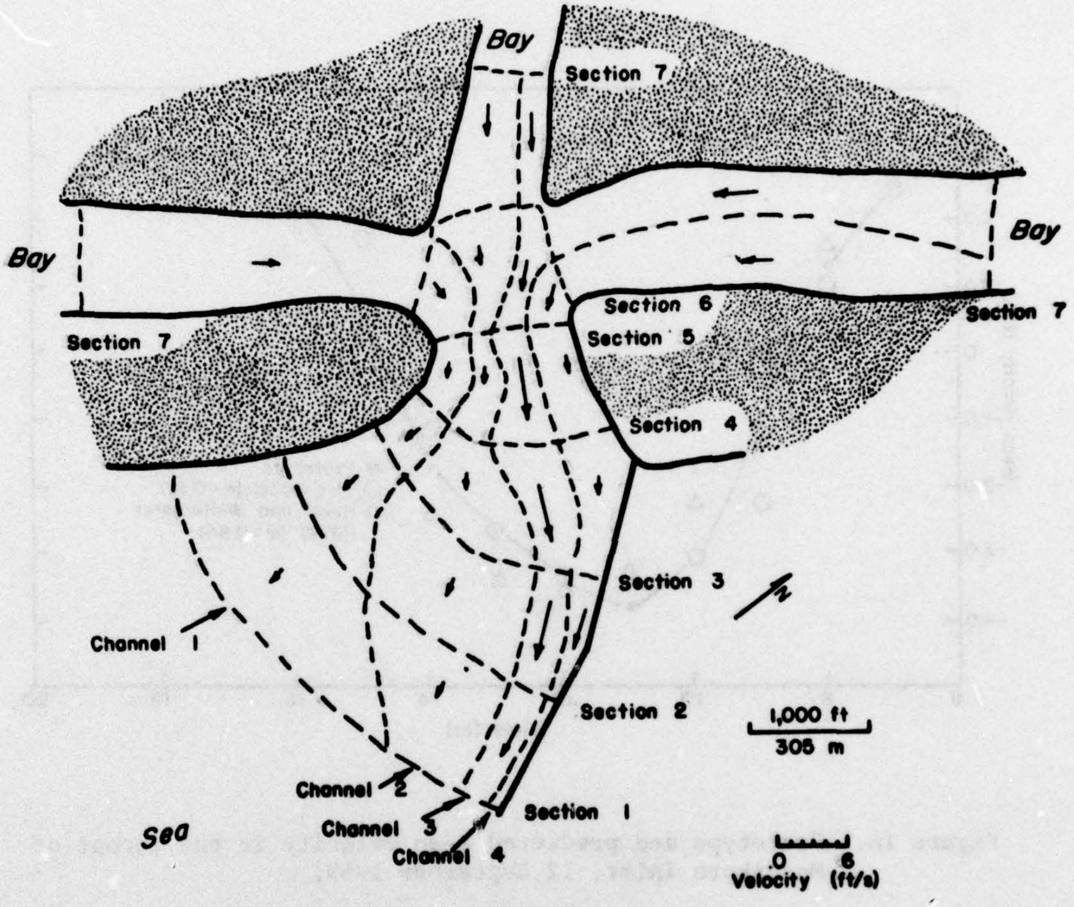


Figure 17. Ebb velocity distribution (minimum friction weighting, 1100 hours, e.s.t.).

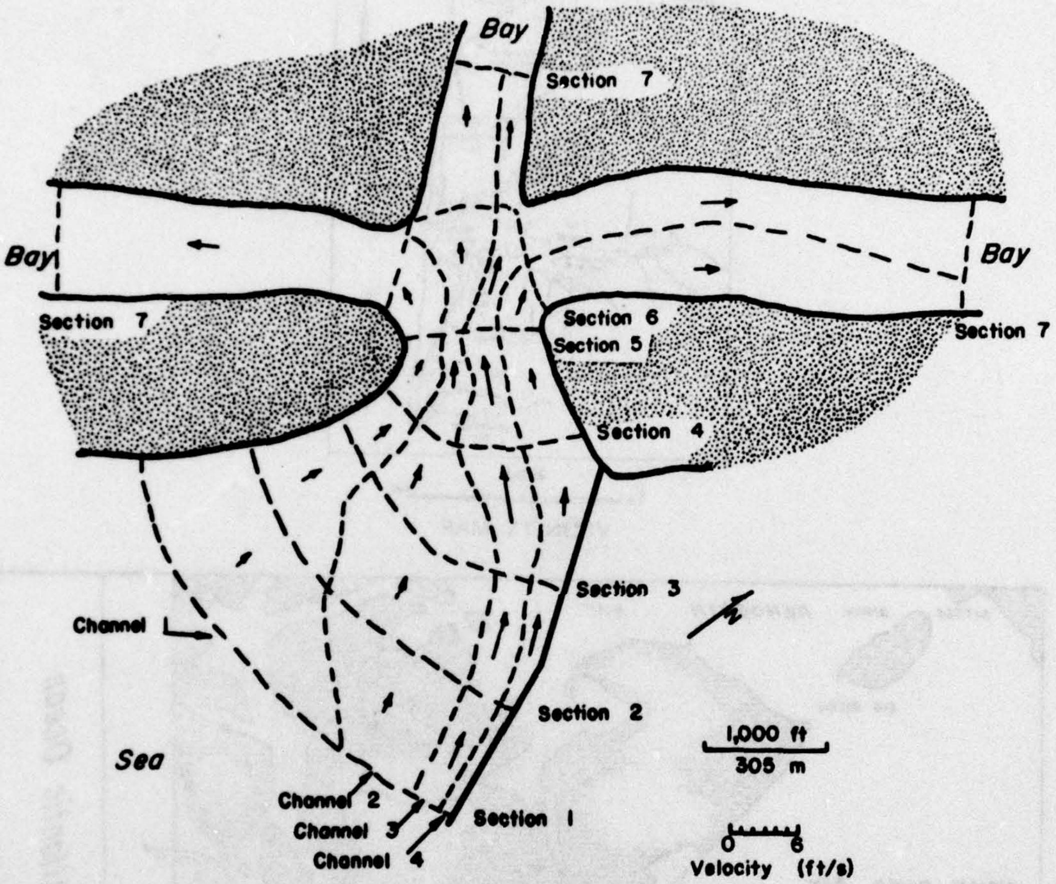
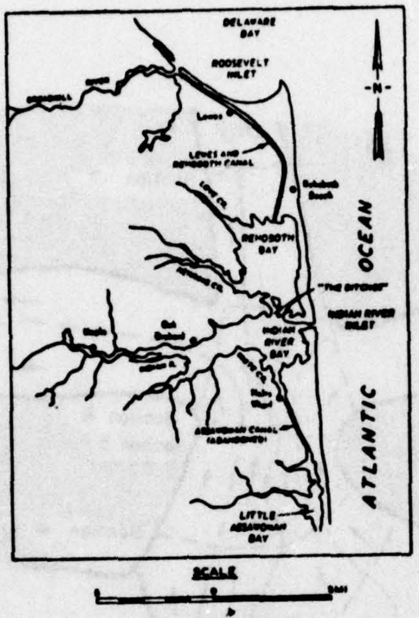
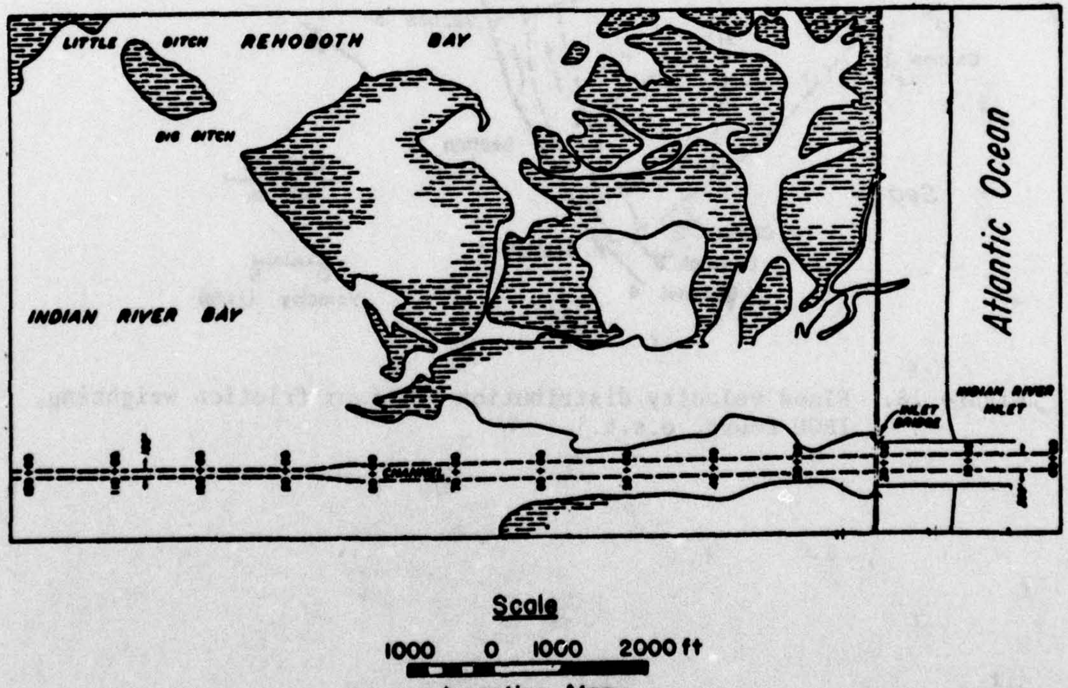


Figure 18. Flood velocity distribution (minimum friction weighting, 1800 hours, e.s.t.).



VICINITY MAP



Location Map

Figure 19. Indian River Inlet, Delaware (after Keulegan, 1967).

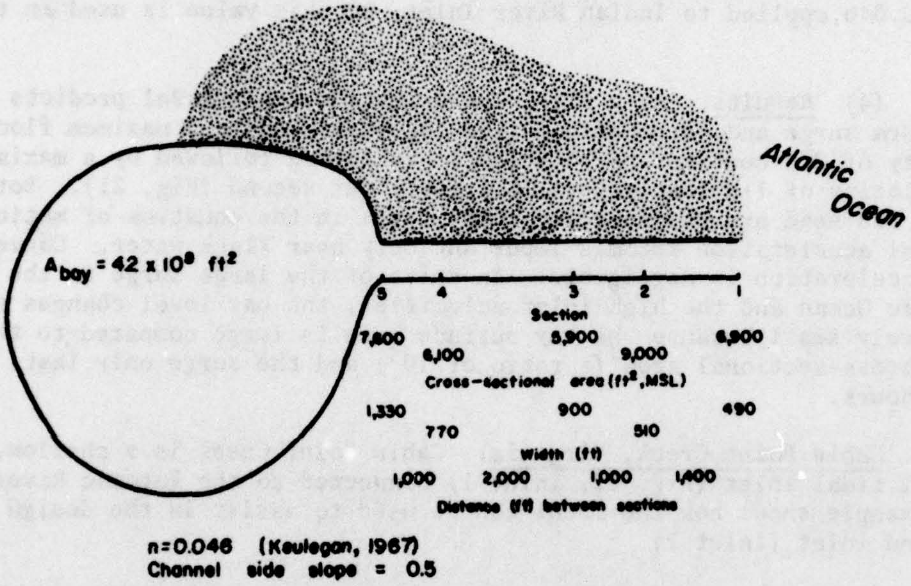


Figure 20. Schematic of Indian River model geometry.

(2) Forcing Hydraulics. The storm surge measured at Atlantic City, New Jersey, 14 and 15 September 1944 is assumed representative of the surge at Indian River (Jelesnianski, 1967). This surge is added to the astronomical tide to obtain a time history of water levels in the Atlantic Ocean at Indian River (Fig. 21).

(3) Calibration. No data are available for calibration of this model to storm surge conditions. Keulegan (1967) found that a Manning's n of 0.046 applied to Indian River Inlet, so this value is used in the model.

(4) Results. As a first approximation, this model predicts that the storm surge and astronomical tide together produce a maximum flood velocity of 200 centimeters (6.5 feet) per second followed by a maximum ebb velocity of 110 centimeters (3.6 feet) per second (Fig. 21). Bottom stress and head are the most important terms in the equation of motion. Temporal acceleration becomes important only near slack water. Convective acceleration is negligible. In spite of the large surge in the Atlantic Ocean and the high inlet velocities, the bay level changes are relatively small because the bay surface area is large compared to the inlet cross-sectional area (a ratio of 10^5) and the surge only lasts for a few hours.

e. Cabin Point Creek, Virginia. Cabin Point Creek is a shallow, natural tidal inlet (Fig. 22, inlet 1) connected to the Potomac River. This example shows how the model can be used to assist in the design of a second inlet (inlet 2).

(1) Geometry. The area of the bay, measured from hydrographic charts, is 3.3×10^5 square meters (3.5×10^6 square feet) and the length of the natural inlet is 580 meters (1,900 feet). Only one cross section, located one-third of the length of the inlet from the sea, was measured for the inlet in May 1976 (Seelig, 1976). The maximum water depth was 0.6 meter (2.1 feet) with an inlet width of 15 meters (50 feet). This inlet was modeled, using a three-channel flow net. The bay surface variation parameter, β, was determined from hydrographic charts as 0.2.

(2) Forcing. Water level measurements in the Potomac River for an 18-hour interval on 24 and 25 May 1976 were used to force the model.

(3) Calibration. The computer program model of Cabin Point was calibrated by comparing observed and predicted bay levels. Masch, Brandes, and Reagan's (1977) recommended relation between n and water depth for depths less than 1.2 meters and ebb- and flood-loss coefficients of 1.0 to adequately model bay levels (Fig. 23).

(4) Prediction. The calibrated model was used to predict the hydraulics of the system if a second inlet (hypothetical), 91 meters (300 feet) long, 1.2 meters deep, and 15 meters wide, were cut at location 2 shown in Figure 22. The model predicts that the bay tide range would increase by a factor of four (from 0.36 to 1.49 feet, 0.1 to

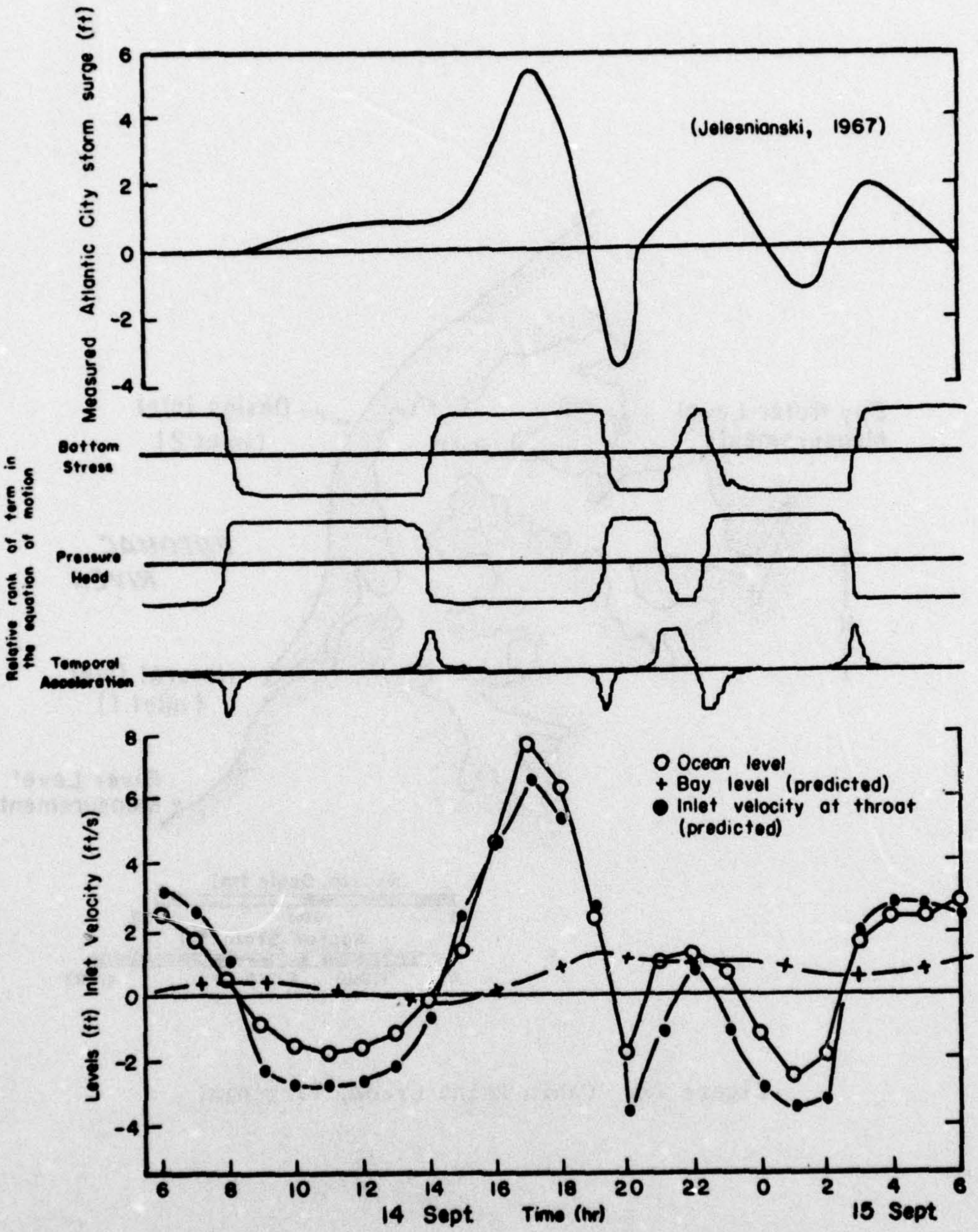


Figure 21. Indian River Inlet channel velocities and bay levels.

