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THE COMPUTATION OF TIDES AND CURRENTS  
IN ESTUARIES AND CANALS

Donald R. F. Harleman, et al

Massachusetts Institute of Technology

Prepared for:

Committee on Tidal Hydraulics (Army)

September 1969

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by

D. R. F. Harleman

C. H. Lee



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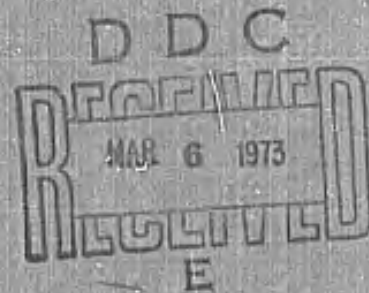
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Corps of Engineers, U. S. Army

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2	Bibliography on Tidal Hydraulics	Feb. 1954
	Supplement No. 1, Material Compiled Through May 1955	June 1955
	Supplement No. 2, Material Compiled from May 1955 to May 1957	May 1957
	Supplement No. 3, Material Compiled from May 1957 to May 1959	May 1959
	Supplement No. 4, Material Compiled from May 1959 to May 1965	May 1965
3	Evaluation of Present State of Knowledge of Factors Affecting Tidal Hydraulics and Related Phenomena (revised edition of Report No. 1)	May 1965

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13. ABSTRACT The investigation was concerned with analysis of one-dimensional tidal motion in the two principal types of tidal waterways: (1) estuaries open to the ocean at one end and merging with a river at the opposite end; and (2) canals or waterways connecting two independent tidal bodies. The objectives of the research program were to classify tidal problems in terms of boundary conditions, to discuss available analytical and numerical procedures, and to recommend an appropriate method of solution for tidal problems. The primary concern was with analytical and numerical methods rather than with analog and physical models. In general, only one-dimensional methods were considered since these are adequate for many practical problems. Tidal motion in a canal or estuary can be described by two equations, one expressing the conservation of mass (the continuity equation), and the other expressing the dynamic equation of motion in the longitudinal direction (the momentum equation). The various ways of dealing with these two equations are: (1) harmonic methods; (2) method of characteristics; and (3) finite difference methods. It is concluded that the non-linear, finite difference method is the most satisfactory for solution of one-dimensional tidal hydraulic problems. Seven case studies are given to demonstrate the versatility of the method in both prismatic and irregular channels, in closed- and open end estuaries and sea-level canals. The diagonal mesh computation method using an explicit scheme results in relatively simple computer programs and efficiency in computer time. Computer programs have been developed for closed-end estuaries, open end estuaries, and sea-level canals.			

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Currents						
Estuaries						
Tidal currents						
Tides						
Water flow						

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Mr. Max Clark III, research assistant at Massachusetts Institute of Technology, contributed to the project by modifying his computer program, formulated according to the method of characteristics, for comparison with the explicit scheme developed in this report. Mr. Keith Stolzenbach, graduate student at M.I.T., provided valuable assistance in the final shaping of the computer programs.

The project was administered under the immediate supervision of Professor D. R. F. Harleman. The research was carried out by Mr. Chok-hung Lee, research assistant at M.I.T. Computations were performed by an IBM-360 Model 40 at the Civil Engineering Systems Laboratory at M.I.T.

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## Chapter 1

### Introduction and Research Program

#### 1.1 Introduction

Tidal motion may be broadly classified into one-dimensional or two-dimensional categories. In the one-dimensional category the lateral boundaries of the system constrain the tidal motion to a direction which roughly coincides with a centerline drawn between the adjacent boundaries. Tides in long, narrow gulfs or bays, fjords, estuaries and sea-level canals can generally be treated in the one-dimensional category. Two-dimensional considerations are generally necessary in treating tidal motion in broad bays, the mouths of estuaries on the continental shelf, wide straits and gulfs and enclosed seas. In these cases, the influence of the earth's rotation, through the Coriolis terms, must be considered in the equations of motion.

Within the one-dimensional category tidal motion may be further subdivided into classes of problems which depend on the boundary conditions imposed at either end of the area of interest. The boundary conditions are generally of two types: (1) specification of the vertical tide or water surface elevation as a function of time, (2) specification of the tidal velocity or discharge. Sea-level canals connecting two bodies of water with independent tides have boundary conditions of the first type. This type also includes the case in which one of the water bodies is non-tidal, hence, the boundary condition at one end is specified as a constant water surface elevation. In an estuary the downstream boundary condition is of type (1) in which the known ocean tidal variation is specified at the estuary mouth. At the upstream end of the estuary the type (2) boundary condition is usually employed. In an estuary having a well-defined head-of-tide (usually a fall line over which the river passes through critical depth) the tidal discharge is set equal to zero. In an estuary in which the tide gradually dies out in the upstream direction, the uppermost section must be chosen far enough upstream so that the vertical tidal motion is negligible and the discharge is assumed to be a constant equal

to the river flow. Engineering problems requiring the calculation of tidal motions generally arise in the planning of new tidal waterways or sea-level canals or in the design of modifications to existing tidal waterways. In either case, it is important that the resulting tides and currents be known with reasonable accuracy before the work begins. The tidal regimen of a proposed canal may be such as to make navigation hazardous and maintenance difficult. Also, a new tidal waterway may introduce saline or polluted water into a body that was free of such pollutants prior to its construction.

Modifications of the geometry of an existing tidal waterway may cause mean low tide elevations to be depressed appreciably, thereby decreasing navigable depths; mean high tide elevations or the elevation of storm surges may be significantly raised, causing flooding of property and affecting adversely the discharge of storm and sanitary sewers; currents may be so accelerated that navigation is impeded or possibly made hazardous; or currents may be reduced to such an extent that shoaling is increased, or takes place where there was no shoaling prior to the modification. Changes in the tidal regimen may also affect the salinity regimen.

Examples of engineering projects which may have significant effects on the regimen of a tidal waterway are:

- Excavating a channel for navigation in an unimproved waterway;
- Deepening or enlarging an existing navigation channel;
- Training works, such as jetties and dikes;
- Barriers for hurricane protection or prevention of salinity intrusion;
- Port facilities, such as wharves, docks and piers;
- Projects that increase the area of the waterway subject to the rise and fall of the tide, such as boat basins, lagoons and turning basins;
- Projects that decrease the area of the waterway subject to the rise and fall of the tide, such as fills resulting from the disposal of dredge spoil, or fills made for the purpose of creating land for development purposes.

Hydraulic models and, possibly, electric analog models can supply the desired information with competence when an existing waterway is involved, since the model can be verified by adjustments to reproduce existing con-

ditions. The accuracy of results decreases when an entirely new waterway is under consideration; moreover, the costs in terms of time and money are often unwarranted for the purposes at hand. Hence, there is a need for mathematical models of tidal motions as well as physical models.