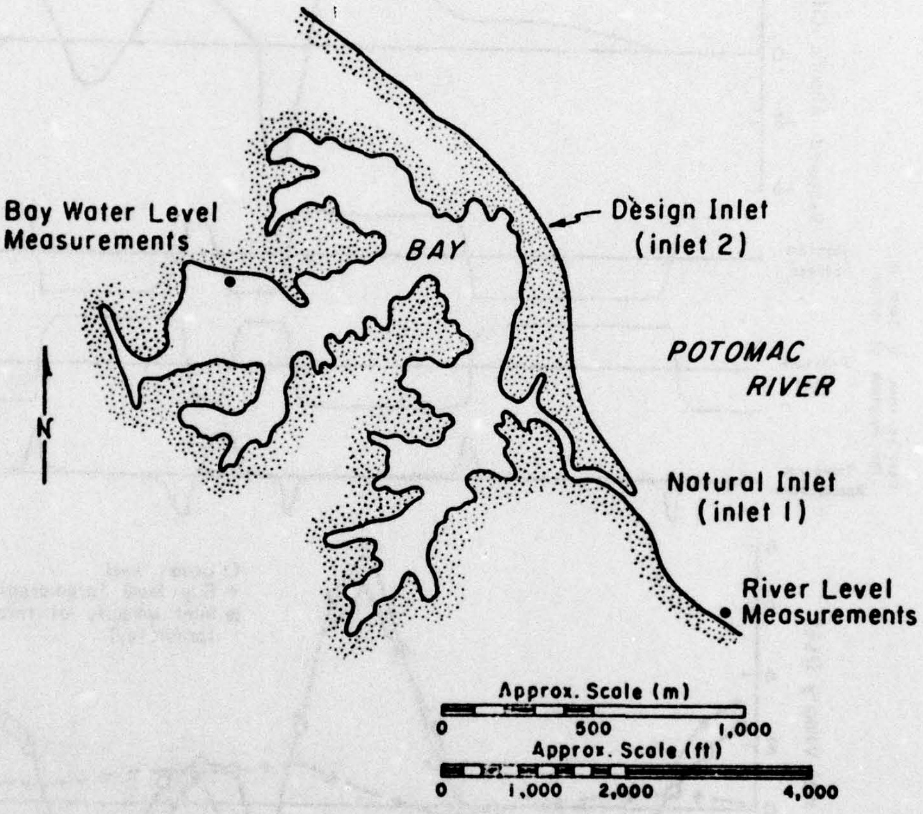


Figure 22. Cabin Point Creek, Virginia.

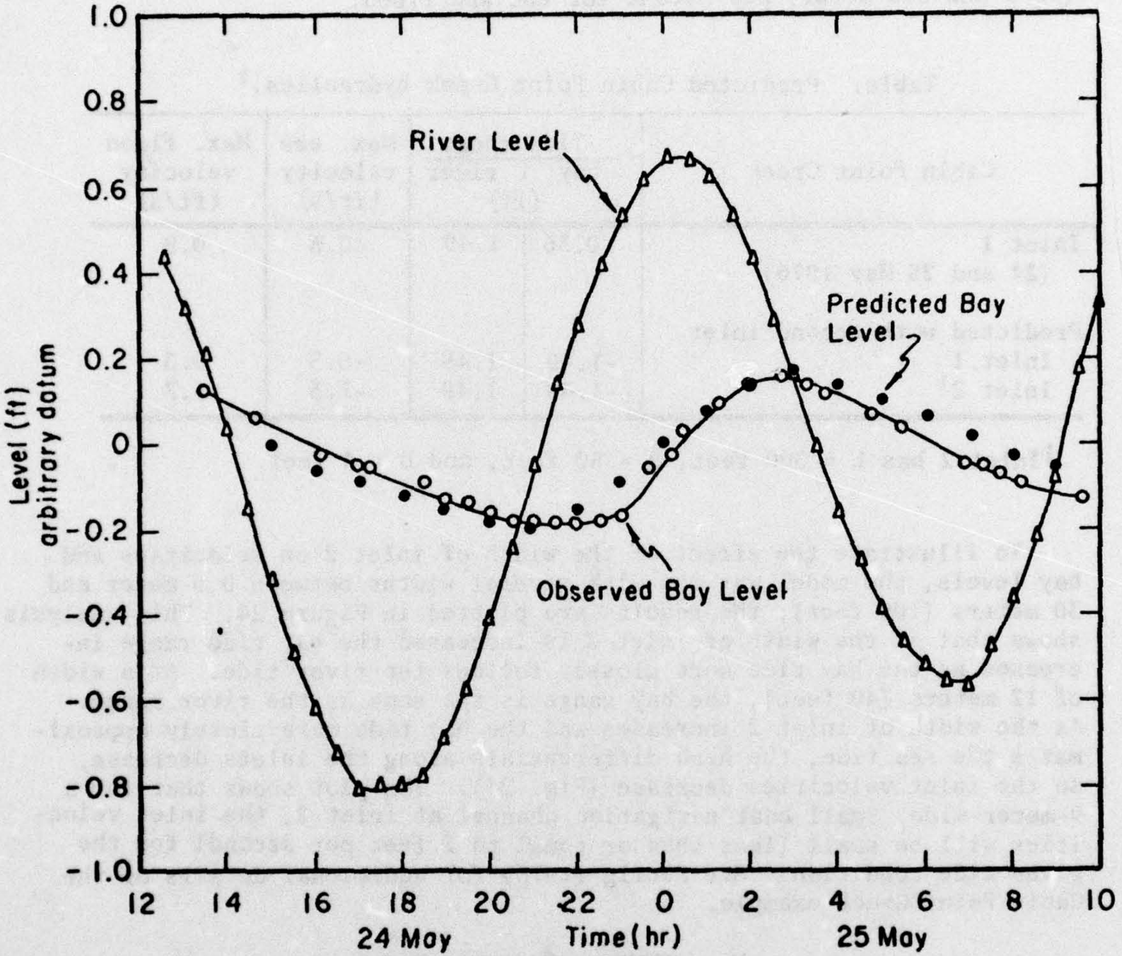


Figure 23. Cabin Point Creek sea and bay levels.

0.45 meter) and the velocities in inlet 1 would decrease (Table 1). The maximum water velocities in inlet 2 would be -1.3 and 1.7 feet (-0.4 and 0.5 meter) per second for ebb and flood.

Table. Predicted Cabin Point Creek hydraulics.[1]

Cabin Point Creek	Tide range (ft) bay	Tide range (ft) river	Max. ebb velocity (ft/s)	Max. flood velocity (ft/s)
Inlet 1 (24 and 25 May 1976)	0.36	1.49	-0.6	0.9
Predicted with second inlet				
Inlet 1	-1.49	1.49	-0.3	0.3
Inlet 2[1]	-1.49	1.49	-1.3	1.7

[1] Inlet 2 has L = 300 feet, B = 50 feet, and D = 4 feet.

To illustrate the effect of the width of inlet 2 on velocities and bay levels, the model was run with several widths between 0.6 meter and 30 meters (100 feet); the results are plotted in Figure 24. This analysis shows that as the width of inlet 2 is increased the bay tide range increases as the bay tide more closely follows the river tide. At a width of 12 meters (40 feet), the bay range is the same as the river range. As the width of inlet 2 increases and the bay tide more closely approximates the sea tide, the head differentials along the inlets decrease, so the inlet velocities decrease (Fig. 24). The plot shows that for a 9-meter-wide, small boat navigation channel at inlet 2, the inlet velocities will be small (less than or equal to 2 feet per second) for the given tide condition. See Seelig (1976) for additional details of the Cabin Point Creek example.

V. SUMMARY AND CONCLUSIONS

A numerical model based on an area averaged momentum equation for the inlet, and a continuity equation for the bay has been shown to give good predictions of bay levels and mean inlet velocities for a variety of inlets and forcing conditions. The model is designed for cases where the bay water level fluctuates uniformly throughout the bay and the volume of water stored in the inlet between high and low water is negligible compared to the prism of water that moves through the inlet.

The ease of use and low cost of this model make it ideal for obtaining a first estimate of inlet hydraulics for inlets forced by the astronomical tide, storm surge, lake seiching, and tsunamis. The computer program INLET (App. D), based on the model, can be used for hydraulic calculations when one or more inlets connect a bay to a sea.

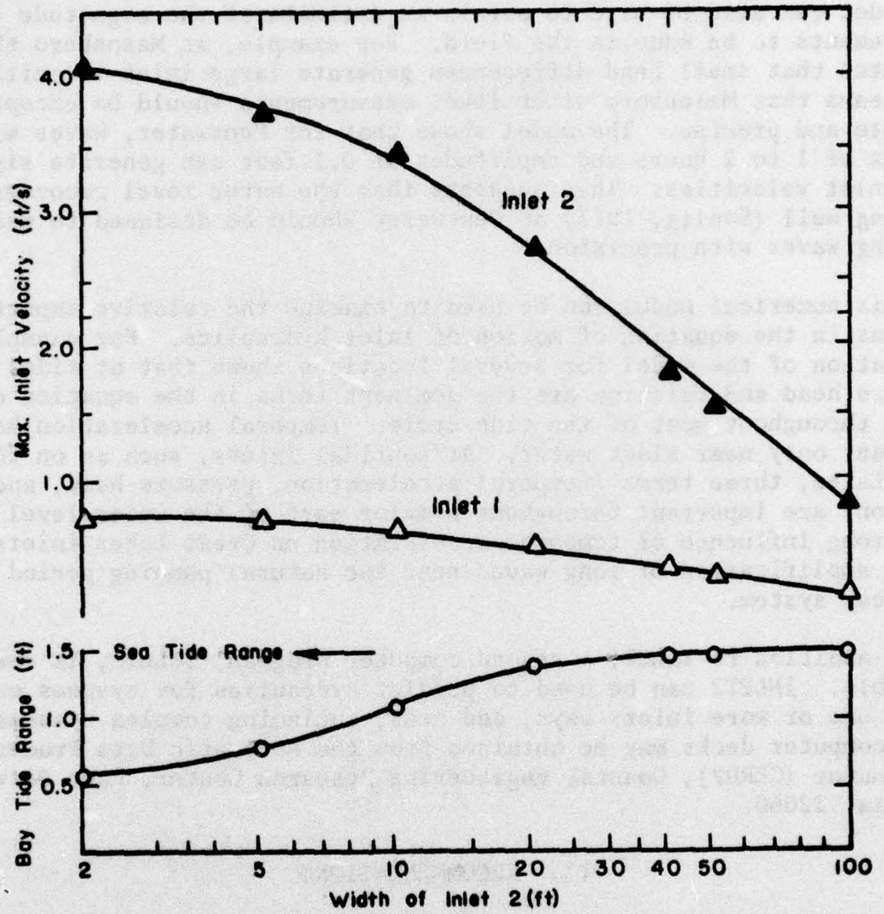


Figure 24. Effect of the width of inlet 2 on inlet and bay hydraulics, Cabin Point Creek, Virginia.

There are several ways that this program can be used to aid the design engineer and researcher. For example, when designing an inlet system many physical parameters can be easily varied in the computer program to determine the influence of each factor on inlet and bay hydraulics. The model can also be used to obtain an estimate of the magnitude of measurements to be made in the field. For example, at Masonboro the model indicates that small head differences generate large inlet velocities. This means that Masonboro water level measurements should be exceptionally accurate and precise. The model shows that for Pentwater, waves with periods of 1 to 2 hours and amplitudes of 0.1 foot can generate significant inlet velocities. This suggests that the water level recorder and stilling well (Seelig, 1977) at Pentwater should be designed to measure the long waves with precision.

This numerical model can be used to examine the relative importance of terms in the equation of motion of inlet hydraulics. For example, application of the model for several locations shows that at tidal inlets, pressure head and friction are the dominant terms in the equation of motion throughout most of the tide cycle. Temporal acceleration becomes important only near slack water. At nontidal inlets, such as on the Great Lakes, three terms (temporal acceleration, pressure head, and friction) are important throughout a major part of the water level cycle. The strong influence of temporal acceleration on Great Lakes inlets causes amplification of long waves near the natural pumping period of the inlet-bay system.

In addition to INLET, a second computer program, INLET2, is now available. INLET2 can be used to predict hydraulics for systems consisting of one or more inlets bays, and seas, including complex systems. These computer decks may be obtained from the Automatic Data Processing Coordinator (CERDP), Coastal Engineering Research Center, Fort Belvoir, Virginia 22060.

VI. RECOMMENDATIONS

There are several changes recommended for the computer programs INLET and INLET2 to increase the generality of the model. Storage of water in inlets, and radiation and wind stresses may be added to the equations of motion for the inlet. Other weighting functions for distributing flow, for example a weighting function which includes the jet action of water exiting the inlet, may be added to the program. Higher order relations to evaluate bay surface area, inlet cross-sectional area, and inflow into the bay from sources other than the inlet can also be added to the computer program. A bottom-friction relation designed for unsteady flow may slightly increase the quality of the results.

LITERATURE CITED

BROWN, E.I., "Inlets on Sandy Coasts," *Proceedings of the American Society of Civil Engineers*, Vol. 54, Part 1, Feb. 1928, pp. 505-553.

DUANE, D.B., and SAYLOR, J.H., Water Level Records, National Oceanic and Atmospheric Administration, Lake Survey Center, unpublished, 1967.

HARRIS, D.L., and BODINE, B.R., "Comparison of Numerical and Physical Models, Masonboro Inlet, North Carolina," GITI Report 6, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Va., and U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss., June 1977.

HUVAL, C.J., and WINTERGERST, G.L., "Simplified Numerical (Lumped Parameter) Simulation," App. 4, GITI Report 6, *Comparison of Numerical and Physical Models, Masonboro Inlet, North Carolina*, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Va., and U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss., June 1977.

INTERNATIONAL BUSINESS MACHINES CORPORATION, "System/360 Scientific Subroutine Package, Version II Programmer's Manual," White Plains, N.Y., 1970.

JELESNIANSKI, C.P., "Numerical Computations of Storm Surges with Bottom Stress," *Monthly Weather Review*, Vol. 95, No. 11, Nov. 1967.

KEULEGAN, G.H., "Tidal Flow in Entrances Water-Level Fluctuations of Basins in Communication with Seas," T.B. No. 14, Committee on Tidal Hydraulics, U.S. Army, Corps of Engineers, Vicksburg, Miss.. July 1967.

KING, D.B., "The Dynamics of Inlets and Bays," T.R. No. 22, Coastal and Oceanographic Engineering Laboratory, University of Florida, Gainesville, Fla., Mar. 1974.

MASCH, F.D., BRANDES, R.J., and REAGAN, J.D., "Numerical Simulation of Hydrodynamics (WRE)," App. 2, GITI Report 6, *Comparison of Numerical and Physical Models, Masonboro Inlet, North Carolina*, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Va., and U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss., June 1977.

MASON, C., and SORENSEN, R., "Properties and Stability of a Texas Barrier Beach Inlet," Sea Grant Report TAMU-SG-71-217, Texas A&M University, College Station, Tex., 1971.

O'BRIEN, M.P., and CLARK, R.R., "Hydraulic Constants of Tidal Entrances," *Proceedings of the 14th Coastal Engineering Conference*, 1974, pp. 1546-1565.

SEELIG, W.N., "Environmental Effects of Inlet Improvement at Cabin Point, Virginia," U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Va., unpublished, July 1976.

SEELIG, W.N., "Stilling Well Design for Accurate Water Level Measurement," TP 77-2, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Va., Jan. 1977.

SEELIG, W.N., and SORENSEN, R.M., "Hydraulics of Great Lakes Inlets," TP 77-8, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Va., July 1977.

APPENDIX A

WEIGHTING FUNCTIONS TO MINIMIZE FRICTION

Let the total bottom stress in an inlet cross section be described by:

$$F_x = \sum_{i=1}^{IC} \frac{1}{C_i} W_i^2 \qquad \text{(A-1)}$$

where C_i is a parameter that can be determined using results from the previous time step:

$$C_i = \frac{A_i^2 \ (D_i)^{1/3}}{n_i^2 \ Q^2 B_i L_i} \qquad \text{(A-2)}$$

where W_i is an unknown weighting function and Q is the inlet discharge. C_i can be evaluated for each grid (as in the computer subroutine WT1), or for each channel (WT2). In many cases, it is reasonable to assume that flow in an inlet is distributed so that total friction is minimized (i.e., flow will follow the path of least resistance). In that case, find W_i to minimize F_x. To find W_i set up a new function, F_N, which includes a Lagrangian multiplier, λ:

$$F_N = \sum_{i=1}^{IC} \frac{W_i^2}{C_i} + \lambda\left(\sum_{i=1}^{IC} W_i - 1\right) \qquad \text{(A-3)}$$

Then differentiate with respect to each W_i to obtain a series of equations:

$$\frac{\partial F_N}{\partial W_i} = \frac{2W_i}{C_i} + \lambda \ ; \ i=1, \ IC \ . \qquad \text{(A-4)}$$

Also differentiate equation (A-3) with respect to λ to obtain:

$$\frac{\partial F_N}{\partial \lambda} = \sum_{i=1}^{IC} W_i - 1 \ . \qquad \text{(A-5)}$$

Setting equations (A-4) and (A-5) to zero will give the values of W_i to obtain the minimum F_x, or

$$W_i = \frac{-C_i \lambda}{2} \ ; \quad i=1,\ IC \ . \qquad \text{(A-6)}$$

Substituting equation (A-6) into equation (A-5) for W_i:

$$\sum_{i=1}^{IC} \left(\frac{-C_i \lambda}{2} \right) - 1 = 0 \qquad \text{(A-7)}$$

and solving for λ:

$$\lambda = \frac{2}{\sum_{i=1}^{IC} (-C_i)} \qquad \text{(A-8)}$$

Then substitute λ into equation (A-6) to obtain the weighting function to minimize friction:

$$W_i = \frac{C_i}{\left(\sum_{i=1}^{IC} C_i \right)} \qquad \text{(A-9)}$$

where C_i is given by equation (A-2).

This function to determine the weighting for minimum friction can be applied in several ways. If flow is allowed to cross channels, the minimum friction weighting can be applied at each cross section of grids (WT1). This will give the lowest possible friction in the model. If flow is not allowed to cross channels, then the routine can be applied to distribute flow in each channel to minimize friction (WT2). This will give more frictional resistance than in WT1.

APPENDIX B

CONSTRUCTING FLOW NETS

A flow net for an inlet is a series of subchannels and cross sections that divide the inlet into a set of grid cells. The primary purpose of the flow net is to evaluate bottom friction throughout the inlet at each time step. The process of constructing the flow net is subjective. The subjectivity can be reduced by following the procedures described here. Friction in each cell is determined by taking the mean geometric and hydraulic conditions throughout each cell and applying them at the centroid of the cell through the use of Manning's bottom-friction relationship. Total inlet friction is the sum of friction in all the cells. The flow net should be drawn so that flow parallels the subchannels and is perpendicular to the cross sections. In prototype inlets, the actual flow net system changes with time and these changes are partially accounted for in the model by reevaluating the weighting function (IWT=1 and IWT=2) at each time step.

1. Drawing Flow Nets.

One method of drawing a flow net for an inlet is by assuming that flow is distributed at each cross section so that friction is minimized (IWT=1 in the computer program; see App. A). The first procedure for applying this method is to (a) draw a number of cross sections which are approximately perpendicular to flow for the inlet, (b) apply the minimum friction weighting function to each section to determine channel locations so that flow through each channel will be equal, and (c) check to see that the estimated cross sections are perpendicular to the channels drawn in (b). If not, repeat steps (a) and (b).

A hypothetical inlet is used to illustrate the technique for drawing flow nets (Fig. B-1). This idealized inlet has a maximum depth of 5.5 meters (18 feet) below MSL in the throat, is 366 meters (1,200 feet) wide at the minimum width, and is symmetric about the longitudinal axis of the inlet. A deep gorge runs through the centerline of the inlet.

The first step in drawing a flow net grid system is to draw a number of inlet cross sections which are approximately perpendicular to flow in the inlet. These estimated cross sections are drawn, keeping in mind that in the throat and near the centerline of the inlet most flow will be parallel to the main axis of the inlet. Beyond the inlet, the flow will move in more of a radial direction where the inlet has the effect of a source. Figure B-2 illustrates 15 cross sections estimated for the idealized inlet. These sections are placed closer together in the throat of the inlet because this is a high friction region.

The second step is to determine water depths at points along each cross section, and based on this information, determine channel locations so that flow is distributed to minimize the head loss due to

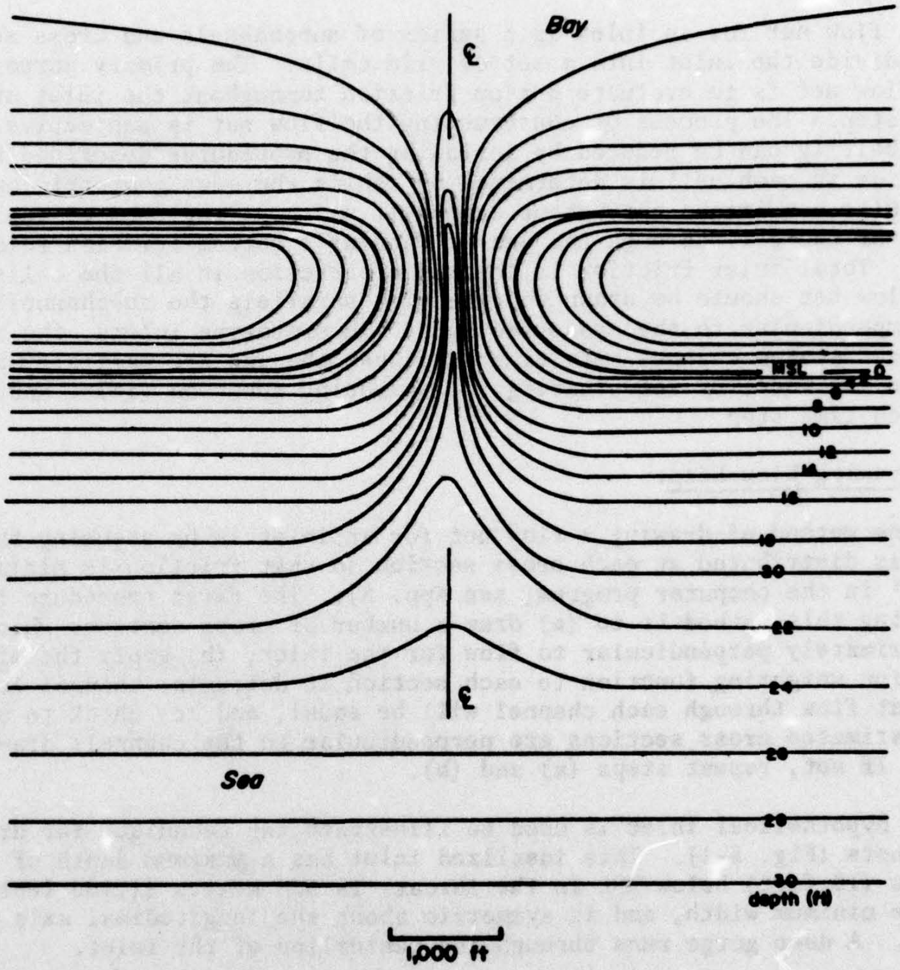


Figure B-1. Depth contours for the idealized inlet (phase I).

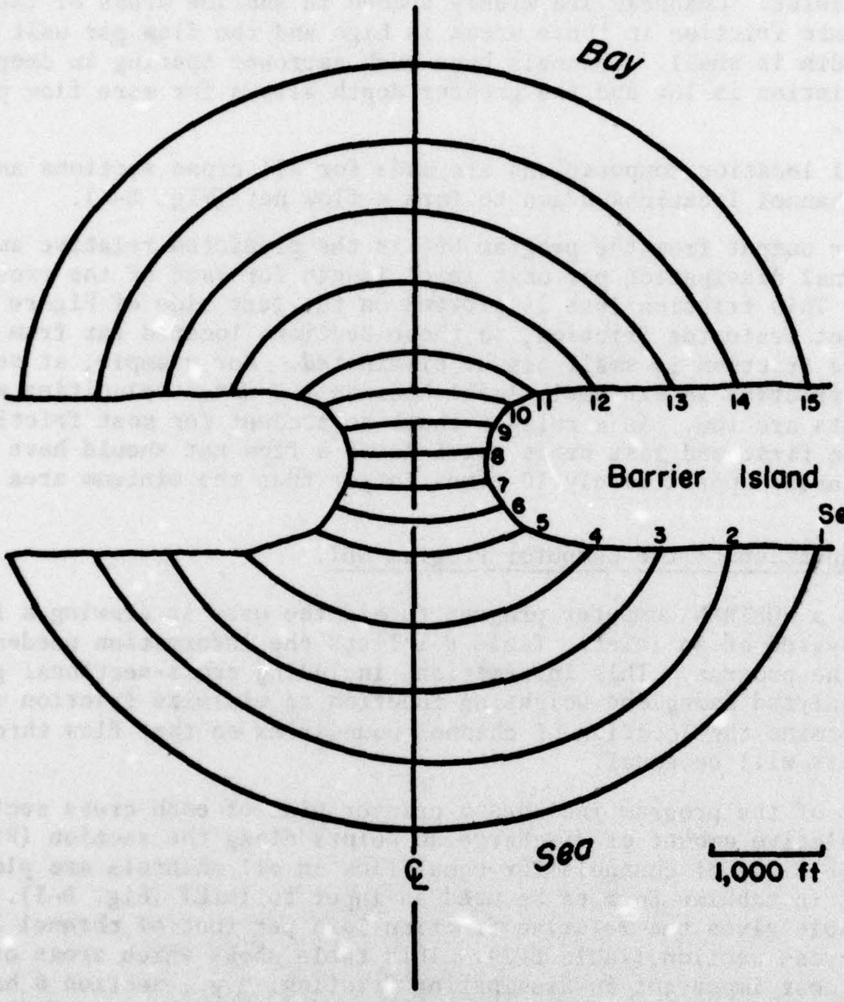


Figure B-2. Selected idealized inlet cross sections.

friction. This task is aided by the FORTRAN computer program, NET, discussed later in this appendix. Figure B-3 shows the channel locations estimated so that flow is equal in all channels for section 12 of the idealized inlet. Channels are widely spaced in shallow areas of the inlet because friction in these areas is high and the flow per unit cross-section width is small. Channels have much narrower spacing in deep areas because friction is low and the greater depth allows for more flow per unit width.

Channel location computations are made for all cross sections and the locus of channel locations drawn to form a flow net (Fig. B-4).

Another output from the program NET is the predicted relative amount of frictional dissipation per unit inlet length for each of the cross sections. This friction loss is plotted on the left side of Figure B-4. The flow net evaluates friction, so those sections located far from the inlet where friction is small can be eliminated. For example, at sections 1 and 15, friction is extremely small because the water velocities at these points are low. As a rule-of-thumb to account for most friction losses, the first and last cross sections of a flow net should have cross-sectional areas approximately 10 times larger than the minimum area in the throat.

2. Documentation of the Computer Program NET.

NET is a FORTRAN computer program to aid the user in drawing a flow net grid system of an inlet. Table B-1 lists the information needed for input to the program. This information, including cross-sectional geometry, is analyzed using the weighting function to minimize friction (App. A) to determine the location of channel boundaries so that flow through all channels will be equal.

Output of the program includes a printer plot of each cross section and the relative amount of discharge at points along the section (Fig. B-3). Dimensions of channels for equal flow in all channels are plotted and output in tabular form to be used as input to INLET (Fig. B-3). A summary table gives the relative friction loss per foot of channel length for each cross section (Table B-2). This table shows which areas of the inlet are most important in dissipating friction; e.g., section 8 has the highest friction loss for the idealized inlet (Table B-2, Fig. B-4).

Table B-3 is a listing of the program NET including comments on program flow.

Output information from NET showing channel location (e.g., Fig. B-3) should be added to each cross section and channels drawn by connecting the channel location points (e.g., points A, B, C, D). If the cross sections are not perpendicular to the computed channel locations in high friction areas of the inlet, these cross sections can be redrawn and channel locations recomputed to obtain a more accurate flow net. However, this should not be necessary in most cases. Point A in Figure B-4 shows that section 1 is not perpendicular to flow and it should be redrawn if used in a model.

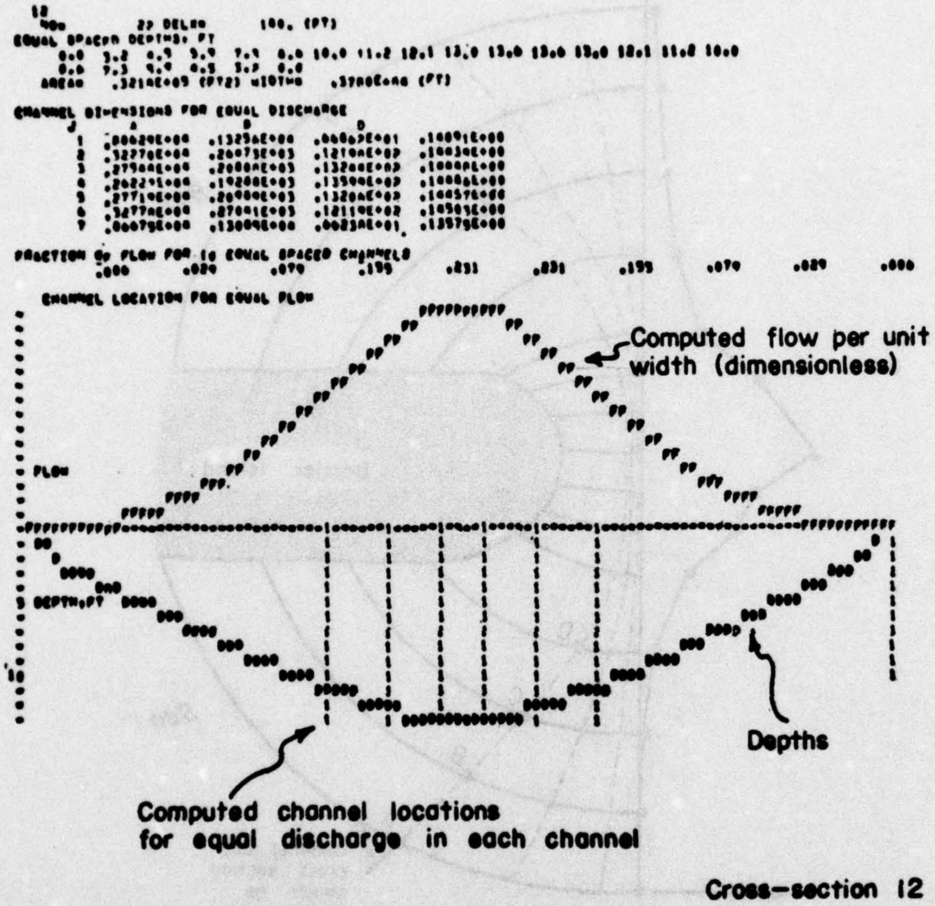


Figure B-3. Computed channel locations for a cross section using minimum friction weighting (output from program NET).

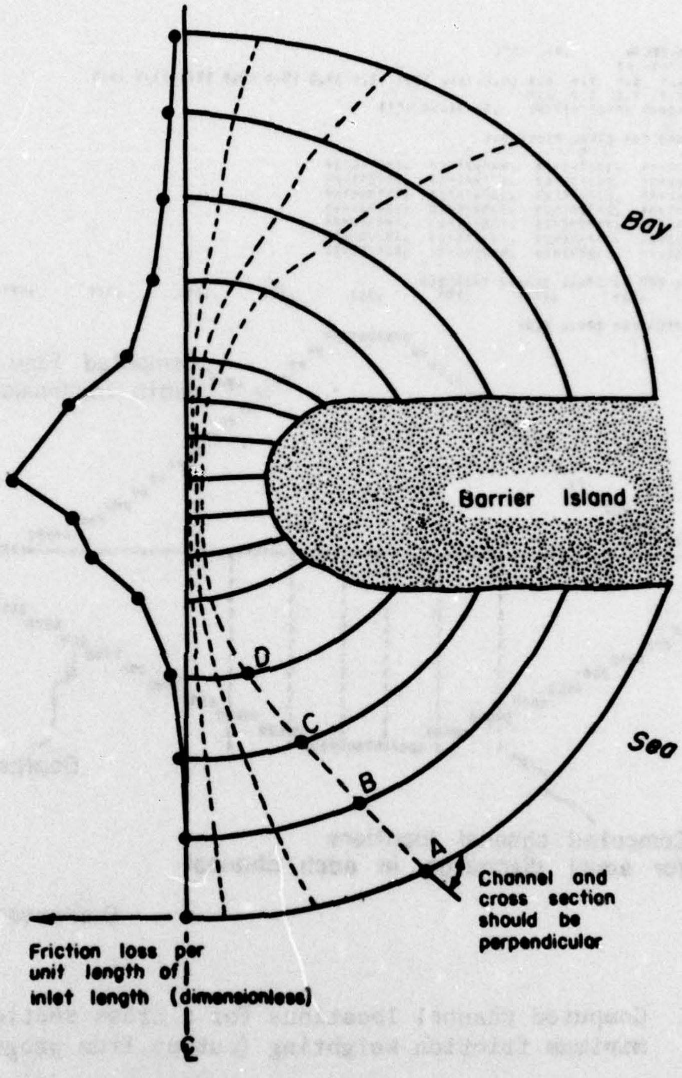


Figure B-4. Idealized inlet flow net and predicted friction loss along the inlet length (adapted from output from the computer program NET).

Table B-1. Input to the computer program NET.

Card	Format	Description
1	I10	Read the number of inlets to be input.
2	I10, F10.0	Read number of channels, inlet discharge (cubic feet per second).
3	I10, F10.0, A4	Read number of depth readings, spacing between depth readings (feet), title of section. Spacing of depth readings should be small enough so that linear interpolation between readings will adequately describe the bottom topography for each segment.
4	16F5.1	Read depths at equal spacing across the channel (feet). The first and last values should be 0.0 (at the waterline at each end of the section). Card type 4 is repeated as many times as necessary to read all the depth values for this section (e.g., for 20 depth readings there would be two card type 4's for that section).

NOTE.--For each cross section for an inlet repeat card types 3 and 4.

Place a blank card after the last cross section of an inlet to indicate the end of that inlet.

For each inlet repeat card types 2, 3, and 4.

Table B-2. Summary of friction losses.

Section	Loss/ft channel length (dimensionless)
1	0.206
2	0.398
3	0.699
4	1.845
5	5.740
6	11.298
7	13.057
8	21.451
9	14.598
10	14.222
11	6.860
12	4.360
13	2.471
14	1.695
15	1.100