A number of analytical procedures are available for solving a variety of tidal problems. Most engineers understandably find it difficult to choose the method best suited to the solution of a given problem. Tidal motion is inherently the most complex type of free surface flow; it is unsteady with periodic reversal of flow directions, non-uniform, and dissipation of energy generally must be taken into account. The most competent mathematicians have concluded that some degree of approximation is necessary in order to obtain an analytical solution. Thus the large number of computational methods which have been devised is due to the variety of approximations which have been used. There is undoubtedly a gap between the efforts of the applied mathematician and application by the practicing engineer. It is desired that this gap be bridged by: (1) providing a classification of tidal problems by which the engineer can determine the computational method best suited to his problem; and (2) illustrating and comparing the computational procedures by numerical examples. It is recognized that the gap must be bridged from both directions. The engineer cannot expect to learn to deal with complex tidal dynamics in terms of elementary mathematical concepts; however, the present level of mathematical training for engineers should inherently make the gap easier to narrow.

Fortunately the advent of the high speed digital computer has greatly reduced the formal mathematical skills needed for tidal computations. Purely analytical methods for highly simplified geometries using linearized, frictionless equations require a high degree of mathematical sophistication in the solution of differential equations. Whereas computer solutions by finite difference methods which retain friction, non-linearities and a realistic geometry involve only a statement of the basic continuity and momentum equations.

## 1.2 Outline of Research Program

This investigation is concerned with one-dimensional tidal motion

in canals and estuaries. The analysis will cover the two principal types of tidal waterways: (1) estuaries open to the ocean at one end and merging with a river at the opposite end; and (2) canals or waterways connecting two independent tidal bodies.

Tidal motion in a canal or estuary can be described by two equations, one expressing the conservation of mass (the continuity equation), and the other expressing the dynamic equation of motion in the longitudinal direction (the momentum equation). In general, the energy equation is redundant unless it is necessary to account for localized energy dissipation due to an abrupt change in cross section. The various ways of dealing with the continuity and momentum equations may be grouped as follows:

#### 1. Harmonic Methods

The tidal motion is generally represented by the superposition of several harmonic functions of time. Thus the momentum equation must be approximated by a linear form. The longitudinal variation of the cross-sectional area is specified by a mathematical function such as an exponential decrease of width or a linear depth change. Straightforward analytical solutions can be obtained for a few simple geometries. A high level of mathematical technique in the solution of the partial differential equations is necessary even for cases in which the geometry is only moderately complex. The ultimate capability of the harmonic method is limited by the necessity to linearize the equations.

#### 2. Method of Characteristics

The tidal motion is represented by the propagation of a succession of small disturbances from an initial state. In the limit a continuous solution can be obtained. In the United States the method of characteristics has not been employed, to any great extent, for tidal computations. Earlier developments have been largely due to engineers and mathematicians in the Netherlands. The method is well suited to problems in which

the development of a tidal bore is expected. If friction is neglected, analytical or graphical solutions can be readily obtained even for complex geometries. When frictional effects must be taken into account, the analysis becomes extremely cumbersome.

### 3. Finite-Difference Methods

The development of the high speed digital computer has made it practical to formulate and solve the basic equations governing tidal motion in a finite-difference form. A canal or estuary of complex geometry is schematized into a series of sections of finite length. A transverse schematization divides the waterway into channels which convey water and parts which store water on the rising tide and return water on the falling tide. A longitudinal sectionalization takes account of the variation in cross-sections along the axis of the waterway.

Quadratic friction and other non-linear effects can be included without difficulty. The finite-difference method undoubtedly holds the most promise for the solution of engineering problems in tidal waterways.

A careful distinction should be made between finite-difference methods which require a computer to carry out the operations and the act of programming various methods of tidal analysis for solution by means of a digital computer. It is obvious that any of the harmonic or characteristic methods can be programmed for computer solution. Hence, the use of a computer is not, in itself, a distinguishing feature of a computational method. There are many examples in the literature in which computer programs have been written for computational methods which were developed in the pre-computer era. These must be regarded as steps backward rather than advances since they contain approximations which are unnecessary if full advantage of numerical techniques is taken. A computer solution by means of the so-called Pillsbury method is a prime example of the unfortunate tendency to modernize an obsolete method of analysis.

The objectives of the research program are to classify tidal problems in terms of boundary conditions, to discuss available analytical and numerical procedures and to recommend an appropriate method of solution for various tidal problems in estuaries and canals. The primary concern is with analytical and numerical methods rather than with analog and physical models. In general, only one-dimensional methods will be considered since these are adequate for many practical problems.

Chapter 2  
Classification of Tidal Propagation Problems  
in Estuaries and Canals

2.1 Practical Tidal Problems in Estuaries and Canals

Practical tidal problems in estuaries and canals can be classified into three categories:

- (A) Tidal problems in existing estuaries and canals involving no change of tidal regimen:
  - (1) to determine tidal currents and to devise operational rules governing navigation in estuaries and canals;
  - (2) to forecast tidal stages in estuaries and canals for storm prediction;
  - (3) to control salt water intrusion in coastal areas;
  - (4) to control water pollution due to waste disposal in estuaries and canals;
  - (5) other problems, such as the choice of suitable locations for inlet and outlet structures for the cooling water system of a thermal power station situated along an estuary or canal.
- (B) Tidal problems in existing waterways involving changes of tidal regimen:
  - (1) to increase navigation capacity in a tidal channel through deepening and widening;
  - (2) to undertake land fills of estuary water areas;
  - (3) to construct new inland harbor facilities, anchorages or turning basins;
  - (4) to protect coastal areas against extreme tides through construction of movable or fixed barriers (for example, the closures of certain sea arms in a delta);
  - (5) others, such as the construction of a tidal power station.
- (C) Tidal problems arising in the planning and design of new waterways:
  - (1) to predict tidal elevations and currents in a proposed sea-level canal connecting two oceans, an ocean and a lake, or two estuaries;
  - (2) to predict tidal elevations and currents in a proposed closed-end estuary connected to an ocean for waste disposal or navigation purposes.

Although no attempt has been made in this chapter to identify specific projects involving the practical problems listed, engineers will have no difficulty in recognizing their existence as typical engineering problems in design and planning offices. In short, tidal problems definitely play an important role in two currently important areas of civil engineering in the United States, namely, transportation and water pollution control.

## 2.2 Basic Characteristics of Tidal Propagation Problems

It is important to identify certain basic characteristics of tidal propagation problems:

- (A) Flow characteristics -- the tidal motion is considered to be a shallow water wave of long period; the flow is unsteady, non-uniform and subcritical, and the direction of flow reverses periodically. The flow is assumed to be incompressible and it may be non-homogeneous due to salinity intrusion.

Most of the flow characteristics are incorporated into the derivation of the basic equations used for solution. The characteristics of reversing flow are in contrast to river flow or flood wave propagation in which only uni-directional flow exists.

- (B) Mathematical characteristics -- second order, quasi-linear partial differential equations of hyperbolic type, mixed boundary and initial value problems of transient nature.