Table B-3. Listing of the computer program NET.

```
PROGRAM NET           74/74    OPT=1                             FTN 4.6+420          10/13/77  14.44.05

            PROGRAM NET(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
            DIMENSION DP2(2000),C(2000),U(7),B(7),A(7),W(7),NS(7),DP(300)
            DIMENSION F(25),FLOW(10),DPT(100),FLOW2(100),IPLOT(102,51)
            DIMENSION XC(7),NCUR(7)
      C
      C PROGRAM TO AID CONSTRUCTION OF INLET FLOW NETS.  FLOW IS DISTRIBUTED BY
      C ASSUMING THAT FRICTION IS MINIMIZED.   SEE SEELIG, HARRIS AND HERCHENRODER,
      C 1977,(A GENERALIZED LUMPED PARAMETER MODEL OF INLET HYDRAULICS(, U.S.
      C ARMY COASTAL ENGINEERING RESEARCH CENTER, KINGMAN BUILDING, FT. BELVOIR,
      C VIRGINIA.
      C WORK UNIT F31019, GENERALIZED INVESTIGATION OF TIDAL INLETS.
      C THIS PROGRAM IS CATALOGED AS 720X6R1AGO(NET) IN THE CERC PROGRAM LIBRARY.
      C
      C NINLETS = NUMBERS OF INLETS TO BE COMPUTED
            READ(5,1) NINLET
            DO 999 IOU=1,NINLET
      C IC = NUMBER OF CHANNELS
      C Q = INLET DISCHARGE,CFS
            READ(5,1) IC,Q
       1    FORMAT(I10,F10.0,A4)
            WRITE(6,31) IC,Q
       31   FORMAT(1H1,5X,3HIC=,I10,3H Q=,F10.0)
            FSUM=0.
            IS=0
            WT=1.0/FLOAT(IC)
            WRITE(6,71) WT
       71   FORMAT(//,5X,34HWEIGHT OF EACH CHANNEL SHOULD BE =  ,F5.2)
       110  CONTINUE
      C FOR EACH CROSS-SECTION READ DEPTH DATA AND DETERMINE CHANNEL GRID SPACING
      C SO THAT FLOW IN EACH CHANNEL IS APPROXIMATELY EQUAL.  FLOW IS ASSUMED
      C TO BE DISTRIBUTED TO MINIMIZE FRICTION.
      C
      C READ CONTROL AND DEPTH INFORMATION FOR EACH CROSS-SECTION
      C ND = NUMBER OF DEPTH READINGS ACROSS THE CHANNEL
      C DELX = DISTANCE BETWEEN THE DEPTH READINGS, FT
      C ITITLE = FOUR CHARACTER TITLE OF SECTION
            READ(5,1) ND,DELX,ITITLE
            DO 109 I=1,10
       109  FLOW(I)=0.
            DO 1109 I=1,100
            DPT(I)=0.
       1109 FLOW2(I)=0.
            IF(ND.EQ.0) GO TO 198
            IS=IS+1
            WRITE(6,332)  IS
       332  FORMAT(1H1   ,2X,I3)
            WRITE(6,32) ND,DELX,ITITLE
       32   FORMAT(5X,3HND=,I10,6H DELX=,F10.0,5H (FT),2X,8HSECTION  ,A4)
      C DP = EQUALLY SPACE DEPTH READINGS ACROSS THE CHANNEL, FT
            READ(5,2) (DP(I),I=1,ND)
       2    FORMAT(16F5.1)
            DO 3370 I=1,ND
       3370 DP(I)=DP(I)+2.
```

```
      WRITE(6,133)
 133  FORMAT(2X,23HEQUAL SPACED DEPTHS, FT)
      WRITE(6,33) (DP(I),I=1,ND)
 33   FORMAT(5X,16F5.1)
      AREA=0.
      NDM1=ND-1
      DO 231 I=1,NDM1
      J=I+1
 231  AREA=AREA+DELX*(DP(I)+DP(J))/2.
      WIDTH=DELX*(FLOAT(NDM1))
      WRITE(6,232) AREA,WIDTH
 232  FORMAT(5X,5HAREA=  ,E12.4,6H (FT2)  ,7H WIDTH=  ,F12.4,5H (FT)  )
C
C CONVERT EQUAL DISTANCE SPACED DEPTH READINGS TU 2000 EQUAL DISTANCE SPACED
C DEPTH READINGS HY LINEAR INTERPOLATION
      DELX2=DELX*FLOAT(ND-1)/1999.
      DP2(1)=0.
      DP2(2000)=0.
      DO 140 I=2,1999
      DIS=FLOAT(I-1)*DELX2
      J1=DIS/DELX
      DELD=DIS-FLOAT(J1)*DELX
      J1=J1+1
      J2=J1+1
      DP2(I)=DP(J1)+((DP(J2)-DP(J1))/DELX)*DELD
      IF(DP2(I).LE.0.0) WRITE(6,191) I,DP2(I)
 191  FORMAT(5X,8HDP2.LE.0  ,2X,I3,2X,E12.4)
      IF(DP2(I).LE.0.0) DP2(1)=1.
 140  CONTINUE
      CSUM=0.
C
C COMPUTE MEAN DEPTHS AND WEIGHTS OF EACH OF 1999 SECTIONS
      DO 141 I=2,2000
      J=I-1
      DP2(J)=(DP2(I)+DP2(J))/2.
      XN=0.03777-0.000067*DP2(J)
      IF(XN.LT.0.01) XN=0.01
      AREA=DP2(J)*DELX2
      C(J)=AREA**2.*DP2(J)**0.3333/(XN**2.*0**2.*DELX2)
 141  CSUM=CSUM+C(J)
      DO 358 J=1,1999
      C(J)=C(J)/CSUM
      ISUB=(J-1)/200+1
      FLOW(ISUB)=FLOW(ISUB)+C(J)
C SAVE INFORMATION FOR 100 GRIDS ACROSS FOR A PRINTER PLOT
      ISUB2=(J-1)/20+1
      FLOW2(ISUB2)=FLOW2(ISUB2)+C(J)*100.
      DPT(ISUB2)=DPT(ISUB2)+DP2(J)/19.99
 358  CONTINUE
C COMPUTE CHANNEL DIMENSIONS SO THAT EACH CHANNEL HAS EQUAL DISCHARGE.
      DO 1102 I=1,7
      NS(I)=0
      A(I)=0.
```

```
      W(I)=0.
 1142 B(I)=0.
C FIRST ESTIMATE
      J=1
      DO 142 I=1,1999
      NS(J)=NS(J)+1
      A(J)=A(J)+DP2(I)*DELX2
      B(J)=B(J)+DELX2
      W(J)=W(J)+C(I)
      IF(W(J).GE.WT) J=J+1
      IF(J.GT.IC) WRITE(6,134)
  134 FORMAT(5X,7HJ ERROR )
  142 CONTINUE
C ITERATE TO ESTIMATE CHANNEL LOCATIONS
      NIT=50
      DO 1010 IPS=1,NIT
      CCS=0.
      DO 241 J=1,IC
      D(J)=A(J)/B(J)
      XN=0.0377-0.000667*D(J)
      IF(XN.LE.0.01) XN=0.01
      W(J)=A(J)**2.*D(J)**0.3333/(XN**2.*B(J))
  241 CCS=CCS+W(J)
      DO 242 J=1,IC
  242 W(J)=W(J)/CCS
C DETERMINE NUMBER OF WIDTHS TO CORRECT EACH CHANNEL
C CARE IS TAKEN TO CORRECTLY ROUND THE NUMBERS TO OBTAIN 1999 WIDTH CELLS
      XMAX=-1000000.
      XMIN=1000000.
      ERROR=0.
      DO 2234 J=1,IC
      ER=ABS(W(J)-WT)*100.
      IF(ER.GT.ERROR) ERROR=ER
      XC(J)=(W(J)-WT)*1999.+0.2
      IF(XC(J).GT.XMAX) JMAX=J
      IF(XC(J).GT.XMAX) XMAX=XC(J)
      IF(XC(J).LT.XMIN) JMIN=J
 2234 IF(XC(J).LT.XMIN) XMIN=XC(J)
      NCC=0
      DO 2235 J=1,IC
      NCOR(J)=XC(J)
 2235 NCC=NCC+NCOR(J)
      IF(NCC.LT.0) NCOR(JMIN)=NCOR(JMIN)-NCC
      IF(NCC.GT.0) NCOR(JMAX)=NCOR(JMAX)-NCC
      I=0
      DO 234 J=1,IC
      A(J)=0.
      B(J)=0.
      NS(J)=NS(J)-NCOR(J)
      IF(NS(J).LT.1) NS(J)=1
      NN=NS(J)
      DO 233 L=1,NN
      I=I+1
```

```
      IF(I.GT.1999) GO TO    233
      A(J)=A(J)+DP2(I)*DELX2
      B(J)=B(J)+DELX2
  233 CONTINUE
  234 CONTINUE
      IF(ERROR.LT.0.3) GO TO 1011
 1010 CONTINUE
C WRITE CHANNEL DIMENSIONS
 1011 WRITE(6,361)
  361 FORMAT(/,2X,39HCHANNEL DIMENSIONS FOR EQUAL DISCHARGE    )
      WRITE(6,1123)
 1123 FORMAT(  8X,1HJ,8X,1HA,12X,1HB,12X,1HD)
      DO 146 J=1,IC
      WRITE(6,147) J,A(J),B(J),D(J),W(J)
  147 FORMAT(5X,I5,4E12.5)
  146 CONTINUE
C COMPUTE AND WRITE THE FRACTION OF FLOW IF THE INLET IS DIVIDED INTO 10
C EQUAL SPACED CHANNELS.
      WRITE(6,362)
  362 FORMAT(/,2X,45HFRACTION OF FLOW FOR 10 EQUAL SPACED CHANNELS      )
      WRITE(6,367) (FLOW(IP),IP=1,10)
  367 FORMAT(  5X,10F10.3)
C PRINTER PLOT DEPTHS AND PREDICTED RELATIVE DISCHARGE ACROSS THE CHANNEL
      DO 601 I=1,102
      DO 602 J=1,51
      IPLOT(I,J)=1H
  602 CONTINUE
  601 CONTINUE
      DO 603 I=2,102
  603 IPLOT(I,16)=1H-
      DO 604 J=1,51
  604 IPLOT(2,J)=1H-
      NN=2
      DO 609 J=1,IC
      NN=NN+(10+NS(J))/20
      IF(NN.GT.102) NN=102
      DO 610 JJ=16,51
  610 IPLOT(NN,JJ)=1HI
  609 CONTINUE
      FMAX=0.
      DO 612 I=1,100
  612 IF(FLOW2(I).GT.FMAX) FMAX=FLOW2(I)
      IDMAX=16
      DO 605 I=1,100
      IID=I+2
      ID=DPT(I)+16
      IF(ID.LT.1.OR.ID.GT.51) ID=51
      IF(ID.GT.IDMAX) IDMAX=ID
      IPLOT(IID,ID)=1HD
      ID=17.-FLOW2(I)/FMAX*16.
      IF(ID.LT.1.OR.ID.GT.51) ID=1
  605 IPLOT(IID,ID)=1HF
      WRITE(6,608)
```

```
  608  FORMAT(/,5X,31HCHANNEL LOCATION FOR EQUAL FLOW  )
       IPLOT(2,21)=1H5
       IPLOT(1,26)=1H1
       IPLOT(2,26)=1H0
       IPLOT(1,31)=1H1
       IPLOT(2,31)=1H5
       IPLOT(1,36)=1H2
       IPLOT(2,36)=1H0
       IPLOT(1,41)=1H2
       IPLOT(2,41)=1H5
       IPLOT(1,46)=1H3
       IPLOT(2,46)=1H0
       IPLOT(1,51)=1H3
       IPLOT(2,51)=1H5
       IPLOT(4,12)=1HF
       IPLOT(5,12)=1HL
       IPLOT(6,12)=1HO
       IPLOT(7,12)=1HW
       IPLOT(4,21)=1HD
       IPLOT(5,21)=1HE
       IPLOT(6,21)=1HP
       IPLOT(7,21)=1HT
       IPLOT(8,21)=1HH
       IPLOT(9,21)=1H,
       IPLOT(10,21)=1HF
       IPLOT(11,21)=1HT
       DO 606 J=1,IDMAX
  606  WRITE(6,607) (IPLOT(I,J),I=1,102)
  607  FORMAT(1X,102A1)
       F(IS)=0.
       DO 681 J=1,IC
       XN=0.03777-0.000667*D(J)
       F(IS)=F(IS)+XN*XN*Q*Q*B(J)/(A(J)**2.*D(J)**0.3333)
  681  CONTINUE
       FSUM=FSUM+F(IS)
       GO TO 110
  198  CONTINUE
C WRITE A SUMMARY TABLE OF THE RELATIVE FRICTION LOSS PER FOOT OF CHANNEL
C LENGTH FOR ALL SECTIONS OF THE INLET.
       WRITE(6,196)
  196  FORMAT(///,5X,26HSUMMARY OF FRICTION LOSSES  ,/,2X,7HSECTION  ,
      1 5X,38HLOSS/FT CHANNEL LENGTH (DIMENSIONLESS)  ,/)
       DO 197 I=1,IS
       F(I)=F(I)/FSUM*100.
       WRITE(6,199) I,F(I)
  199  FORMAT(6X,I2,12X,F9.3)
  197  CONTINUE
  999  CONTINUE
       STOP
       END
```

A suggested flow net grid system which includes important friction zones of the idealized inlet is shown in Figure B-5.

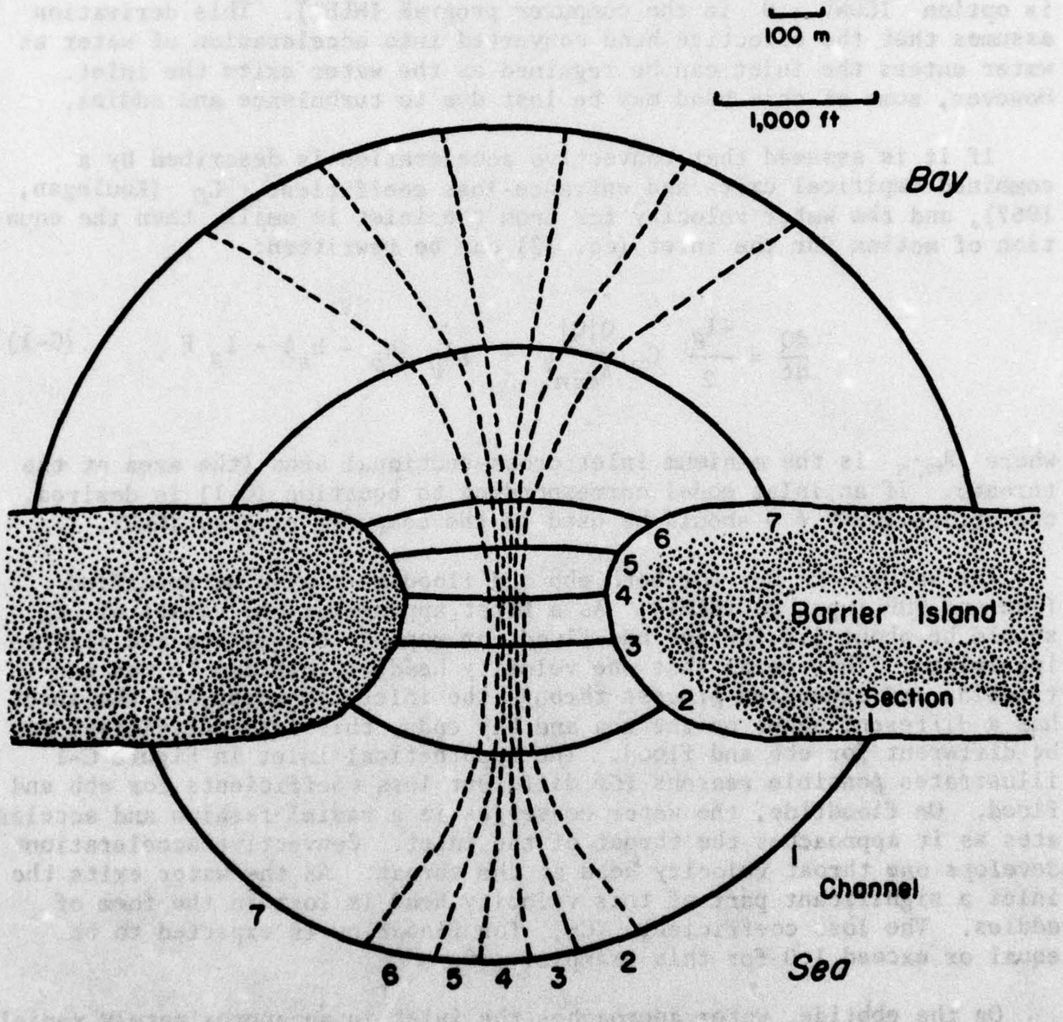


Figure B-5. A suggested grid cell system for the idealized inlet (seven channels and eight cross sections).

APPENDIX C

ALTERNATIVE DEVELOPMENT OF THE CONVECTIVE ACCELERATION TERM

In equation (1) it was assumed that the convective acceleration term could be integrated along the length of the inlet. The resulting expression for convective acceleration is $1/2\ (1/A_b^2 - 1/A_s^2)$ (see eq. 6, this is option ICONV = 0 in the computer program INLET). This derivation assumes that the effective head converted into acceleration of water as water enters the inlet can be regained as the water exits the inlet. However, some of this head may be lost due to turbulence and eddies.

If it is assumed that convective acceleration is described by a combined empirical exit- and entrance-loss coefficient, C_D (Keulegan, 1967), and the water velocity far from the inlet is small, then the equation of motion for the inlet (eq. 12) can be rewritten:

$$\frac{dQ}{dt} = \frac{-I_g}{2} C_D \frac{Q|Q|}{A_{min}{}^2} - gI_g (h_b - h_s) - I_g F \qquad \text{(C-1)}$$

where A_{min} is the minimum inlet cross-sectional area (the area at the throat). If an inlet model corresponding to equation (C-1) is desired, the option ICONV ≠ 0 should be used in the computer program INLET.

The values of C_D for both ebb and flood must also be specified (CDE and CDF input to INLET). As a first approximation, values of C_D should be about 1.0 for ebb and flood for rapidly converging and diverging inlets. This means that one velocity head is lost due to the contraction and expansion process through the inlet. However, if the inlet has a different shape on the sea and bay ends, this loss coefficient may be different for ebb and flood. The hypothetical inlet in Figure C-1 illustrates possible reasons for different loss coefficients for ebb and flood. On floodtide, the water converges in a radial fashion and accelerates as it approaches the throat of the inlet. Convective acceleration develops one throat velocity head at the throat. As the water exits the inlet a significant part of this velocity head is lost in the form of eddies. The loss coefficient, C_D, for floodflow is expected to be equal or exceed 1.0 for this example.

On the ebbtide, water approaches the inlet in an approximately radial fashion and then diverges slowly due to the funnel shape of the seaside of the inlet. This pattern of flow causes little head loss due to eddies, so a significant part of head converted into acceleration of water on entrance is regained as the flow exits the inlet. The value of C_D for this flow condition is expected to be less than 1.0.

As a first approximation values of C_D for ebb and flood can be taken as 1.0 for rapidly converging inlets. These loss coefficients can

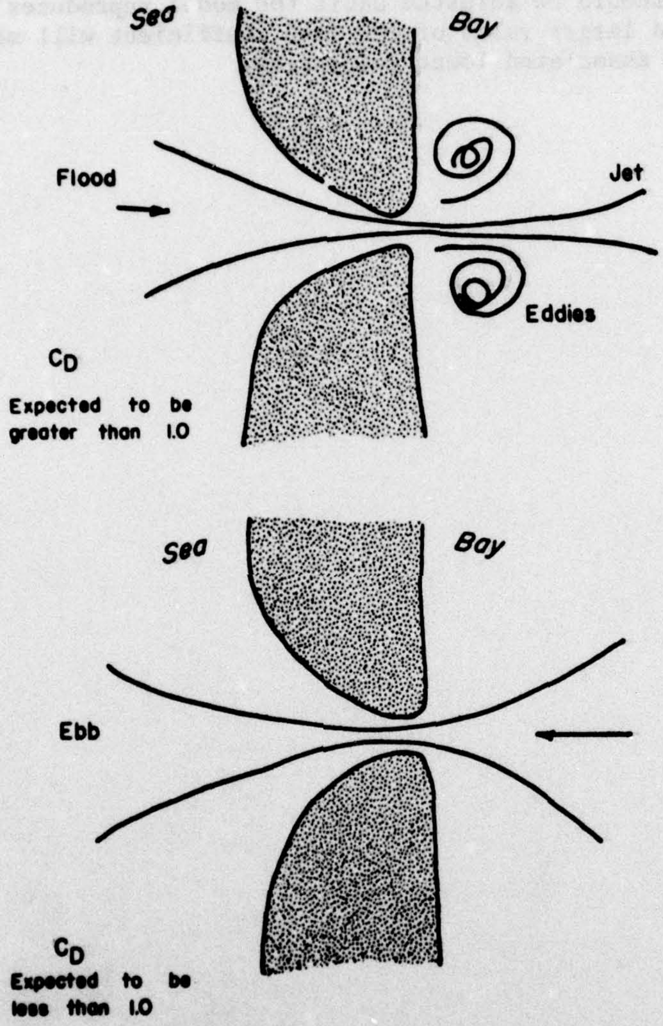


Figure C-1. Flood and ebb convective losses for a hypothetical inlet.

then be adjusted during calibration to account for differences in ebb flow and floodflow. For example, if in the prototype flood velocities are lower than ebb velocities, the values of the ebb- and flood-loss coefficients should be adjusted until the model reproduces observed velocities. A larger value of the loss coefficient will mean a greater head loss and associated lower velocities.

APPENDIX D

COMPUTER PROGRAM (INLET) DOCUMENTATION

1. Program Description.

The numerical model to predict inlet hydraulics described in the text is programed in FORTRAN for a CDC 6600 computer. The simultaneous differential equations are solved using a variable time step Runge-Kutta-Gill marching procedure. The organization of the computer program is shown in Figure D-1. The following is a brief description of each routine:

INLET is the main routine which controls input-output and calls subroutines to execute a specific task. Figure D-1 summarizes control throughout the program. Variable names in the program corresponding to symbols used in the text are given in Symbols and Definitions. The program is organized to accept up to three inlets connecting the bay to the sea, up to seven channels for each inlet, and up to eight cross sections (seven grids long).

Subroutine HELM uses an iterative method of estimating the natural pumping period or Helmholtz period, T_H', for the inlet-bay system by neglecting friction in the inlet to give

$$T_H' = 2\pi \sqrt{\frac{(L_{in} + L')\, A_{bay}}{g A_c}} \,, \qquad \text{(D-1)}$$

where L' is added inlet length due to radiation, and given by:

$$L' = \frac{-B}{\pi} \ln \left(\frac{\pi B}{\sqrt{gd}\; T_H} \right) \qquad \text{(D-2)}$$

Subroutine RKGS is a routine to solve simultaneous differential equations. This subroutine was adapted from the Scientific Subroutine Package (International Business Machines, 1970).

Subroutine SETEQ evaluates the right-hand side of the equation of motion, one for each inlet, and the continuity equation between the inlet and bay for each time step. This routine also evaluates the relative rank of the four terms in the equation of motion for flow in each inlet.

Subroutine LEVEL determines the water level in the grids at each time step. The routine interpolates the level between the sea and bay based on the relative amount of friction in each grid cell.

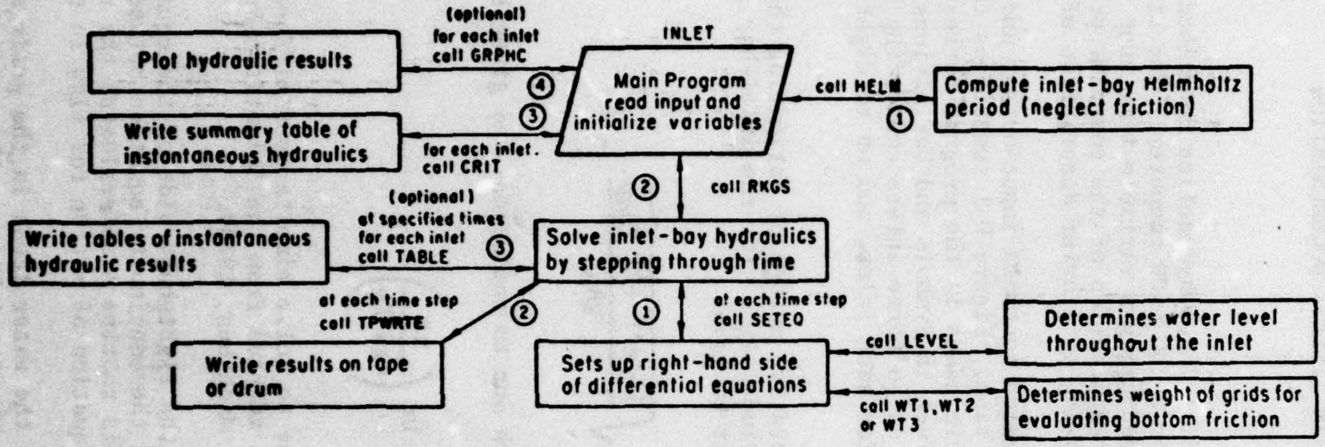


Figure D-1. Flow chart of the computer program (INLET).

Subroutine TPWRTE writes hydraulic results from each time step on a tape or disc, so that this information can be used later by the output routines.

Subroutine TABLE outputs a table of instantaneous hydraulics each time the routine is called.

Subroutine SEA determines the water level in the sea as a function of time either for a given sine wave or by interpolating equal time-series data.

Subroutine WT1 determines the grid weighting function by assuming that the flow is distributed across each section so that friction is minimized. This routine allows flow to cross channel boundaries, but assumes that this flow will be small, so the flow is neglected in the equation of motion. See Appendix A for a derivation of the procedure used in this routine.

Subroutine WT2 is similar to WT1, except that flow is not allowed to cross channel boundaries, and the flow is distributed in each channel so that friction is minimized.

Subroutine WT3 determines the weighting function so that flow is distributed equally in all grids. This is generally unrealistic, since it will be difficult to visually draw this grid system. However, this routine is useful since it provides an upper limit on frictional effects and therefore gives a lower limit of bay levels and inlet velocities. This weighting can be used to model simple geometry inlets where only one channel is used to represent the inlet.

Subroutine CRIT prints a table of critical instantaneous hydraulics (i.e., at high water, low water, maximum velocity, and maximum discharge). This table is determined by storing a summary of conditions for each time step, then scanning this list for critical values (routine adapted from Huval and Wintergerst, 1977).

Subroutine GRPHC plots mean inlet hydraulics by scaling hydraulics in storage and plotting the time interval requested on a digital x-y pen plotter (adapted from Huval and Wintergerst, 1977).

Subroutine READIN is used by GRPHC to read data in storage and scale values for plotting (adapted from Huval and Wintergerst, 1977).

2. Input.

The computer program INLET requires the following input, one deck for each inlet-bay system:

Card Type	Variables	Format	Description
1	ALABL1	4A10	First line of title
	ALABL2	4A10	Second line of the title
2		5I10, 2F10.5, I10	
	NINLET		Number of inlets
	IPLOT		=1 for plot of results
	IWT		Weighting type =1 flow distributed to minimize friction at each section =2 flow distributed in each channel to minimize friction =3 equal flow in channels
	ITABLE		=1 for tables of instantaneous hydraulics
	C1, C2		Manning's n evaluated by: n = C1 - C2 * D; where D is stillwater depth. If blank, default values of C1 = 0.03777 and C2 = 0.000667 are assumed.
	ICONV		ICONV = 0 for convective acceleration as derived in the text ICONV ≠ 0 for alternative derivation (see App. C).
3		3F10.5, E10.4, 3F10.5, 2F5.1	
	T		Forcing period, hours
	DELT		Approximate time increment
	AO		Forcing wave amplitude (feet)
	AB		Bay area at datum (square feet)
	BETA		Bay area variation parameter
	ZETA		Inlet side slope D (z)/D(y)

Card Type	Variables	Format	Description
	QINFLO		Bay inflow from sources other than the inlet (cubic feet per second)
	CDF		An empirical flood-loss coefficient
	CDE		An empirical ebb-loss coefficient
4		2I10, F10.0	
	IC		Number of channels
	IS		Number of cross sections
	QINT		Estimated inlet discharge at the time the model starts
5	(one card per section)	10X, 7F10.5	
	A'		Cell cross-sectional areas at the ends of each cell at datum (square feet) (see Fig. B-2)
6	(one card per section)	10X, 7F10.5	
	B'		Grid cell widths for the end of each cell (feet) (see Fig. 2)
7	(one less card than sections)	10X, 7F10.5	
	L'		Lengths of the sides of cells (see Fig. 2) (one less card than number of sections, one more value per card than the number of channels)

For card types 5, 6, and 7 there will be one card for each cross section of the inlet. The first card will be for the first cross section, i.e., the section closest to the sea; the last section is adjacent to the bay. The first value on each card will correspond to the first channel

Card Type	Variables	Format	Description
which is adjacent to land, and the last value on a card will be for the last channel, which is also adjacent to land (Fig. 2).			
(FOR MORE THAN ONE INLET CONNECTING THE BAY TO THE SEA REPEAT CARD TYPES 3 TO 7 FOR EACH ADDITIONAL INLET).			
8	TDEL	34X, F6.2	Water level sampling interval (minutes)
	NPTS	6X, I3	Number of sample points = 0 for no data
9	(optional-no cards if NPTS = 0 from card type 8)		
	Y		Eight water level values per card, as many cards to include NPTS points; start the model at a time when the sea level is zero. Use 25 or more points per forcing cycle for best results (i.e., levels at 30- or 15-minute intervals for a 12-hour tide).
10	(optional-two plot cards, first card used only if IPLOT = 1 on card type 1)		
		8F10.5/,3F10.5, I10	
	XO		Starting time of plot (hours)
	XF		Ending time of plot (hours)
	SCALX		Time scale (hours per inch)
	YLO		Minimum value of water levels (feet)
	YL		Overall height of plot (inches)
	YLSCAL		Scale of water level height (feet per inch)
	YRO		Minimum flows (thousands cubic feet per second)
	YRSCAL		Scale of flows (thousands cubic feet per second per inch)

Card Type	Variables	Format	Description
Second card	YVO		Minimum velocity (feet per second)
	YVSCAL		Scale of velocities (feet per second per inch)
	SCALE		Scale factor for total plot size
	IQ		IQ = 0 for no plot of inlet discharge

11 If a plot is requested, repeat card types 8 and 9 for observed bay levels to compare with predictions (card type 8 required; use NPTS = 0 for no observed bay levels). Only one set of card types 10 and 11 will be required for plotting even though the system modeled may have more than one inlet.

12 End of file card.

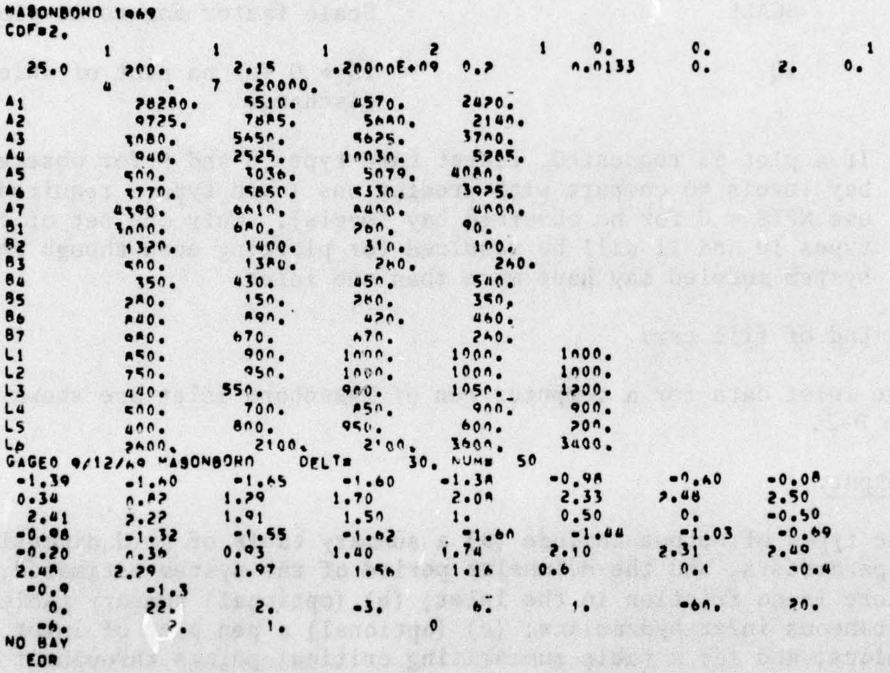
The inlet data for a computer run of Masonboro Inlet are shown in Figure D-2.

3. Output.

The types of output include (a) a summary table of grid dimensions, input parameters, and the Helmholtz period of the system estimated, assuming there is no friction in the inlet; (b) (optional) summary tables of instantaneous inlet hydraulics; (c) (optional) a pen plot of inlet hydraulics; and (d) a table summarizing critical points throughout model operation, such as high water, low water, point of maximum discharge, and maximum velocity. Samples of input and output for the Masonboro run are given in Figures D-3, D-4, and D-5. The computer plot is included in the text (Fig. 15).

4. Computer Program.

A listing of the computer program INLET follows the sample output (Table D-5). The program was written in FORTRAN IV for a CDC 6600 computer with plotter. Control cards, plotting instructions, and file controls may have to be changed for other computers. If no plotter is available, the subroutine GRPHC and the call to the subroutine in the main program may be removed.



```
MASONBORO 1969
CDF=2.
        1           1           1           2           1   0.          0.          1
 25.0     200.      2.15    .20000E+09  0.2        0.0133     0.       2.      0.
       4     .     7  -20000.
A1          28280.     5510.     4570.      2420.
A2           9725.     7885.      5680.      2140.
A3          3080.     5450.      9625.      3700.
A4           940.     2525.     10030.      5285.
A5          500.       3036.      5079.    4080.
A6          3770.      5850.     5330.    3925.
A7         4390.      6610.      8400.      4000.
B1         3000.      680.       260.     90.
B2          1320.      1400.      310.     100.
B3          500.       1380.       260.       260.
B4           350.     430.       450.       540.
B5          280.       150.      280.       350.
B6          840.       890.       420.      460.
B7          980.      670.       670.       240.
L1          850.       900.      1000.     1000.      1000.
L2          750.       950.      1000.     1000.      1000.
L3          440.     550.       900.      1050.      1200.
L4          500.       700.      850.       900.       900.
L5          400.      800.      950.       600.       200.
L6          2600.      2100.     2100.     3600.      3400.
GAGEO 9/12/69 MASONBORO    DELT=      30. NUM=  50
 -1.39      -1.60      -1.65      -1.60      -1.38      -0.98      -0.60      -0.08
 0.34       0.82      1.29       1.70       2.09       2.33       2.48       2.50
  2.41      2.22      1.91       1.50       1.         0.50       0.         -0.50
 -0.98      -1.32      -1.55      -1.62       -1.60      -1.44      -1.03     -0.69
 -0.20      0.36      0.93       1.40       1.74       2.10       2.31       2.49
 2.48      2.29       1.97       1.56       1.16       0.6        0.1         -0.4
  -0.9       -1.3
    0.       22.       2.        -3.        6.         1.         -60.       20.
   -6.        2.       1.                  0
NO BAY
 EOR
```

Figure D-2. Sample of input data for a computer run of Masonboro Inlet, North Carolina.

```
------------------------
      MASONBORO 1969
      TEST

    CONTROL CARDS
         1          1          0          2          1  0.00000    0.00000      1
 25.00000 200.00000  2.15000 .2000E+09   .20000    .01330  0.00000  2.0  0.0

    SUMMARY OF INLET GRID CHARACTERISTICS
              INLET NUMBER  1
       4        6

SECTION  1
    CHANNEL #          1          2          3          4
    AREA(FT2)    19002.5     6697.5     5125.0     2280.0
    WIDTH(FT)     2160.0     1040.0      285.0       95.0
    DEPTH(FT)       8.80       6.44      17.98      24.00
    LEN(FT)        875.0      950.0     1000.0     1000.0
    N              .0319      .0335      .0258      .0218

SECTION  2
    CHANNEL #          1          2          3          4
    AREA(FT2)     6402.5     6767.5     5652.5     2920.0
    WIDTH(FT)      910.0     1390.0      295.0      180.0
    DEPTH(FT)       7.04       4.87      19.16      16.22
    LEN(FT)        850.0      975.0     1000.0     1000.0
    N              .0331      .0345      .0250      .0269

SECTION  3
    CHANNEL #          1          2          3          4
    AREA(FT2)     2010.0     4087.5     7827.5     4492.5
    WIDTH(FT)      425.0      905.0      365.0      400.0
    DEPTH(FT)       4.73       4.52      21.45      11.23
    LEN(FT)        495.0      725.0      975.0     1125.0
    N              .0346      .0348      .0235      .0303

SECTION  4
    CHANNEL #          1          2          3          4
    AREA(FT2)      720.0     2780.5     7556.5     4682.5
    WIDTH(FT)      315.0      290.0      365.0      445.0
    DEPTH(FT)       2.29       9.59      20.70      10.52
    LEN(FT)        600.0      775.0      875.0      900.0
    N              .0362      .0314      .0240      .0308

SECTION  5
    CHANNEL #          1          2          3          4
    AREA(FT2)     2135.0     4443.0     5204.5     4002.5
    WIDTH(FT)      560.0      920.0      350.0      405.0
    DEPTH(FT)       3.81       8.54      14.87       9.88
    LEN(FT)        600.0      875.0      775.0      400.0
    N              .0352      .0321      .0279      .0312

SECTION  6
    CHANNEL #          1          2          3          4
    AREA(FT2)     4080.0     6230.0     6869.0     3962.5
    WIDTH(FT)      910.0      780.0      565.0      360.0
    DEPTH(FT)       4.48       7.99      12.00      11.01
    LEN(FT)       2350.0     2100.0     2050.0     3800.0
    N              .0348      .0324      .0294      .0304
FORCING PERIOD=  25.00 HOURS
THELM(APPROX)=    3.17 HOURS
TF/TM=            7.88
INLET LENGTH  ADDED LENGTH
    1 6622.5  1749.4


    TDEL, MIN=   30.00   NPTS=   50

   -1.39 -1.60 -1.65 -1.60 -1.38  -.98  -.60  -.08   .34   .82  1.29  1.70  2.08  2.33  2.48  2.50
    2.41  2.22  1.91  1.50  1.00   .50  0.00  -.50  -.98 -1.32 -1.55 -1.62 -1.60 -1.44 -1.03  -.69
    -.20   .36   .93  1.40  1.74  2.10  2.31  2.49  2.48  2.29  1.97  1.56  1.16   .60   .10  -.40
    -.90 -1.30
```

Figure D-3. Sample output from INLET (summary table for Masonboro Inlet input data).

```
----------------------------
   TIME, HOURS =    6.000    DELT, SEC =  400.00

        INLET  1
        SEA LEVEL,FT=    2.08
        BAY LEVEL,FT=    1.23
        DISCHARGE,CFS= .5481E+05
        BAY AREA= .2493E+09 FT2
CHANNEL          SECTION 1          2          3          4          5          6          7  FRICTION
       FRIC            .04        .06        .07        .42        .11        .31
    1                                                                                           .12
    1  LEVEL          2.08       2.08       2.06       1.70       1.32       1.26
    1  V(FPS)          .12        .33        .94       2.14        .96        .53
    1  Q(CFS)        2802.      2802.      2802.      2802.      2802.      2802.
    1  WEIGHT          .05        .05        .05        .05        .05        .05
    1  FRIC            .00        .00        .00        .10        .01        .01
    2                                                                                           .19
    2  LEVEL          2.06       2.02       1.94       1.66       1.39       1.29
    2  V(FPS)         1.01        .93       1.52       2.71       1.73       1.24
    2  Q(CFS)        8993.      8993.      8993.      8993.      8993.      8993.
    2  WEIGHT          .16        .16        .16        .16        .16        .16
    2  FRIC            .01        .01        .02        .10        .02        .03
    3                                                                                           .46
    3  LEVEL          2.06       2.00       1.95       1.83       1.67       1.42
    3  V(FPS)         5.40       4.98       3.63       3.77       5.35       4.07
    3  Q(CFS)       31238.     31238.     31238.     31238.     31238.     31238.
    3  WEIGHT          .57        .57        .57        .57        .57        .57
    3  FRIC            .03        .03        .02        .11        .07        .20
    4                                                                                           .23
    4  LEVEL          2.07       2.04       1.98       1.75       1.54       1.37
    4  V(FPS)         4.60       3.50       2.20       2.13       2.52       2.62
    4  Q(CFS)       11772.     11772.     11772.     11772.     11772.     11772.
    4  WEIGHT          .21        .21        .21        .21        .21        .21
    4  FRIC            .00        .01        .02        .10        .01        .08
   TEMP ACC=      .6 CONV ACC=   32.4 HEAD= -100.0 FRIC=   67.0
   MEAN VELOCITY AT THE MINIMUM AREA SECTION=   2.97 FT/SEC  AMIN= 18429.73 FT2
----------------------------
```