It can be shown that the basic equations used for solution are quasi-linear partial differential equations of the hyperbolic type (Hildebrand, 1953). Since it is a mixed boundary and initial value problem, the solution is transient and sensitive to changes of the boundary conditions.

Boundary conditions refer to the time variation of water surface elevations or average velocities or total discharges at both ends of the tidal channel while initial conditions refer to the spatial variation along the tidal channel at a particular time when the solution is initiated.

- (C) Characteristics of channel geometry:

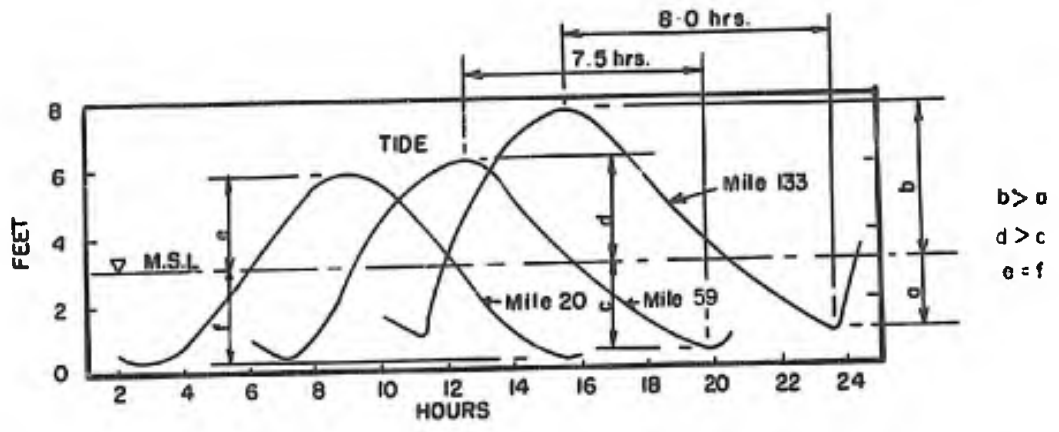
- (1) Estuaries -- uniform, converging or irregular channels of prismatic or non-prismatic type;
- (2) Canals -- uniform and prismatic channels.

Some implications due to the basic characteristics of tidal motion are illustrated by the tidal data for the Delaware estuary shown in Fig. 1. The tide curve in Delaware Bay at Miah Maull (mile 20) is sinusoidal with equal amplitudes above and below mean sea level (M.S.L.). Near the head of tide at mile 133 (near Trenton) the distortion of the tidal elevation curve is clearly shown. The tidal range (HW to LW) has increased and the mean water level is higher than the M.S.L. The duration of the falling tide (ebb) is almost twice as long as the duration of the rise (flood) and the time of low water is eight hours later at mile 133 than at mile 20. If an average depth of 21 feet is assumed for the Delaware, the frictionless propagation velocity of the tidal wave,  $c = \sqrt{gh} = 26$  ft/sec. On this basis it would require 6.4 hours for the wave to move a distance of 113 miles. The difference between the computed and the observed time of 8 hours is undoubtedly due to friction, reflection and depth variations along the estuary.

### 2.3 Factors Affecting Tidal Propagation in Estuaries and Canals

The various factors involved are as follows:

- (A) Ocean tides: the ocean tide constitutes the major cause of tidal motion in estuaries and canals. Therefore, its variations with respect to time must be known a priori. Under conditions of extreme tides, the effects due to interaction with surges should not be ignored.
- (B) Geometry of the channel: the cross-sections, the bottom elevation of the channel (with respect to a reference datum), and the length of the channel must be known. The existence of junctions with other channels must be considered, unless the branching channels are much smaller in size in comparison with the main channel.
- (C) Boundary roughness of the channel: some measure of the boundary roughness must be employed for a correct estimation of flow resistance in a tidal channel. In the present study, Manning's coefficient is adopted.
- (D) Fresh water discharge at the river end of an estuary: tidal motion in an estuary may be influenced by variations in the river discharge.
- (E) Inflow of fresh water from side channels: lateral inflows from side channels may exist within the reach of an estuary or a canal.
- (F) Local wind: strong winds may affect the time of high and low waters as well as the high and low water planes along the channel.



$b > a$   
 $d > c$   
 $e = f$

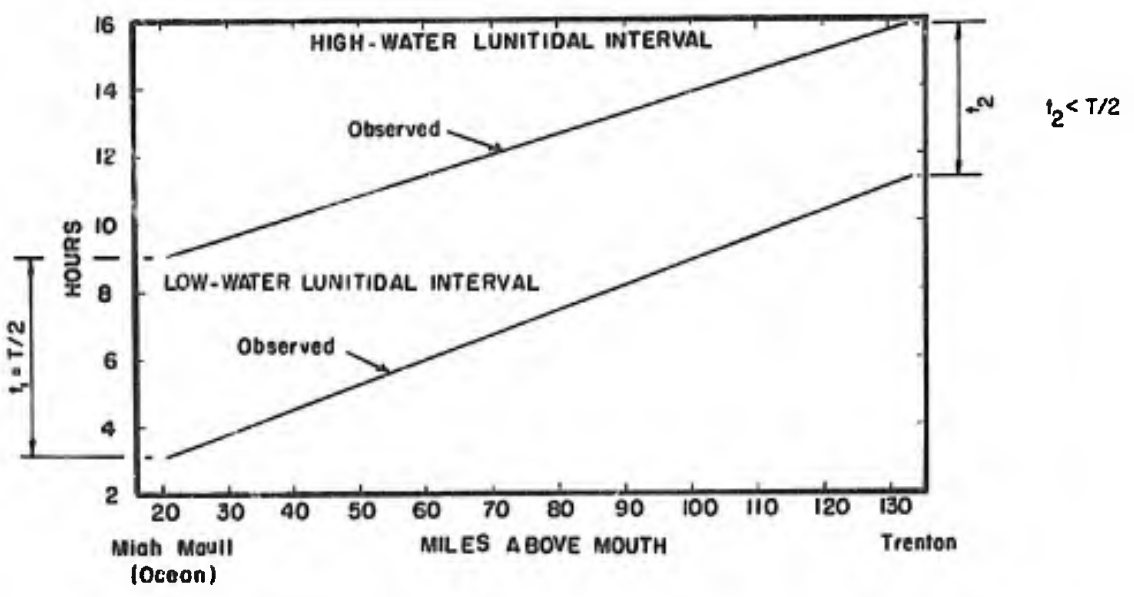
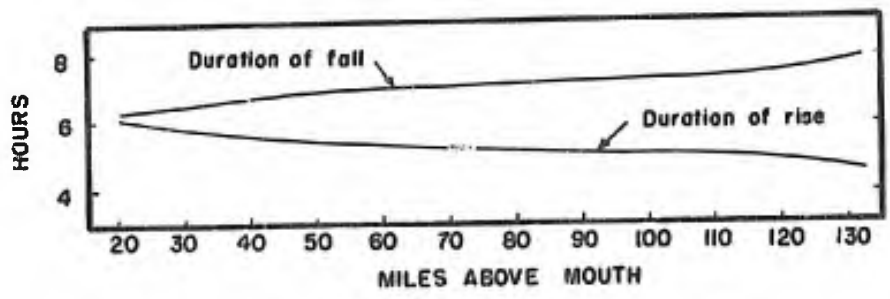