Figure D-4. Sample output from INLET (summary table of instantaneous hydraulics for Masonboro after 6 hours of model time).

```
           SUMMARY TABLE OF HYDRAULICS  INLET     1
  TIME       HS      INFLOW      HB       VEL        Q
   HRS       FT       KCFS       FT       FPS      KCFS

   .334   -1.906     0.000     -.239   -3.061*   -55.166*
  1.056   -1.650*    0.000     -.951   -2.919    -39.568
  2.167   -1.303     0.000    -1.562*    .053       .683
  3.834     .155     0.000     -.541    2.463*    37.947
  3.945     .245     0.000     -.456    2.481*    38.631
  5.167    1.386     0.000      .516    2.922*    50.286
  5.389    1.568     0.000      .698    2.940*    51.646
  5.500    1.656     0.000      .788    2.945*    52.193
  5.611    1.744     0.000      .878    2.948*    52.656
  5.723    1.834     0.000      .967    2.957*    53.252
  5.834    1.922     0.000     1.056    2.968*    53.884
  5.945    2.005     0.000     1.145    2.976*    54.441
  6.056    2.080     0.000     1.234    2.974*    54.806
  6.167    2.146     0.000     1.321    2.958*    54.889*
  7.389    2.506*    0.000     2.147    2.156     41.977
  8.389    2.296     0.000     2.462*    .088      1.714
 10.611     .444     0.000     1.191   -3.308    -55.734*
 10.667     .389     0.000     1.146   -3.337*   -55.713
 10.778     .278     0.000     1.055   -3.362*   -55.607
 10.889     .166     0.000      .962   -3.382*   -55.425
 11.000     .055     0.000      .869   -3.398*   -55.177
 11.111    -.056     0.000      .774   -3.411*   -54.870
 11.223    -.168     0.000      .679   -3.422*   -54.519
 11.334    -.279     0.000      .582   -3.429*   -54.126
 11.445    -.391     0.000      .485   -3.433*   -53.680
 11.556    -.500     0.000      .387   -3.433*   -53.170
 11.667    -.611     0.000      .288   -3.430*   -52.606
 11.778    -.723     0.000      .188   -3.427*   -52.037
 11.889    -.831     0.000      .087   -3.420*   -51.412
 12.000    -.933     0.000     -.014   -3.403*   -50.657
 13.723   -1.625*    0.000    -1.418   -1.764    -22.758
 14.445   -1.495     0.000    -1.665*   -.073      -.923
 15.389    -.912     0.000    -1.245    1.880*    25.949
 17.278    1.153     0.000      .185    2.994*    50.979
 17.389    1.257     0.000      .283    3.020*    52.006
 17.500    1.354     0.000      .382    3.036*    52.865
 17.667    1.484     0.000      .520    3.049*    53.400*
 17.778    1.559     0.000      .625    3.002*    53.485
 17.834    1.595     0.000      .672    3.004     53.720*
 17.889    1.630     0.000      .719    3.033*    53.719
 18.056    1.740     0.000      .858    2.996     53.442*
 18.111    1.780     0.000      .904    2.973*    53.488
 18.223    1.864     0.000      .994    2.965*    53.749
 18.334    1.949     0.000     1.083    2.967*    54.204
 18.445    2.030     0.000     1.172    2.969*    54.648
 18.556    2.100     0.000     1.240    2.962     54.803*
 19.778    2.508*    0.000     2.099    2.267     44.163
 20.723    2.196     0.000     2.416*   -.016      -.312
 21.778    1.390     0.000     1.904   -2.904*   -52.620*
 21.889    1.305     0.000     1.827   -2.921*   -52.545
 22.000    1.211     0.000     1.750   -2.942    -52.477*
 22.778     .373     0.000     1.157   -3.394*   -56.639*
 22.889     .264     0.000     1.064   -3.415*   -56.470*
 23.000     .155     0.000      .970   -3.429*   -56.184
 23.111     .044     0.000      .876   -3.440*   -55.836
 23.223    -.067     0.000      .780   -3.449*   -55.460
 23.334    -.178     0.000      .684   -3.456*   -55.044
 23.445    -.289     0.000      .587   -3.459*   -54.588
 23.556    -.400     0.000      .489   -3.461*   -54.092
 23.667    -.513     0.000      .390   -3.461*   -53.574
 23.778    -.628     0.000      .290   -3.463*   -53.063
 23.889    -.741     0.000      .189   -3.462*   -52.518
 24.000    -.849     0.000      .087   -3.454*   -51.870
 24.111    -.951     0.000     -.015   -3.435*   -51.063
 24.223   -1.052     0.000     -.117   -3.409*   -50.167
 25.000   -1.390*    0.000     -.855   -2.599    -35.948

   * CRITICAL POINT VALUE
```

Figure D-5. Sample output from INLET (table of critical points for the model time: high water, low water, etc., for Masonboro Inlet).

Table D-1. Listing of the computer program INLET.

```
      PROGRAM INLET(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE9,TAPE10,  INLET
     1 TAPE3,PUNCH=TAPE3)                                                INLET
C PROGRAM NUMBER 720X6R1850 (INLET) ANALYSES AND PREDICTS INSTANEOUS INL INLET
C HYDRAULICS USING A LUMPED PARAMETER SCHEME (SEE SEELIG, HARRIS AND     INLET
C HERCHENRODER, 1976, (A GENERALIZED LUMPED PARAMETER MODEL OF INLET     INLET
C HYDRAULICS(, A DRAFT CERC REPORT)                                      INLET
      REAL L,LENGTH,LIN,LX,N,NX                                          INLET
      COMMON/NUM5/NI,G,NINLET,ICH(3),ISF(3),QR,L(7,7),B(7,7),D(7,7),     INLET
     1 A(7,7),N(7,7),W(7,7),V(7,7),Q(7,7),HS,HB,H(7,7),IC,IS,AMINI(3),   INLET
     1BMINI(3),LIN,QX(3),QINFLO,ARAY,LENGTH(3)                           INLET
      COMMON/NUM1/Y(5),DERY(5),X,NT,INT,ZETA,HM                          INLET
      COMMON/NUM2/BX(3,7,7),DX(3,7,7),HX(3,7,7),WX(3,7,7),LX(3,7,7),NX(3 INLET
     1,7,7)                                                              INLET
      COMMON /NUM3/AO,T,AR,BETA                                          INLET
      COMMON/NUM4/RNK(3,4)                                               INLET
      DIMENSION CORL(3)                                                  INLET
      DIMENSION ALABL1(4),ALABL2(4),IBUF(1000),NUMBER(20)                INLET
 3370 CONTINUE                                                           INLET
      DO 2193 II=1,3                                                     INLET
 2193 QX(II)=1.                                                          INLET
C   G= ACCELERATION OF GRAVITY                                           INLET
      G=32.2                                                             INLET
      DO 1211 I=1,20                                                     INLET
 1211 NUMBER(I)=I                                                        INLET
      WRITE(6,2937)                                                      INLET
 2937 FORMAT(//,1X,(--------------------------()                         INLET
      READ(5,1167) (ALABL1(I),I=1,4)                                     INLET
      READ(5,1167) (ALABL2(I),I=1,4)                                     INLET
 1167 FORMAT(4A10)                                                       INLET
      WRITE(6,1168) (ALABL1(I),I=1,4)                                    INLET
      WRITE(6,1168) (ALABL2(I),I=1,4)                                    INLET
 1168 FORMAT(8X,4A10)                                                    INLET
      WRITE(6,1268)                                                      INLET
 1268 FORMAT(/,5X,(CONTROL CARDS()                                       INLET
C READ CONTROL CARDS                                                      INLET
C                                                                        INLET
      READ(5,1011) NINLET,NCYCLES,IPLOT,INT,ITABLE,C1,C2                 INLET
      WRITE(6,1012) NINLET,NCYCLES,IPLOT,INT,ITABLE,C1,C2                INLET
 1011  FORMAT(5I10,2F10.5)                                               INLET
 1012 FORMAT(1X,5I10,2F10.5)                                             INLET
C  NINLET=THE NUMBER OF INLETS                                           INLET
C  NCYCLES= NUMBER OF TIDAL CYCLES                                       INLET
C  IPLOT  (1 FOR A PLOT OF MEAN HYDRAULICS, 0 FOR NO PLOT)               INLET
C INT IS A PARAMETER DESCRIBING THE TYPE OF WEIGHTING DESIRED            INLET
C  INT=1 FOR FLOW WEIGHTING TO ACHIEVE MINIMUM FRICTION                  INLET
C  INT=2 FOR WEIGHTING FOR MINIMUM FRICTION WITH NO FLOW ACROSS CHANNELS INLET
C  INT=3 FOR EQUAL FLOW IN ALL GRIDS TO GIVE MAXIMUM FRICTION            INLET
C ITABLE=1 FOR A TABLE OF OUTPUT                                         INLET
C  C1,C2  N=C1-C2 * D.  IF C1 AND C2 ARE ZERO THE MASCH VALUES OF        INLET
C  C1 =.03777 AND C2=.000667 ARE USED                                    INLET
      IF(C1.EQ.0.0.AND.C2.EQ.0.0) C2= 0.000667                           INLET
      IF(C1.EQ.0.) C1=0.03777                                            INLET
C                                                                        INLET
```

```
 1    FORMAT(8I10)
      READ(5,111) T,DELT,AO,AB,BETA,ZETA,QINFLO
      WRITE(6,111) T,DELT,AO,AB,BETA,ZETA,QINFLO
 111  FORMAT(3F10.5,E10.4,4F10.5)
C   T=TIDAL PERIOD, HRS (LATER CONVERTED TO SECONDS)
C   DELT=ESTIMATED TIME STEP,SEC
C   AO= SEA TIDAL AMPLITUDE,FT
C   AB= BAY AREA AT THE DATUM, SQUARE FEET
C   BETA= BAY AREA VARIATION PARAMETER ( D(AB)/D(HB))
C   ZETA= CHANNEL SLOPE (D(Y)/D(X))
C   QINFLO= INFLOW INTO THE BAY FROM OTHER SOURCES (FT3/SEC)
C
      ENDT=T*NCYCLES*3600.
      IF(ZETA.LE.0.)ZETA=1.0E25
      NT=0
C
C READ IN INFORMATION OF EACH INLET
      DO 1110 NI=1,NINLET
      IUNIT=8+NI
      REWIND IUNIT
      READ(5,1) IC,IS
C  IC= NUMBER OF CHANNELS
C  IS= NUMBER OF INLET CROSS-SECTIONS
      IF(IC.GT.7.OR.IS.GT.7) WRITE(6,1671)
 1671 FORMAT(///,5X,'*****  TOO MANY GRIDS FOR DIMENSIONS',//)
      ICH(NI)=IC
C  READ SECTION AREAS ( ONE CARD PER SECTION)
      DO 5 I=1,IS
 5    READ(5,2) (A(I,J),J=1,IC)
 2    FORMAT(10X,7F10.5)
C
C  READ SECTION WIDTHS (ONE CARD PER SECTION)
      DO 6 I=1,IS
 6    READ(5,2)  (B(I,J),J=1,IC)
C.
      ICP1=IC+1
      ISM1=IS-1
C READ LENGTHS (ONE MORE LENGTH PER CARD THAN CHANNELS)
C              ( ONE LESS CARD THAN THE NUMBER OF SECTIONS)
      DO 7 I=1,ISM1
 7    READ(5,2)  (L(I,J),J=1,ICP1)
C
C INITIALIZE VARIABLES TO BEGIN ITERATION
C NUMBER OF GRIDS ALONG THE CHANNEL IS ONE LESS THAN THE NUMBER OF
C CROSS-SECTIONS
 80   IS=IS-1
      ISE(NI)=IS
      ISM1=IS-1
      WRITE(6,3678)  NI
 3678 FORMAT( /,5X,'SUMMARY OF INLET GRID CHARACTERISTICS',/
     1 15X,'INLET NUMBER',I3)
      WRITE(6,1) IC,IS
      DO 10 I=1,IS
```

```
      DO 11 J=1,IC
      LENGTH(NI)=LENGTH(NI)+L(I,J)/FLOAT(IC)
      A(I,J)=(A(I,J)+A(I+1,J))/2.
      L(I,J)=(L(I,J)+L(I,J+1))/2.
      B(I,J)=(B(I,J)+B(I+1,J))/2.
      D(I,J)=A(I,J)/B(I,J)
      N(I,J)=C1-C2*D(I,J)
      LX(NI,I,J)=L(I,J)
      BX(NI,I,J)=B(I,J)
      DX(NI,I,J)=D(I,J)
      NX(NI,I,J)=N(I,J)
      WX(NI,I,J)=1./FLOAT(IC)
 11   CONTINUE
      WRITE(6,1207) I
 1207 FORMAT(/,1X,'SECTION',I3)
      WRITE(6,1221) (NUMBER(II),II=1,IC)
 1221 FORMAT(5X,'CHANNEL =',10I10,/)
C PRINT A SUMMARY TABLE OF GEOMETRIES
      WRITE(6,1971) (A(I,J),J=1,IC)
      WRITE(6,1972) (B(I,J),J=1,IC)
      WRITE(6,1973) (D(I,J),J=1,IC)
      WRITE(6,1974) (L(I,J),J=1,IC)
      WRITE(6,1975) (N(I,J),J=1,IC)
 1971 FORMAT(5X,'AREA(FT2)',10F10.1)
 1972 FORMAT(5X,'WIDTH(FT)',10F10.1)
 1973 FORMAT(5X,'DEPTH(FT)',1X,10F10.2)
 1974 FORMAT(5X,'LEN(FT)',2X,10F10.1)
 1975 FORMAT(5X,'N',10X,10F10.4)
 10   CONTINUE
C FIND AREA AND WIDTH AT THE MINIMUM SECTION
      AMINI(NI)=99.E+12
      DO 109 I=1,IS
      AA=0.
      BB=0.
      DO 108 J=1,IC
      AA=AA+A(I,J)
 108  BB=BB+B(I,J)
      IF(AA.GT.AMINI(NI)) GO TO 109
      AMINI(NI)=AA
      BMINI(NI)=BB
 109  CONTINUE
 1110 CONTINUE
C ESTIMATE THE INLET-BAY HELMHOLTZ PERIOD
      CALL HELM(THELM,AB,CORL)
      THTF=T/THELM
      WRITE(6,201) T,THELM,THTF
 201  FORMAT(1X,'FORCING PERIOD=',F7.2,' HOURS',
     1/,1X,'THELM(APPROX)=',F8.2,' HOURS',/
     1 1X,'TF/TH=',10X,F6.2)
      WRITE(6,1337) ((J,LENGTH(J),CORL(J)),J=1,NINLET)
 1337 FORMAT(  ,1X,'INLET LENGTH  ADDED LENGTH',  (/,8X,I2,1X,
     1 F6.1,2X,F6.1))
      T=T*3600.
      CALL RKGS(END,DELT,NINLET,QINFLO,ITAB(·,T)
      DELT=END/FLOAT(NT)
      DO 2269 NI=1,NINLET
      NN=NS
      WRITE(6,2268) NI
 2268 FORMAT(//,10X,'SUMMARY TABLE OF HYDRAULICS  INLET',I5)
      IUNIT=NI+8
      CALL CRIT(NT,DELT,IUNIT,T,NCYCLES)
      IF(IPLOT.EQ.1.AND.NI.EQ.1) CALL PLOTS(IBUF,1000,3)
      IF(IPLOT.EQ.1) CALL GRPHC(ALABL1,ALABL2,DELT,IUNIT,NI)
      IF(IPLOT.EQ.1.AND.NI.EQ.NINLET) CALL PLOT(0.,0.,999)
 2269 CONTINUE
      STOP
      END
```

```
      SUBROUTINE RKGS(END,DELT,NINLET,QINFLO,ITABLE,T)
C ROUTINE TO SOLVE A SET OF SIMUTANEOUS DIFFERENTIAL EQUATIONS
C ADAPTED FROM SCIENTIFIC SUBROUTINE PACKAGE, IBM, 1970
      COMMON/NUM1/Y(5),DERY(5),X,NT,INT,ZETA,HS
      COMMON/NUM4/RNK(3,4)
      DIMENSION AUX(8,5),A(4),B(4),C(4),PRMT(5),AMINI(3)
      NDIM=NINLET+1
      PRMT(1) = 1.
      PRMT(2)=END
      PRMT(3)=DELT
      PRMT(4) = .1
      IF(T.GT.30000.) DELT=3000.
      IF(T.LE.36000.) DELT=T/9.
      DO 1122 JN=1,NINLET
      Y(JN)=0.01
 1122 DERY(JN)=0.001
      Y(NDIM)=0.
      DERY(NDIM)=1.0-FLOAT(NINLET)*0.001
      DO 1 I=1,NDIM
1     AUX(8,I)=0.06666667*DERY(I)
      X=PRMT(1)
      XEND=PRMT(2)
      H=PRMT(3)
      PRMT(5)=0.
      CALL SETEQ(AMINI)
      IF(H*(XEND-X))38,37,2
    2 CONTINUE
      A(1)=0.5
      A(2)=0.2928932
      A(3)=1.707107
      A(4)=0.16666667
      B(1)=2.
      B(2)=1.
      B(3)=1.
      B(4)=2.
      C(1)=0.5
      C(2)=0.2928932
      C(3)=1.707107
      C(4)=0.5
      DO 3 I=1,NDIM
      AUX(1,I)=Y(I)
      AUX(2,I)=DERY(I)
      AUX(3,I)=0.
3     AUX(6,I)=0.
      IREC=0
      H=H+H
      IHLF=-1
      ISTEP=0
      IEND=0
    4 CONTINUE
      IF((X+H-XEND)*H)7,6,5
    5 CONTINUE
    6 CONTINUE
```

```
      H=XEND-X
      IEND=1
    7 CONTINUE
      CALL SEA(HS,X)
      CALL TPWRTE(NINLET,X,HS,QINFLO,Y,AMINI,RNK,NT)
      IFLAG1=X/DELTB
      IF(IFLAG1.NE.IFLAG2.AND.ITABLE.EQ.1) CALL TABLE
      IFLAG2=IFLAG1
      IF(PRMT(5))40,8,40
    8 CONTINUE
      ITEST=0
    9 CONTINUE
      ISTEP=ISTEP+1
      J=1
   10 CONTINUE
      AJ=A(J)
      BJ=B(J)
      CJ=C(J)
      DO 11 I=1,NDIM
      R1=H*DERY(I)
      R2=AJ*(R1-BJ*AUX(6,I))
      Y(I)=Y(I)+R2
      R2=R2+R2+R2
11    AUX(6,I)=AUX(6,I)+R2-CJ*R1
      IF(J-4)12,15,15
   12 CONTINUE
      J=J+1
      IF(J-3)13,14,13
   13 CONTINUE
      X=X+0.5*H
   14 CONTINUE
      CALL SETEQ(AMINI)
      GO TO 10
   15 CONTINUE
      IF(ITEST)16,16,20
   16 CONTINUE
      DO 17 I=1,NDIM
17    AUX(8,I)=Y(I)
      ITEST=1
      ISTEP=ISTEP+ISTEP-2
   18 CONTINUE
      IHLF=IHLF+1
      X=X-H
      H=0.5*H
      DO 19 I=1,NDIM
      Y(I)=AUX(1,I)
      DERY(I)=AUX(2,I)
19    AUX(6,I)=AUX(3,I)
      GO TO 9
   20 CONTINUE
      IMOD=ISTEP/2
      IF(ISTEP-IMOD-IMOD)21,23,21
   21 CONTINUE
```

```
      CALL SETEQ(AMINI)
      DO 22 I=1,NDIM
      AUX(5,I)=Y(I)
22    AUX(7,I)=DERY(I)
      GO TO 9
   23 CONTINUE
      DELT=0.
      DO 24 I=1,NDIM
24    DELT=DELT+AUX(8,I)*ABS(AUX(4,I)-Y(I))
      IF(DELT-PRMT(4))28,28,25
   25 CONTINUE
      IF(IHLF-10)26,36,36
   26 CONTINUE
      DO 27 I=1,NDIM
27    AUX(4,I)=AUX(5,I)
      ISTEP=ISTEP+ISTEP-4
      X=X-H
      IEND=0
      GO TO 18
   28 CONTINUE
      CALL SETEQ(AMINI)
      DO 29 I=1,NDIM
      AUX(1,I)=Y(I)
      AUX(2,I)=DERY(I)
      AUX(3,I)=AUX(6,I)
      Y(I)=AUX(5,I)
29    DERY(I)=AUX(7,I)
      CALL SEA(HS,X-H)
      CALL TPWRTE(NINLET,X-H,HS,QINFLO,V,AMINI,RNK,NT)
      IFLAG1=(X-H)/DELTB
      IF(IFLAG1.NE.IFLAG2.AND.ITABLE.EQ.1) CALL TABLE
      IFLAG2=IFLAG1
      IF(PRMT(5))40,30,40
   30 CONTINUE
      DO 31 I=1,NDIM
      Y(I)=AUX(1,I)
31    DERY(I)=AUX(2,I)
      IREC=IHLF
      IF(IEND)32,32,39
   32 CONTINUE
      IHLF=IHLF-1
      ISTEP=ISTEP/2
      H=H+H
      IF(IHLF)4,33,33
   33 CONTINUE
      IMOD=ISTEP/2
      IF(ISTEP-IMOD-IMOD)4,34,4
   34 CONTINUE
      IF(DELT-0.02*PRMT(4))35,35,4
   35 CONTINUE
      IHLF=IHLF-1
      ISTEP=ISTEP/2
      H=H+H
      GO TO 4
   36 CONTINUE
      IHLF=11
      CALL SETEQ(AMINI)
      GO TO 39
   37 CONTINUE
      IHLF=12
      GO TO 39
   38 CONTINUE
      IHLF=13
   39 CONTINUE
      CALL SEA(HS,X)
      CALL TPWRTE(NINLET,X,HS,QINFLO,V,AMINI,RNK,NT)
      IFLAG1=X/DELTB
      IF(IFLAG1.NE.IFLAG2.AND.ITABLE.EQ.1) CALL TABLE
      IFLAG2=IFLAG1
40    CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SETEQ(AMIN)
C ROUTINE TO SEUP THE EQUATIONS FOR THE RIGHT HAND SIDE OF THE EQUATIONS
C MOTION AND TO DETERMINE THE RANK OF THE TERMS IN THE EQUATION OF MOTIO
      REAL L,LENGTH,LIN,LX,N,NX,LE
      COMMON/NUM5/NI,G,NINLET,ICH(3),ISE(3),QR,L(7,7),B(7,7),D(7,7),
     1 A(7,7),N(7,7),W(7,7),V(7,7),Q(7,7),HS,HB,H(7,7),IC,IS,AMINI(3),
     1BMINI(3),LIN,QX(3),QINFLO,ARAY,LENGTH(3)
      COMMON/NUM1/Y(5),DERY(5),X,NT,INT,ZETA,HH
      COMMON/NUM2/BX(3,7,7),DX(3,7,7),HX(3,7,7),WX(3,7,7),LX(3,7,7),NX(3
     1,7,7)
      COMMON /NUM3/A0,T,ARV,BETA
      COMMON/NUM4/RNK(3,4)
      DIMENSION AMIN(3)
      G=32.2
      DO 220 NI=1,3
      DO 119 I=1,4
  119 RNK(NI,I)=0.
  220 CONTINUE
      CALL SEA(HS,X)
      HH=HS
C FIND THE  BAY AREA
      HR=Y(NINLET+1)
      ARAY=ABY*(1.+BETA*HR)
      QT=0.
C SET UP EQUATIONS FOR EACH INLET
      DO 100 NI=1,NINLET
      AMIN(NI)=99999999999.
      QQ=Y(NI)
      QT=QT+QQ
      IC=ICH(NI)
      IS=ISE(NI)
      LE=0.
      DO 95 I=1,IS
      DO 94 J=1,IC
      N(I,J)=NX(NI,I,J)
      L(I,J)=LX(NI,I,J)
      LE=LE+L(I,J)/(FLOAT(IC))
   94 B(I,J)=BX(NI,I,J)
   95 CONTINUE
      CALL LEVEL
      AS=0.
      AH=0.
      AF=0.
      DO 97 I=1,IS
      AA=0.
      DL=0.
      DO 96 J=1,IC
      DL=DL+L(I,J)/(FLOAT(IC)*LE)
      D(I,J)=DX(NI,I,J)+H(I,J)
      IF(D(I,J).LT.0.) D(I,J)=0.001
      A(I,J)=B(I,J)*D(I,J)+H(I,J)*ABS(H(I,J))/(ZETA*FLOAT(IC))
      IF(A(I,J).LT.0.) A(I,J)=0.001
      IF(I.EQ.1) AS=AS+A(I,J)
```

```
      IF(I.EQ.IS) AB=AB+A(I,J)
96    AA=AA+A(I,J)
      IF(AA.LT.AMIN(NI)) AMIN(NI)=AA
97    AE=AE+DL/AA
      AMINI(NT)=AMIN(NI)
      AE=1./AE
      IF(IWT.EQ.1) CALL WT1
      IF(IWT.EQ.2) CALL WT2
      IF(IWT.EQ.3) CALL WT3
      DO 140 I=1,IS
      DO 139 J=1,IC
      HX(NI,I,J)=H(I,J)
139   WX(NI,I,J)=W(I,J)
140   CONTINUE
      RNK(NI,2)=AE/(2.*LE)*(1./(AR**2)-1./(AB**2))*QQ*QQ
      RNK(NI,3)=G*AE/LE*(HB-HS)
      DO 85 I=1,IS
      AC=0.
      DO 84 J=1,IC
84    AC=AC+A(I,J)
      DO 83 J=1,IC
83    RNK(NI,4)=RNK(NI,4)+AE/(LE*AC)*G*N(I,J)**2*ABS(W(I,J)*QQ)*
     1W(I,J)*QQ/(2.208*D(I,J)**0.33333*A(I,J)**2)*L(I,J)*B(I,J)
85    CONTINUE
      RNK(NI,1)=-RNK(NI,2)-RNK(NI,3)-RNK(NI,4)
      DERV(NI)=RNK(NI,1)
C FIND THE RELATIVE RANK OF TERMS, NORMALIZE BY THE LARGEST TERM.
      XMAX=0.
      DO 101 I=1,4
101   IF(ABS(RNK(NI,I)).GT.XMAX) XMAX=ABS(RNK(NI,I))
      DO 102 I=1,4
102   RNK(NI,I)=100.*RNK(NI,I)/XMAX
100   CONTINUE
      DERV(NINLET+1)=QT/ABAY+QINFLO/ABAY
      RETURN
      END


      SUBROUTINE TPWRTE(NINLET,X,HS,QINFLO,Y,AMINI,RNK,NT)
C SUBROUTINE TO WRITE HYDRAULIC INFORMATION ON TAPES
      DIMENSION RNK(3,4),Y(5),AMINI(3)
      HOURS=X/3600.
      NT=NT+1
      DO 100 NI=1,NINLET
      IUNIT=NI+8
      V=Y(NI)/AMINI(NI)
100   WRITE(IUNIT) HOURS,HS,QINFLO,Y(NINLET+1),V,Y(NI),(RNK(NI,J),J=1,4)
      RETURN
      END
```

```
      SUBROUTINE LEVEL
C THIS ROUTINE COMPUTES WATER LEVELS THROUGHOUT THE INLET ASSUMING LEVEL
C ARE LINEAR FROM BAY TO SEA
      REAL L,LENGTH,LIN,LX,N,NX
      COMMON/NUM5/NI,G,NINLET,ICH(3),ISE(3),QB,L(7,7),B(7,7),D(7,7),
     1 A(7,7),N(7,7),W(7,7),V(7,7),Q(7,7),HS,HB,H(7,7),IC,IS,AMINI(3),
     1BMINI(3),LIN,QX(3),QINFLO,ABAY,LENGTH(3)
      DO 20 J=1,IC
      XL=0.
      DO 10 I=1,IS
 10   XL=XL+L(I,J)
      XX=L(1,J)/2.
      H(1,J)=HS+(HB-HS)/XL*XX
      DO 11 I=2,IS
      XX=(L(I-1,J)+L(I,J))/2.+XX
 11   H(I,J)=HS+(HB-HS)/XL*XX
 20   CONTINUE
      RETURN
      END


      SUBROUTINE SEA(HS,TIME)
C THIS SUBROUTINE DETERMINES THE FORCING SEA LEVEL EITHER FROM
C EQUAL-TIME-SERIES DATA (IF AVAILABLE) OR BY SINUSODIAL FORCING.
      COMMON /NUM3/A0,T,AB,BETA
      DIMENSION Y(52)
      NN=NN+1
      IF(NN.NE.1) GO TO 10
      READ(5,1) TDEL,NPTS
 1    FORMAT(34X,F6.2,5X,I3)
      TDEL=TDEL*60.
C READ SEA LEVEL EQUAL TIME SERIES DATA THE FIRST TIME SEA IS CALLED
C IF NPTS IS GREATER THAN 1
      IF(NPTS.GT.1) READ(5,2) (Y(J),J=1,NPTS)
 2    FORMAT(8F10.5)
      IF(NPTS.GT.1) WRITE(6,3) (Y(J),J=1,NPTS)
 3    FORMAT(3X,16F6.2)
      N1=NPTS+1
      N2=NPTS+2
      Y(N1)=Y(1)
      Y(N2)=Y(2)
 10   IF(NPTS.LT.1) GO TO 100
C INTERPOLATE IN TIME
      IT=TIME/T
      XT=TIME-IT*T
       J=XT/TDEL
      J=J+1
      HS=Y(J)+((Y(J+1)-Y(J))*(XT-(J-1)*TDEL)/TDEL )
      RETURN
C DETERMINE LEVEL IF SEA LEVEL FLUCTUATION IS SINUSODIAL
 100  HS=A0* SIN(2.*3.14158*TIME/T)
      RETURN
      END
```

AD-A050 315 COASTAL ENGINEERING RESEARCH CENTER FORT BELVOIR VA F/G 8/3
A SPATIALLY INTEGRATED NUMERICAL MODEL OF INLET HYDRAULICS.(U)
NOV 77 W N SEELIG, D L HARRIS
UNCLASSIFIED CERC-GITI-14 NL

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      SUBROUTINE HELM(THELM,AB,CORL)                                    INLET     504
C ESTIMATE THE INLET-BAY HELMHOLTZ PERIOD                                INLET     505
C OF THE INLET/BAY SYSTEM (NEGLECT FRICTION)                            INLET     506
      REAL L,LENGTH,LIN,LX,N,NX                                         INLET     507
      COMMON/NUMS/NI,G,NINLET,ICH(3),ISE(3),DB,L(7,7),B(7,7),D(7,7),    INLET     508
     1 A(7,7),N(7,7),W(7,7),V(7,7),Q(7,7),NS,NB,H(7,7),IC,IB,AMINI(3),  INLET     509
     1BMINI(3),LIN,QX(3),QINFLO,ABAY,LENGTH(3)                          INLET     510
      DIMENSION CORL(3)                                                 INLET     511
C USE FIVE ITERATIONS TO OBTAIN THE ESTIMATE                             INLET     512
      DO 1000 II=1,5                                                    INLET     513
      SUM=0.                                                            INLET     514
      DO 100 NN=1,NINLET                                                INLET     515
      AMIN=AMINI(NN)                                                    INLET     516
 100  SUM=SUM+AMIN/(LENGTH(NN)+CORL(NN))                                INLET     517
      THELM=2.*3.14159* SQRT(AB/G)/ SQRT(SUM)                           INLET     518
C ESTIMATE THE HELMHOLTZ PERIOD                                         INLET     519
      DO 101 NN=1,NINLET                                                INLET     520
C ESTIMATF THF INLET LENGTH CORRECTION DUE TO RADIATION                 INLET     521
 101  CORL(NN)=-BMINI(NN)/3.14159*ALOG(3.14159*BMINI(NN)/( SQRT(        INLET     522
     132.2*AMINI(NN)/BMINI(NN))*THELM))                                 INLET     523
 1000 CONTINUF                                                          INLET     524
C CONVERT THE HELMHOLTZ PERIOD TO HOURS                                 INLET     525
      THELM=THELM/3600.                                                 INLET     526
      RETURN                                                            INLET     527
      END                                                               INLET     528


      SUBROUTINE WT1                                                    INLET     529
C THIS SUBROUTINE WEIGHTS THE FLOW IN EACH SECTION SO THAT FRICTION     INLET     530
C IN THAT SECTION IS MINIMIZED.  THIS MEANS THAT AT EACH SECTION FLOW IS INLET     531
C ALLOWED TO REDISTRIBUTE ISTSELF THROUGHOUT THE CHANNELS TO MINIMIZE FR INLET     532
C HOWEVER, FLOW PERPENDICULAR TO THE CHANNELS IS ASSUMED TO BE SMALL AND INLET     533
C FLOW IS NOT INCLUDED IN THE EQUATIONS OF MOTION.  BY MINIMIZING FRICTI INLET     534
C ROUTINE GIVES AN UPPER LIMIT FOR BAY LEVEL FLUCTUATIONS AND INLET VELO INLET     535
      REAL L,LENGTH,LIN,LX,N,NX                                         INLET     536
      COMMON/NUMS/NI,G,NINLET,ICH(3),ISE(3),DB,L(7,7),B(7,7),D(7,7),    INLET     537
     1 A(7,7),N(7,7),W(7,7),V(7,7),Q(7,7),NS,NB,H(7,7),IC,IB,AMINI(3),  INLET     538
     1BMINI(3),LIN,QX(3),QINFLO,ABAY,LENGTH(3)                          INLET     539
      DIMENSION C(20)                                                   INLET     540
      DO 100 I=1,IB                                                     INLET     541
      SUMC=0.                                                           INLET     542
      DO 50 J=1,IC                                                      INLET     543
      C(J)=A(I,J)**2*(D(I,J)**.333)/                                    INLET     544
     1 (N(I,J)**2*QX(NI)**2*B(I,J)*L(I,J))                              INLET     545
 50   SUMC=SUMC+C(J)                                                    INLET     546
      DO 60 J=1,IC                                                      INLET     547
 60   W(I,J)=C(J)/SUMC                                                  INLET     548
 100  CONTINUE                                                          INLET     549
      RETURN                                                            INLET     550
      END                                                               INLET     551
```

```
      SUBROUTINE WT2
C ROUTINE TO DETERMINF THE GRID WEIGHTING FUNCTION ASSUMING THAT
C FLOW IN A GIVEN CHANNEL IS THF SAME ALONG THE ENTIRF CHANNEL
C FLOW IS DISTRIBUTED IN CHANNELS TO GIVE A MINIMUM TOTAL FRICTION
C  FRICTION IN THIS ROUTINE WILL BE SLIGHTLY HIGHER THAN IN WT1 AND THE
C IN THIS SYSTEM IS CONSISTANT WITH THE EQUATIONS OF MOTION.
      REAL L,LENGTH,LIN,LX,N,NX
      COMMON/NUMS/NI,G,NINLET,ICH(3),ISE(3),DR,L(7,7),B(7,7),D(7,7),
     1 A(7,7),N(7,7),W(7,7),V(7,7),Q(7,7),HS,HB,H(7,7),IC,IS,AMINI(3),
     1BMINI(3),LIN,QX(3),QINFLO,ABAY,LENGTH(3)
      DIMENSION C(20)
      SUMC=0.
      DO 100 I=1,IC
      C(I)=0.
      DO 50 J=1,IS
 50   C(I)=C(I)+(N(J,I)**2*QX(NI)**2*(B(J,I)*L(J,I))/
     1 (A(J,I)**2*(         D(J,I))**.33333))
      C(I)=1./C(I)
 100  SUMC=SUMC+C(I)
      DO 70 J=1,IS
      DO 60 I=1,IC
 60   W(J,I)=C(I)/SUMC
 70   CONTINUE
      RETURN
      END


      SUBROUTINF WT3
C THIS ROUTINE ASSUMES THAT DISCHARGE IS EQUALLY DISTRIBUTED THROUGHOUT
C THE INLFT GRID SYSTFM.  IN GENERAL THIS WILL NOT BE TRUE BECAUSE IT IS
C DIFFICULT TO ACCURATELY DRAW THIS TYPE OF GRID BY EYE AND FLOW DISTRUB
C CHANGES WITH TIME IN MOST INLETS.  THIS ROUTINE IS USEFUL IN GIVING AN
C VELOCITIES AND BAY LEVEL FLUCTUATIONS.
C GRIDS WITH DEPTHS LT 0.01 FOOT ARE ASSUMED TO HAVE NO FLOW
      REAL L,LENGTH,LIN,LX,N,NX
      COMMON/NUMS/NI,G,NINLET,ICH(3),ISE(3),DR,L(7,7),B(7,7),D(7,7),
     1 A(7,7),N(7,7),W(7,7),V(7,7),Q(7,7),HS,HB,H(7,7),IC,IS,AMINI(3),
     1BMINI(3),LIN,QX(3),QINFLO,ABAY,LENGTH(3)
      DO 2 I=1,IS
      X=IC
      DO 1 J=1,IC
 1    IF(D(I,J).LT.0.01) X=X-1.
      IF(X.LE.0.) WRITE(6,100)  NI,IS
 100  FORMAT(////,5X,' ERROR -- INLET HAS DRIED UP AS INDICATED IN WT3',/
     1 5X, 'INLET=',I4,'  SECTION=',I4,///)
      IF(X.LE.0.) STOP   .
      DO 3 J=1,IC
      W(I,J)=1./X
 3    IF(D(I,J).LT.0.01) W(I,J)=0.
 2    CONTINUE
      RETURN
      END
```