Fig. 1 Tidal Data on the Delaware Estuary

- (G) Coriolis effect in wide estuaries: in the Northern Hemisphere, the water level in a channel tends to be higher on the right bank than the left one when one faces in the direction of flow; and vice versa, in the Southern Hemisphere. Since this report is confined to one-dimensional problems, it is neglected in the present study.
- (H) Characteristics of soil at channel bottom: seasonal and long-term variations of channel geometry depend on the characteristics of soil at the channel bottom if erosion or deposition is taking place.
- (I) Coastal processes and coastline features near the entrance to the channel: the coastal processes and coastline features may also have a significant effect on seasonal and long-term variations of channel geometry. Any artificial changes of coastline features may lead to changes in characteristics of shoaling or erosion in a tidal channel.

#### 2.4 Characteristics of Ocean Tides

The ocean tide is the major factor contributing to the tidal propagation in estuaries and canals. A brief review of some characteristics of ocean tides is given.

The three major types of ocean tides are:

- (A) Diurnal tide which consists of one high water and one low water in a lunar day (i.e., a tidal period of 24.85 hours).
- (B) Semi-diurnal tide which consists of two nearly equal high waters and low waters in a lunar day (i.e., a tidal period of 12.42 hours).
- (C) Mixed tide which consists of a mixture of diurnal and semi-diurnal tides in a lunar month.

Depending on the location and its local topography, characteristics of ocean tides vary from place to place and coast to coast. In general, one may find diurnal tides prevailing on the coasts of China, Alaska, the Gulf of Mexico and the Gulf of St. Lawrence (Northumberland Strait); semi-diurnal tides, on the shores of the Atlantic; and mixed tides on the Pacific Coast of North America.

The tidal range at a particular location also varies with respect to the time in a lunar month. Spring tides occur after the full or new moon, while neap tides occur after the time of the first or third quarter of a lunar month. Excluding the effect of interaction with surges due to swells from nearby open seas or the local effect due to gusts blowing over

the channel, a spring tide normally represents the largest tidal range; and a neap tide, the least.

A continuous tidal record of at least 28 days, preferably a year, is considered essential for the prediction of ocean tides at any location by the method of harmonic analysis. The resulting record should be adjusted to represent long-time mean conditions of sea level and upland discharges.

#### 2.5 Types of Estuaries

An estuary is the reach of a river adjoining the ocean, in which the flow is affected by both the fresh water discharge from the river and the seawater flowing in from the ocean due to tidal propagation. The geometry of an estuary is such that its cross-sectional area and profile vary along the estuary. Depending on the degree of mixing, produced by the tidal motion, different mixing mechanisms result in two general types of estuaries:

- (I) Highly stratified estuaries due to high fresh water discharge and small tidal range (example: Southwest Pass of Mississippi River).
- (II) Partially and well mixed estuaries due to low fresh water discharges and large tidal range (examples: Hudson, St. Johns, Savannah, Delaware and Raritan estuaries).

In general, both horizontal and vertical density gradients exist within the salinity intrusion region. Nevertheless, Ippen and Harleman (1961) concluded from test results obtained from the W.E.S. Tidal Flume that salinity intrusion has a very small effect on tidal stages and discharges in estuaries. Thus, separate treatments for tidal calculations in different types of estuaries are not considered a necessity in this report.

### Chapter 3

#### Basic Equations for Analysis Of One-Dimensional Tidal Motion

The general one-dimensional continuity and momentum equations for unsteady, non-uniform flow in variable area tidal channels are derived in this section. The objective of this chapter is to provide a framework for discussion of various analytical methods.

A cross section of an irregular channel is shown in Fig. 2a. The  $x$  coordinate is measured horizontally along the longitudinal axis of the channel from the ocean end of the estuary and  $h$  is the distance to the instantaneous position of the water surface from a horizontal reference datum. The flow is assumed to be one-dimensional, hence, channel curvature and Coriolis effects are neglected and the transverse water surface is horizontal. The density is homogeneous and hydrostatic pressure is assumed to prevail at all points in the channel.

Within the Eulerian viewpoint, the conservation of mass and momentum equations may be formulated in either of two ways: the material method or the control volume method. In the material method the flow characteristics at a section are obtained by following the motion of a given mass of fluid,  $\Delta m$ , through a small increment of time,  $\Delta t$ , in the vicinity of the fixed section. In the control volume method, the equations are derived by considering the fluxes of mass and momentum through a fixed control volume. The one-dimensional momentum equation is most readily derived by means of the material method, whereas the continuity equation is usually derived by the control volume method. In order to be consistent, the material method will be used for both developments.

Derivations of the unsteady continuity and momentum equations for variable area channels have also been given by Stoker (1957), Lai (1965) and others.

If, as shown in Fig. 2a, the cross section has both deep and very shallow portions, the channel may be divided into conveyance and storage regions. In this case the tidal flow is assumed to be confined to the