```
      SUBROUTINE TABLE                                                  INLET     602
C ROUTINE TO WRITE A TABLE OF INSTANTANEOUS HYDRAULICS                  INLET     603
      REAL L,LENGTH,LTN,LX,N,NX                                         INLET     604
      COMMON/NUMS/NI,G,NINLET,ICH(3),ISE(3),QR,L(7,7),B(7,7),D(7,7),    INLET     605
     1 A(7,7),N(7,7),W(7,7),V(7,7),Q(7,7),HS,HB,H(7,7),IC,IS,AMINI(3),  INLET     606
     1HMINI(3),LIN,DX(3),QINFLO,ABAY,LENGTH(3)                          INLET     607
      COMMON/NUM1/Y(5),DERY(5),X,NT,INT,ZETA,HH                         INLET     608
      COMMON/NUM2/BX(3,7,7),DX(3,7,7),HX(3,7,7),WX(3,7,7),LX(3,7,7),NX(3 INLET     609
     1,7,7)                                                             INLET     610
      COMMON/NUM4/RNK(3,4)                                              INLET     611
      DIMENSION NAME(4)                                                 INLET     612
      DATA NAME/6HV(FPS)  ,6HA(FT2)  ,6HHEIGHT  ,6HLEVEL                INLET     613
      HRS=X/3600.                                                       INLET     614
      WRITE(6,1) HRS                                                    INLET     615
    1 FORMAT(1X,(------------------------------(,/                      INLET     616
     15X,(TIME, HOURS =(,F8.3)                                          INLET     617
      DO 100 NI=1,NINLET                                                INLET     618
      WRITE(6,10) NI,HS,HB,Y(NI)                                        INLET     619
   10 FORMAT(/,10X,(INLET (,I3,/,10X,(SEA LEVEL,FT=(,F7.2,/,10X,(BAY LEVE INLET     620
     1L,FT=(,F7.2,/,10X,(DISCHARGE,CFS=(,E10.4,/,2X,(CHANNEL          SECT INLET     621
     1ION 1         2          3          4          5          6()     INLET     622
      IC=ICH(NI)                                                        INLET     623
      IS=ISE(NI)                                                        INLET     624
      DO 4 J=1,IC                                                       INLET     625
      DO 3 I=1,IS                                                       INLET     626
      A(I,J)=BX(NI,I,J)*(DX(NI,I,J)+HX(NI,I,J))+HX(NI,I,J)*ABS(HX(NI,I,J INLET     627
     1))/(ZETA*FLOAT(IC))                                               INLET     628
      IF(A(I,J).LT.0.01) A(I,J)=0.                                      INLET     629
      V(I,J)=Y(NI)*WX(NI,I,J)/A(I,J)                                    INLET     630
   3, IF(A(I,J).LE.0.01) V(I,J)=0.                                      INLET     631
      IF(J.EQ.1) WRITE(6,50) J,NAME(4),(HX(NI,I,J),I=1,IS)              INLET     632
      WRITE(6,69)                                                       INLET     633
   69 FORMAT(/)                                                         INLET     634
      WRITE(6,50) J,NAME(1),(V(I,J),I=1,IS)                             INLET     635
   50 FORMAT(4X,I2,3X,A6,2X,6F10.2)                                     INLET     636
      WRITE(6,50) J,NAME(2),(A(I,J),I=1,IS)                             INLET     637
      WRITE(6,50) J,NAME(3),(WX(NI,I,J),I=1,IS)                         INLET     638
    4 CONTINUE                                                          INLET     639
      WRITE(6,59) (RNK(NI,II),II=1,4)                                   INLET     640
   59 FORMAT(5X,(TEMP ACC=(,F7.1,( CONV ACC=(,F7.1,( HEAD=(,F7.1,( FRIC= INLET     641
     1(,F7.1)                                                           INLET     642
      VBAR=Y(NI)/AMINI(NI)                                              INLET     643
      WRITE(6,61) VBAR ,AMINI(NI)                                       INLET     644
   61 FORMAT(5X,(MEAN VELOCITY AT THE MINIMUM AREA SECTION=(,F7.2,( FT/S INLET     645
     1EC(,(  AMIN=(,F9.2,( FT2()                                        INLET     646
  100 CONTINUE                                                          INLET     647
      RETURN                                                            INLET     648
      END                                                               INLET     649
```

```
      SUBROUTINE CRIT(NT,DELT,IUNIT,T,NCYCLES)
C     SUBROUTINE CRIT COMPARES 3 CONSECUTIVE FUNCTION POINTS
C     AND WRITES MIDDLE POINT IF IT IS A CRITICAL POINT
C
      DIMENSION F(3,5),MARK(5),TERM(4)
      DATA MARKA/1H /, MARKB/1H*/
      REWIND IUNIT
      NLINES=0
      TF=T/3600.
      WRITE(6,1009)
      DO 1 N=1,2
    1 READ(IUNIT) X,(F(N,J),J=1,5),(TERM(II),II=1,4)
      DO 100 N=3,NT
      READ(IUNIT) X,(F(3,J),J=1,5),(TERM(II),II=1,4)
      IF(X.LT.-1.0E+10) GO TO 101
      IOUT=0
      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
C    CRITICAL POINT VALUE FOUND
 2015 IOUT = 1
      MARK(IA) = MARKB
      IF(IA.EQ.1.AND.F(2,IA).GT.0.) HSH=F(2,IA)
      IF(IA.EQ.1.AND.F(2,IA).GT.0.) T1=X
      IF(IA.EQ.1.AND.F(2,IA).LE.0.) HSL=F(2,IA)
      IF(IA.EQ.1.AND.F(2,IA).LE.0.) T2=X
      IF(IA.EQ.3.AND.F(3,IA).GT.0.) HOH=F(3,IA)
      IF(IA.EQ.3.AND.F(3,IA).GT.0.) T3=X
      IF(IA.EQ.3.AND.F(3,IA).LE.0.) HOL=F(3,IA)
      IF(IA.EQ.3.AND.F(3,IA).LE.0.) T4=X
      IF(IA.EQ.4.AND.F(2,IA).LT.0.) VE=F(2,IA)
      IF(IA.EQ.4.AND.F(2,IA).GT.0.) VF=F(2,IA)
 2020 CONTINUE
      DO 2025 IA = 1, 5
      F(1,IA) = F(2,IA)
 2025 F(2,IA) = F(3,IA)
      IF (IOUT.EQ.0) GO TO 100
C     IF(X.LT.(NCYCLES-2)*TF) GO TO 100
      NLINES=NLINES+1
      IF(NLINES.GT.150) GO TO 100
      WRITE (6    ,2101)     X,(F(1,IA),MARK(IA),IA=1,5)
  100 CONTINUE
  101 BONT
      AMPH=HOH/HSH
      AMPL=HOL/HSL
      PHH= ABS(T3-T1)*360./TF
      PHL= ABS(T4-T2)*360./TF
      WRITE(6,1011) AMPH,PHH,VF,AMPL,PHL,VE
      WRITE(6,1111) TF
 1111 FORMAT(  5X,'TF=',F7.2)
      RETURN
 2101 FORMAT (2F8.3,A1,-3PF8.3,A1,2(0PF7.3,A1),
      3PF9.3, A1, 2(F8.3, A1))
 1009 FORMAT(4X,4HTIME,5X,2HHS,4X,6HINFLOW,5X,2HHO,
     1  5X,3HVEL,7X,1HO,/,5X,3HHRS,5X,2HFT,5X,4HKCFS,
     1  6X,2HFT,5X,3HFPS,4X,4HKCFS,/)
 1011 FORMAT(//,1X,' CRITICAL POINT VALUE',///,15X,
     1 'WAVE PROPAGATION',/,15X,'AD/AO',5X,'PHASE LAG(DEG)   MAX VEL',
     1//,2X,'HIGH WATER',2X,3F10.4,/,
     1 2X,'LOW WATER ',2X,3F10.4)
      END
```

```
      SUBROUTINE READIN (X,Y,YFAC,XFAC,X0,XF,INDC,KK,LN,IUNIT)
C     SUBROUTINE TO READ SOLUTION TABULATION FROM FILE
C
      DIMENSION Y(9), YFAC(9)
      DTS=.5*1./60.
      READ (IUNIT)  X, Y
      IF(X.LT.-1.E+10) KK=2
      INDC = 0
      IF (KK - 1) 10, 10, 50
10    IF (X0 - X - DTS) 20, 50, 50
20    IF (X - XF - DTS) 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,DELT,IUNIT,NI)
C
C     SUBROUTINE GRPHC WRITES PLOTTER TAPE FOR GRAPHICAL
C     OUTPUT OF SOLUTION
C
      DIMENSION BL(2), ISYM(5)
      DIMENSION YLABLL(3),ALEGN(3,6),ALABL1(4),ALABL2(4),SYM(3),Y(9),YFA
     1C(9),XX(2000),YY(2000),TT(9,2)
      DATA YLABLL/10HHEIGHTS, V,10HELOCITIES-,8H-FT, FPS/
      DATA ALEGN/10HFLOW (KCFS,10H)          ,3H   ,10HINLET VELO,10HCITY
     1 (FT/S,3HEC),10HBAY LEVEL(,10HFT)          ,3H   ,10HINFLOW    ,10H
     2          ,3H   ,10HOCEAN LEVE,10HL(FT)      ,3H   ,10HLEGEND    ,10H
     3          ,3H   /
      DATA BL/10HOBSERVED B,10HAY TIDE   /
      DATA ISYM/5,4,3,2,1/
      DATA TT(6,1)/10HTEMPORAL A/
      DATA TT(6,2)/10HCCEL      /
      DATA TT(7,1)/10HCONVECTIVE/
      DATA TT(7,2)/10H ACC      /
      DATA TT(8,1)/10HPRESSURE H/
      DATA TT(8,2)/10HEAD       /
      DATA TT(9,1)/10HBOTTOM STR/
      DATA TT(9,2)/10HESS       /
C
C READ INFORMATION TO DIRECT PLOTTING
C
C  FIRST CARD
C  X0 = STARTING TIME OF PLOT (HRS)
C  XF = ENDING TIME OF PLOT (HRS)
C  SCALX = TIME AXIS SCALE IN HOURS PER INCH
C  YLO = MINIMUM VALUE OF TIDAL HEIGHTS (FT)
C  YL = OVERALL HEIGHT OF PLOT (INCHES)
C  YLSCAL = SCALE OF TIDAL HEIGHTS (FT/INCH)
C  YRO = MINIMUM VALUE OF FLOWS (THOUSANDS OF CUBIC FEET PER SECOND)
C  YRSCAL = SCALE OF FLOW ( THOUSANDS OF CUBIC FEET PER SECOND/INCH)
C
C  CARD 2
C  YVO = MINIMUM VELOCITY (FT/SEC)
C  YVSCAL = SCALE OF VELOCITY (FEET PER SECOND/INCH)
C  SCAL = SCALE FACTOR FOR TOTAL PLOT SIZE
C  IO = NOT EQUAL TO ZERO FOR A PLOT OF INLET DISCHARGE
C
```

```
      IF(NI.EQ.1)                                                       INLET
     1READ ( 5,2001) XO,XF,SCALX,VLO,VL,VLSCAL,VRO,VRSCAL,YVO,YVSCAL,   INLET
     1 SCALE,IO                                                         INLET
 2001 FORMAT(8F10.5,/,3F10.5,I10)                                       INLET
      WRITE(6,2002)  XO,XF,SCALX,VLO,VL,VLSCAL,VRO,VRSCAL,YVO,YVSCAL,   INLET
     1 SCALE,IO                                                         INLET
 2002 FORMAT(///,5X,'PLOT INFORMATION'/                                 INLET
     1 1X,8F10.5,/,1X,3F10.5,I10)                                       INLET
C DETERMINE SYMBOL SPACING                                              INLET
      LINTYP=.25*SCALX/(DELT/3600.)                                     INLET
      WRITE(6,1215) LINTYP                                              INLET
 1215 FORMAT(1X,'LINTYP=',I6)                                           INLET
C                                                                       INLET
C     PLOT LEGEND                                                       INLET
C                                                                       INLET
      CALL SYMBOL(1.,-VL/2.-.8,.20,6HLEGEND,0.,6)                       INLET
      DO 20 LN = 1, 5                                                   INLET
      INDX = 0                                                          INLET
      VP=-VL/2.-.8-LN*.2                                                INLET
      LLN=ISYM(LN)                                                      INLET
      CALL SYMBOL(0.,VP+.06,.14,LLN,0.,-1)                              INLET
      SYM(1) = ALEGN(1,LN)                                              INLET
      SYM(2) = ALEGN(2,LN)                                              INLET
      SYM(3)= ALEGN(3,LN)                                               INLET
      CALL SYMBOL( .4,VP,0.1 ,SYM,0.,23)                                INLET
20    CONTINUE                                                          INLET
C PLOT TITLE                                                            INLET
      CALL SYMBOL(3.5,-VL/2.-1.,.21,ALABL1,0.,32)                       INLET
      CALL SYMBOL(3.5,-VL/2.-1.4,.21,ALABL2,0.,32)                      INLET
C PLOT AXES                                                             INLET
      VLO=-VL/2.*VLSCAL                                                 INLET
      CALL AXIS(0.,-VL/2.,16HVELOCITY, FT/SEC,16,VL,90.,YVO             INLET
     1,YVSCAL)                                                          INLET
      CALL AXIS(-.8,-VL/2.,11HHEIGHTS, FT,11,VL,90.,VLO,VLSCAL)         INLET
      CALL AXIS(0.,-VL/2.,9HTIME, HRS,-9,(XF-XO)/SCALX,0.,0.,SCALX)     INLET.
      IF(IO.NE.0)                                                       INLET
     1CALL AXIS((XF-XO)/SCALX,-VL/2.,10HFLOW, KCFS,-10,VL ,90.,-VL/2.*VR INLET
     1SCAL,VRSCAL)                                                      INLET
      IF(IO.EQ.0) CALL PLOT(( XF-XO)/SCALX,-VL/2.,3)                    INLET
      IF(IO.EQ.0) CALL PLOT((XF-XO)/SCALX,VL/2.,2)                      INLET
      CALL PLOT((XF-XO)/SCALX,VL/2.,3)                                  INLET
      CALL PLOT(0.,VL/2.,2)                                             INLET
      YFAC(1) = 1./VLSCAL                                               INLET
      YFAC(2) = 0.001/VRSCAL                                            INLET
      YFAC(3) = YFAC(1)                                                 INLET
      YFAC(4) = 1./YVSCAL                                               INLET
      YFAC(5) = YFAC(2)                                                 INLET
      DO 1234 II=6,9                                                    INLET
 1234 YFAC(II)=.003                                                     INLET
      XFAC = 1./SCALX                                                   INLET
60    DO 85 I = 1, 9                                                    INLET
C IF IO=0 DO NOT PLOT DISCHARGE                                         INLET
      IF(IO.EQ.0.AND.I.EQ.5) GO TO 85                                   INLET
      COR=VL/2.+(I-5)*0.8                                               INLET
      CALL PLOT (0., 0., 3)                                             INLET
      KK = 1                                                            INLET
      ISUM=0                                                            INLET
      REWIND IUNIT                                                      INLET
```

```
      INDX = 0
65    CALL READIN (X,Y,YFAC,XFAC,X0,XF,INDC,KK,I,IUNIT)
      GO TO (70, 80), KK
 70   IF(INDC.LE.0) GO TO 65
 72   ISUB=ISUB+1
      IF(ISUB.GE.1998) ISUB=1998
      XX(ISUB)=X
      YY(ISUB)=Y(I)
      IF(I.GT.5) YY(ISUB)=YY(ISUB)+COR
      IF(ISUB.EQ.1998) GO TO 80
      GO TO 65
 80   XX(ISUB+1)=0.
      XX(ISUB+2)=1.0
      YY(ISUB+1)=0.
      YY(ISUB+2)=1.
C PLOT CURVES ( DO NOT PLOT IF EQUAL TO ZERO THROUGHOUT)
      IF(YY(ISUB-2).EQ.0.0.AND.
     1 YY(ISUB-1).EQ.0.0.AND.YY(ISUB).EQ.0.0) GO TO 85
      IF(I.GT.5) GO TO 885
      CALL LINE(XX,YY,ISUB,1,LINTYP,I)
      GO TO 85
 885  CALL LINE(XX,YY,ISUB,1,0,0)
      CALL PLOT((XF-X0)/SCALX,COR,3)
      CALL PLOT(0.,COR,2)
      SYM(1)=TT(I,1)
      SYM(2)=TT(I,2)
      CALL SYMBOL(-2,2,COR,0.1,SYM,0.,20)
 85   CONTINUE
C READ PROTOTYPE BAY TIDE (DATA STARTS AT BEGINNING OF PLOT,SAME DATUM)
      IF(NI.NE.1) GO TO 2019
      READ(5,1) TDEL,NPTS
 1    FORMAT(34X,F6.2,6X,I3)
      IF(NPTS.LT.2) GO TO 2019
      IF(NPTS.GT.1) READ(5,2) (YY(J),J=1,NPTS )
 2    FORMAT(8F10.5)
      XX(NPTS+1)=0.
      XX(NPTS+2)=1.
      YY(NPTS+1)=0.
      YY(NPTS+2)=1.
      DO 3 J=1,NPTS
      YY(J)=YY(J)*YFAC(1)
 3    XX(J)=(TDEL/60.)*XFAC*(J-1)
      CALL PLOT(XX(1),YY(1),3)
      CALL LINE(XX,YY,NPTS,1,0,0)
      CALL PLOT(XX(NPTS/2),YY(NPTS/2),3)
      CALL PLOT(XX(NPTS/2),YY(NPTS/2)+.75,2)
      CALL SYMBOL(XX(NPTS/2)+.1,YY(NPTS/2)+.75,.1,BL,0.,17)
2019  CALL PLOT((XF-X0)/SCALX+4.,0.,-3)
      RETURN
      END
```

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