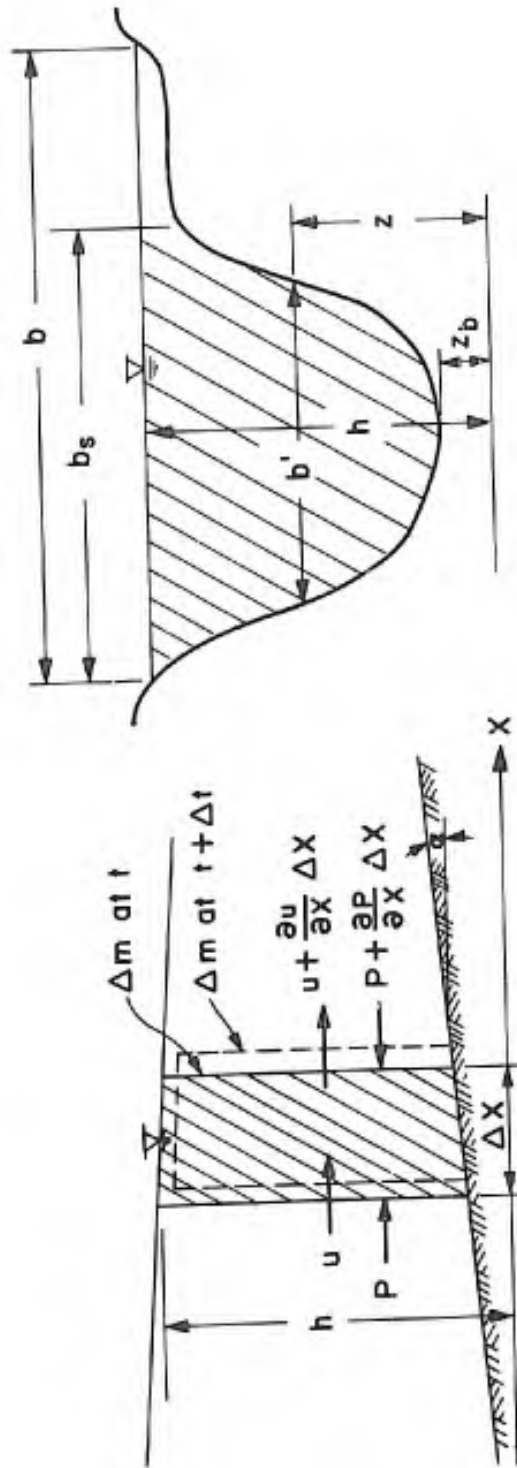


Fig. 2a Definition Sketch - Irregular Channel

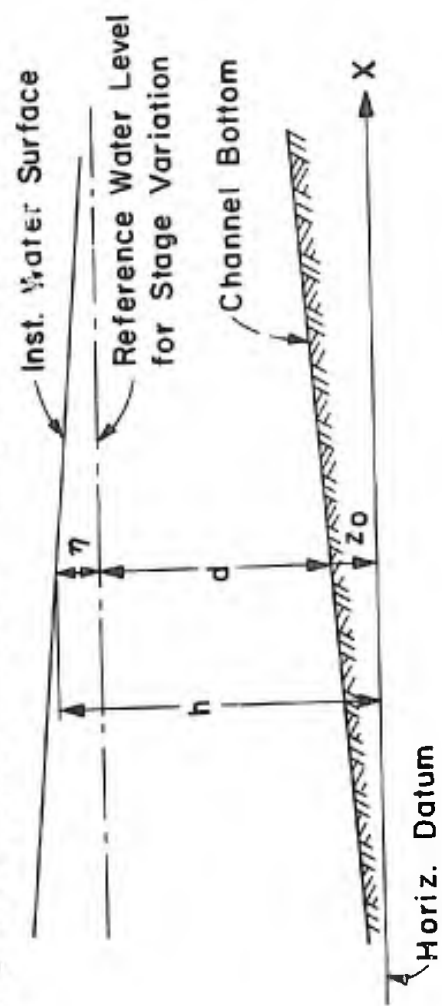


Fig. 2b Definition Sketch - Rect. Channel

conveyance channel area, defined by the width  $b_s$ , and the shallow portion, defined by the width  $b - b_s$ , contributes to channel storage only. The cross-sectional area  $A$  is defined as the area of the conveyance channel. Hence, the average velocity  $u = Q/A$ , where  $Q$  is the longitudinal discharge.

The fluid mass,  $\Delta m$ , at time  $t$  is shown in Fig. 2a by the planes at  $x_1$  and  $x_2$ . The mass of water in motion at time  $t$  is given by  $\rho A \Delta x$ , in which  $\rho$  is the density of water,  $A$  is the cross-sectional area and  $\Delta x = x_2 - x_1$  is the length of the element.

### 3.1 Continuity Equation

The continuity equation is derived by applying the law of conservation of mass to the fluid element  $\Delta m$ . Assuming no lateral inflow or outflow, this may be expressed mathematically by the requirement that the total (or substantial) derivative be equal to zero, thus

$$\frac{D(\Delta m)}{Dt} = \frac{D(\rho A \Delta x)}{Dt} = 0$$

In <sup>a</sup>tidal channel two factors may contribute to a change in the mass of the moving element: (1) a change due to storage in the stagnant shallow portion equal to

$$- \rho (b - b_s) \frac{\partial h}{\partial t} \Delta x$$

(2) a change due to external lateral flow into the element (caused by tributary inflow, spillage over a levee or seepage through the channel bank) equal to

$$\rho q \Delta x$$

where  $q$  is the lateral discharge per unit of longitudinal length (positive for inflow and negative for outflow). Thus the continuity equation can be written,

$$\frac{D(\rho A \Delta x)}{Dt} = - \rho (b - b_s) \frac{\partial h}{\partial t} \Delta x + \rho q \Delta x \quad (1)$$

The total derivative can be expressed in terms of partial derivatives through the relation,

$$\frac{D}{Dt} = \frac{\partial}{\partial t} + u \frac{\partial}{\partial x} \quad (2)$$

where  $u$  is the average longitudinal velocity at the cross section. Considering a homogeneous, incompressible fluid of constant density, equation (1) can be expanded to the form,

$$\Delta x \left( \frac{\partial A}{\partial t} + u \frac{\partial A}{\partial x} \right) + A \frac{D(\Delta x)}{Dt} = -(b - b_s) \frac{\partial h}{\partial t} \Delta x + q \Delta x \quad (3)$$

The term  $\frac{D(\Delta x)}{Dt}$  may be treated as follows:

at time  $t$ ,  $\Delta x = x_2 - x_1$ ,

at time  $t + \Delta t$ ,  $\Delta x' = x_2 + \left( u + \frac{\partial u}{\partial x} \Delta x \right) \Delta t - (x_1 + u \Delta t)$

or  $\Delta x' = x_2 - x_1 + \frac{\partial u}{\partial x} \Delta x \Delta t$

therefore,

$$\frac{D(\Delta x)}{Dt} = \frac{\Delta x' - \Delta x}{\Delta t} = \frac{\partial u}{\partial x} \Delta x \quad (4)$$

and equation (3) becomes, after dividing by  $\Delta x$ ,

$$\frac{\partial A}{\partial t} + u \frac{\partial A}{\partial x} + A \frac{\partial u}{\partial x} + (b - b_s) \frac{\partial h}{\partial t} - q = 0$$

or, since the discharge  $Q = Au$ ,

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} + (b - b_s) \frac{\partial h}{\partial t} - q = 0 \quad (5)$$

Referring to Fig. 2a, where the moving stream surface width  $b_s = \partial A / \partial h$ , it follows that

$$\frac{\partial A}{\partial t} = \frac{\partial A}{\partial h} \frac{\partial h}{\partial t} = b_s \frac{\partial h}{\partial t}$$

and equation (5) becomes

$$b \frac{\partial h}{\partial t} + \frac{\partial Q}{\partial x} - q = 0 \quad (6)$$

Equation (6) is known as the continuity equation.

### 3.2 Momentum Equation

The equation of motion is derived from Newton's Second Law, in the momentum equation form, which states that the time rate of change of longitudinal momentum is equal to the sum of external longitudinal forces acting on the moving fluid element.

The longitudinal momentum is given by the product

$$(\Delta m)u = (\rho A \Delta x) \frac{Q}{A} = \rho Q \Delta x$$

The time rate of change of momentum is given by the total derivative which is equated to the summation of forces  $\sum F_x$  to obtain the momentum equation

$$\frac{D(\rho Q \Delta x)}{Dt} = \rho \Delta x \frac{DQ}{Dt} + \rho Q \frac{D(\Delta x)}{Dt} = \sum F_x \quad (7)$$

From equations (2) and (4)

$$\frac{DQ}{Dt} = \frac{\partial Q}{\partial t} + u \frac{\partial Q}{\partial x} \quad \text{and} \quad \frac{D(\Delta x)}{Dt} = \frac{\partial u}{\partial x} \Delta x$$

and equation (7) becomes

$$\rho \Delta x \left( \frac{\partial Q}{\partial t} + u \frac{\partial Q}{\partial x} \right) + \rho Q \frac{\partial u}{\partial x} \Delta x = \sum F_x \quad (8)$$

The possibility of a change in the longitudinal momentum flux due to flow entering or leaving the main channel from the storage area and due to the lateral inflow  $q$  has been discussed by various investigators.

This involves an inherent assumption as to the direction in which the flow enters or leaves the conveyance section. As pointed out by Dronkers (1964, p. 194), the momentum effect also depends on whether the water level is rising or falling. It is generally agreed that the effect on the momentum equation is small, hence, in this development it will be assumed that the lateral flows enter or leave the main channel at right angles to the longitudinal axis and that there is no contribution to the longitudinal momentum flux.

The correction to the longitudinal momentum flux due to the non-uniform velocity distribution at a cross section has also been neglected in this development. The momentum correction factor is usually of the order of three to five percent. The possibility of schematization of the channel cross section into conveyance and storage regions is an approximate method of accounting for highly non-uniform velocity distributions and further refinements concerning the velocity distribution are not warranted.

The summation of external forces,  $\sum F_x$ , consists of  $P$ , the resultant hydrostatic pressure force on the vertical cross section;  $(P_w)_x$ , the  $x$  component of the horizontal pressure force exerted by the converging boundaries of the section;  $(F_f)_x$ , the frictional resistance force exerted by the boundaries. Hence, the three forces, using the notation shown in Figure 2a, are

$$\sum F_x = [P - (P + \frac{\partial P}{\partial x} \Delta x)] + (P_w)_x - (F_f)_x$$

or

$$\sum F_x = - \frac{\partial P}{\partial x} \Delta x + (P_w)_x - (F_f)_x \quad (9)$$

The total pressure force on a vertical face is

$$P = \int_{z_b}^h \rho g (h - z) b' dz$$

where  $b'$  is the channel width at elevation  $z$ ; hence, by the use of Leibnitz's rule

$$\frac{\partial P}{\partial x} = \rho g \frac{\partial h}{\partial x} A + \rho g \int_{z_b}^h (h - z) \frac{\partial b'}{\partial x} dz \quad (10)$$

where the flow area  $A = \int_{z_b}^h b' dz$

The boundary pressure force is

$$(P_w)_x = \rho g \int_{z_b}^h (h - z) \frac{\partial b'}{\partial x} \Delta x dz \quad (11)$$

The average frictional shear stress on the boundary of the element is

$$\tau_o = \rho g R S_E$$

where  $R$  is the hydraulic radius,  $R = \frac{A}{P_r}$ ,  $P_r$  is the wetted perimeter and  $S_E$  is the slope of the energy gradient. The frictional force is therefore

$$F_f = \tau_o (P_r \Delta x) = \rho g A S_E \Delta x \quad (12)$$

The  $x$  component may be taken equal to  $F_f$  since the  $\cos \alpha \approx 1$ . The slope of the energy gradient is evaluated from the Chezy equation in which

$$S_E = \frac{u|u|}{C^2 R} = \frac{Q|Q|}{A^2 C^2 R} \quad (13)$$

and  $C = \frac{1.49}{n} R^{1/6}$  ( $n$  = Manning roughness coefficient) in ft -sec units.

Equation (12) becomes

$$(F_f)_x = \frac{\rho g Q|Q|}{A C^2 R} \Delta x \quad (14)$$

Equations (10), (11) and (14) may be substituted into equation (9) to obtain the expression for  $\sum F_x$

$$\sum F_x = -\rho g \frac{\partial h}{\partial x} A \Delta x - \frac{\rho g Q|Q|}{AC^2R} \Delta x \quad (15)$$

It is noted that the integrals in the boundary pressure force equations (10) and (11) cancel.

The general one-dimensional momentum equation is obtained by substituting equation (15) into equation (8) and dividing by the product  $\rho \Delta x$ , thus

$$\frac{\partial Q}{\partial t} + u \frac{\partial Q}{\partial x} + Q \frac{\partial u}{\partial x} + g \frac{\partial h}{\partial x} A + g \frac{Q|Q|}{AC^2R} = 0 \quad (16)$$

Equation (16) together with the continuity equation (6) form the pair of equations to be used for the solution of tidal propagation problems in variable area channels.

### 3.3 Basic Equations for Uniform Rectangular Channels

The momentum and continuity equations can be put into a more familiar form if the cross section is assumed to be rectangular and of constant width such that  $b = b_s = \text{constant}$ . If the bottom of the channel is plane, a mean depth  $d$  may be defined as shown in Figure 2b. Hence

$$h = z_o + d + \eta \quad (17)$$

$$A = b_s (d + \eta) \quad (18)$$

$$Q = u b_s (d + \eta) \quad (19)$$

In the above equations  $\eta$  is the instantaneous position of the water surface with respect to the mean depth  $d$  as shown in Figure 2b. In the following development lateral inflow will be ignored, hence  $q = 0$ . Under the above restrictions the continuity equation (6) becomes

$$\frac{\partial \eta}{\partial t} + \frac{\partial}{\partial x} (u(d + \eta)) = 0 \quad (20)$$

and the momentum equation (16) becomes, after algebraic manipulations and use of equation (20)

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + g \frac{\partial z_0}{\partial x} + g \frac{\partial d}{\partial x} + g \frac{\partial \eta}{\partial x} + g \frac{u|u|}{C^2 R} = 0 \quad (21)$$

Equations (20) and (21) may be further simplified by assuming frictionless flow and by employing the long wave approximation which neglects the non-linear term  $u \partial u / \partial x$ . If it is also assumed that the slope of the channel bottom is zero ( $\partial z_0 / \partial x = 0$ ) and that the mean water level plane is horizontal ( $\partial d / \partial x = 0$ ), the momentum equation (21) becomes

$$\frac{\partial v}{\partial t} + g \frac{\partial \eta}{\partial x} = 0 \quad (22)$$

If the wave amplitude is small compared to the depth ( $\eta \ll d$ ) the continuity equation (20) may be written as

$$\frac{\partial \eta}{\partial t} + d \frac{\partial u}{\partial x} = 0 \quad (23)$$

The velocity term may be eliminated from the above by differentiating equation (22) with respect to  $x$  and equation (23) with respect to  $t$ , thus

$$\frac{\partial^2 \eta}{\partial t^2} = c^2 \frac{\partial^2 \eta}{\partial x^2} \quad (24)$$

where  $c = \sqrt{gd}$  is the frictionless wave velocity. Equation (24) is the classical wave equation.

The various forms of the continuity and momentum equations presented above form the starting point for most of the previous work on tidal calculations.

## Chapter 4

### Analytical and Numerical Methods for Solution of Tidal Propagation Problems

A complete bibliography of the papers which have applied analytical methods to the solution of tidal propagation problems in estuaries and canals would be composed of several hundred items. (See the Bibliography on Tidal Hydraulics and Supplements 1 through 4 published by the Committee on Tidal Hydraulics.) Most of the analytical approaches may be grouped into the categories described in section 1.2:

1. Harmonic Methods.
2. Method of Characteristics.
3. Finite Difference Methods.

The objective of this chapter is to discuss the essential features of the various methods and to cite some pertinent references from the literature.

#### 4.1 The Harmonic Methods

The basic feature of the harmonic method is the assumption that the solution to the second order partial differential equation resulting from a combination of the continuity and momentum equations is a harmonic function. If the tide at the ocean end can be represented as a simple sine curve and if the differential equations are linearized, the calculated tide in the estuary will also be sinusoidal. This is known as the single-harmonic method. (Dronkers, 1959a) The momentum equation (16) contains three non-linear terms: the advective accelerations  $u \partial Q / \partial x$  and  $Q \partial u / \partial x$  and the quadratic friction term. In order to obtain a linear equation, the acceleration terms are ignored and the friction term is replaced by a linear form known as the Lorentz approximation.

The condition that all tidal elevations and discharges are periodic functions of time replaces the initial condition usually required for the solution of a differential equation for unsteady motion. A second feature

of the harmonic method is that the geometric variation of the channel area in the longitudinal direction should be expressed as an algebraic function of  $x$ . This is a serious limitation of the harmonic method for estuaries of complex geometry. Furthermore, if the ocean tide is other than a simple sine curve, higher harmonics must be considered using the principle of superposition applicable to linear equations. The consideration of more than two harmonic components is impractical by this method. This is due to the difficulty of developing a linear friction expression which takes into account the interaction of the multiple harmonics. Dronkers (1959b) illustrates the application of the double-harmonic method to the calculation of tidal motion in Tampa Bay. The Bay was divided into a series of reaches, each having a constant geometry and a system of linear equations is written for each reach. The amount of computation is excessive and the method is not considered to be a practical one in the light of more recent developments.

A few examples of the single harmonic method for certain special cases are given in the following sections.

#### 4.1.1 Linear Equations Without Friction

A concise review of the mathematical description of tides without friction has been given by Ippen (1966). The linearized equations (22) and (23) for a constant width, rectangular section result in the wave equation (24) which has harmonic solutions of the form

$$\eta = a \cos (\sigma t - kx) \quad (25)$$

where,  $a$  = tidal amplitude =  $\eta_{\max}$

$\sigma$  = tidal frequency =  $2\pi/T$

$T$  = tidal period

$k$  = wave number =  $2\pi/L$

$L$  = tidal wave length

$c$  = frictionless tidal wave velocity =  $\sigma/k = \sqrt{gd}$

$t$  = time

$x$  = longitudinal coordinate

Solutions for uniform channels having various end boundary conditions can be obtained by the method of superposition. The following special cases for uniform rectangular channels are summarized by Ippen (1966):

- (a) Ocean tide entering a channel closed at one end.
- (b) Ocean tide entering a channel connected to a large basin without tide.
- (c) Two oceans with independent tides connected by a canal.

The solution for case (a), for example, is given by

$$\eta = 2a_0 \cos \sigma t \cos kx \quad (26)$$

with the notation as shown in Fig. 3. With  $\eta$  given by equation (26), the tidal velocity may be obtained from the continuity equation (23)

$$u = \frac{2a_0 c}{d} \sin \sigma t \sin kx \quad (27)$$

Thus the amplitudes and velocities are out of phase by one-quarter of the tidal period. In addition, high or low water occurs simultaneously at all points in the channel.

Many investigators have treated the frictionless case of rectangular channels of gradually varying depth and/or width. Ippen (1966) summarizes solutions for the following conditions which are based on the assumption of constant energy flux:

- (a) Channel of constant depth and linear width variation.
- (b) Channel of constant depth with exponential variation of width (i.e.  $b_x = b_e e^{f(x)}$ ).
- (c) Channel of constant width and linear depth variation.

In these cases the ocean tides are assumed to be sinusoidal and the basic wave form in the channel also remains sinusoidal or is the result of the superposition of sine waves. The assumption of constant energy

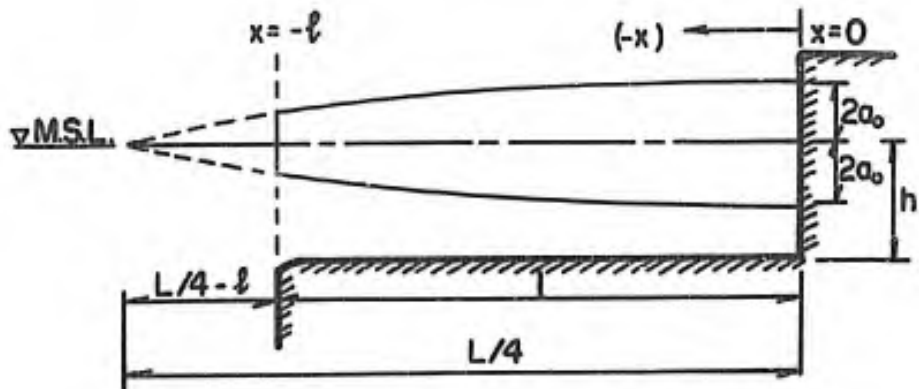


Fig. 3 Longitudinal Cross section of a Rectangular Channel of Length  $< L/4$

flux neglects reflection of wave energy from the converging side walls or the sloping bottom. This requires that the percentage changes in depth and breadth occurring in one wave length be small. (Lamb, 1932) Since most estuaries have a total length which is less than the tidal wave length, this condition is rarely fulfilled. Dean (1962) has shown that for a constant width the percentage change in depth divided by the wave length must be less than 60%, while for a constant depth and varying width the corresponding figure is 30%.

Evangelisti (1955) has given a more general treatment for channels in which both the width and depth may be functions of  $x$  of the form

$$b = Bx^\alpha$$

and  $d = Dx^\gamma$

where  $B$ ,  $D$ ,  $\alpha$  and  $\gamma$  are arbitrary constants. The linearized form of the frictionless momentum equation (16) for a variable area, rectangular channel is

$$\frac{\partial(Au)}{\partial t} + gA \frac{\partial h}{\partial x} = 0 \quad (28)$$

and the continuity equation (6) becomes, ( $q = 0$ )

$$\frac{\partial(Au)}{\partial x} + b \frac{\partial h}{\partial t} = 0 \quad (29)$$

The velocity terms can be eliminated by cross-differentiation. The approximate result is

$$\frac{\partial^2 \eta}{\partial t^2} = \frac{g}{b} \frac{\partial}{\partial x} \left( bd \frac{\partial \eta}{\partial x} \right) \quad (30)$$

No assumption of constant energy flux is made; hence, this method is not subject to the restrictions discussed above.

The solution to equation (30) for a channel connected to an ocean having a harmonic tide is given in terms of complex Bessel functions.

The foregoing analytical relations for frictionless tidal propagation in prismatic channels are primarily of instructional value. It is concluded that there are few engineering problems in tidal waterways or canals in which the frictionless solutions would be of value for more than preliminary estimates.

#### 4.1.2 Linear Equations with Friction

The friction term in the momentum equation is linearized by means of the Lorentz (1926) approximation. This assumes that the work done by tidal friction during a tidal period is the same whether determined by the quadratic resistance law or by a substitute linear approximation. Thus in a horizontal channel, in which the mean water surface is also horizontal, equation (16) becomes after neglecting the acceleration terms

$$\frac{\partial u}{\partial t} + g \frac{\partial \eta}{\partial x} + g M u = 0 \quad (31)$$

where  $M$ , the coefficient of the linear friction term, is given by

$$M = \frac{8 u_{\max}}{3\pi C^2 R} \quad (32)$$

and  $u_{\max}$  = maximum tidal velocity  
 $C$  = Chezy resistance coefficient  
 $R$  = hydraulic radius

Within the degree of approximation involved, equation (31) may be used for rectangular channels of either constant or variable area. For a constant area channel, equation (23) is the appropriate form of the continuity equation. The equations may be combined by cross-differentiation into the linear second order friction equation (Harleman and Ippen,

1961).

$$\frac{\partial^2 \eta}{\partial t^2} + g M \frac{\partial \eta}{\partial t} = g d \frac{\partial^2 \eta}{\partial x^2} \quad (33)$$

The primary difficulty in using equation (33) for the prediction of tidal motion is in the choice of M which, from equation (32), depends upon the amplitude of the tidal velocity. This is unknown a priori; furthermore, it is generally a function of x. Equation (33) can be solved analytically only if M is assumed to be a constant for the entire channel; hence, its choice will be a matter of rough approximation.

Perroud (1959) used the linear friction equation (31) and the variable area continuity equation (6) to solve tidal wave propagation into constant depth rectangular channels whose width varied either linearly or exponentially. He also considered a channel of uniform breadth and linearly varying depth. The results are subject to the inaccuracies of neglecting the non-linear inertial term and of the proper choice of the coefficient of the linear friction term. In addition, the question of upstream boundary conditions related to the head of tide was not discussed.

A practical application of the single harmonic, linear friction theory is in the partial analysis of tidal motion in an existing estuary. Given the estuary geometry and the boundary conditions, a complete analysis implies that it is possible to calculate both the tidal elevations and the tidal discharges throughout the estuary. A partial analysis implies that it is desired to calculate the tidal discharges (or velocities) throughout the estuary using information on the tidal elevations in the estuary. Since tidal elevations are more easily measured than discharges, the results may be useful in many cases. For example, information on tidal velocities is needed in the analysis of salinity intrusion and in the determination of the distribution of pollutants or dredge spoils discharged from various sources in an estuary. In general, it is sufficient to have information on the elevation of high (or low) water and the time

of its occurrence at various points along an estuary. For many estuaries this information can be obtained from the published tide tables of the Coast and Geodetic Survey.

The essential features of the method can be illustrated by considering a closed-end estuary of constant mean depth whose width varies exponentially. Taking  $x = 0$  at the closed end and the positive direction toward the ocean, the estuary width can be represented by

$$b = b_e e^{\delta x} \quad (34)$$

where  $b_e$  and  $\delta$  are constants determined by the estuary geometry. A harmonic solution of the linear function equation for the tidal elevation at any  $x$  and  $t$  is given by

$$\eta = \frac{\eta_{oH}}{2} e^{-\frac{\delta x}{2}} \left( e^{\mu x} \cos(\sigma t + kx) + e^{-\mu x} \cos(\sigma t - kx) \right) \quad (35)$$

where

$\eta_{oH}$  = tidal amplitude at closed end ( $x = 0$ ,  $t = 0$ )

$\mu$  = amplitude attenuation coefficient

Equation (35) is the result of the superposition of two waves travelling in opposite directions in the estuary. This arises from the wave entering the estuary from the ocean and its reflection from the closed end. The resulting motion is known as a damped co-oscillating tide. The local time of high tide  $\sigma t_H$  occurs when  $\partial \eta / \partial t = 0$ ; hence, from equation (35) it follows that

$$\sigma t_H = \tan^{-1} (-\tan kx \tanh \mu x) \quad (36)$$

The local amplitude of high tide  $\eta_{xH}$  can be found by substituting  $\sigma t_H$  into equation (35) for  $\sigma t$ , thus

$$\eta_{xH} = \eta_{oH} e^{-\frac{\delta x}{2}} \left( \frac{1}{2} \cos 2kx + \cosh 2\mu x \right)^{1/2} \quad (37)$$

If the time of high tide and its amplitude are known at various distances (x) along the estuary, the two unknowns  $kx$  and  $\mu x$  can be obtained by solving the pair of equations (36) and (37) for each value of x.

Figures 4a and 4b show the values of  $kx$  and  $\mu x$  obtained in this manner by Harleman (1966) for the Delaware estuary. In Fig. 4a, the plot of  $kx$  versus x is linear, therefore  $k = 0.58 \times 10^{-5}$  rad/ft. Since  $k = 2\pi/L$  it follows that the tidal wave length L is given by

$$L = \frac{2\pi}{k} = 1,080,000 \text{ ft (or 205 miles)}$$

The total length of the estuary from Trenton to Breakwater at the ocean end is approximately 132 miles or about two-thirds of the tidal wave length. The velocity of the tidal wave is given by

$$c = \frac{L}{T} = \frac{\sigma}{k}$$

where  $\sigma = \frac{2\pi}{T} = 1.41 \times 10^{-4}$  rad/sec for a semi-diurnal tide of  $T = 12.4$  hours. Therefore

$$c = \frac{1.41}{10^4} \cdot \frac{10^5}{0.58} = 24.3 \text{ ft/sec.}$$

The frictionless tidal wave velocity, based on a mean depth of 21 feet in the Delaware, is

$$c = \sqrt{gd} = 26.0 \text{ ft/sec.}$$

The instantaneous tidal discharge Q at any x is found by integrating the continuity equation (29). Since  $Q = Au$  and  $h = \eta + d + z_o$  (Figure 2b), the continuity equation can be written as

$$\frac{\partial Q}{\partial x} + b \frac{\partial \eta}{\partial t} = 0 \quad (38)$$

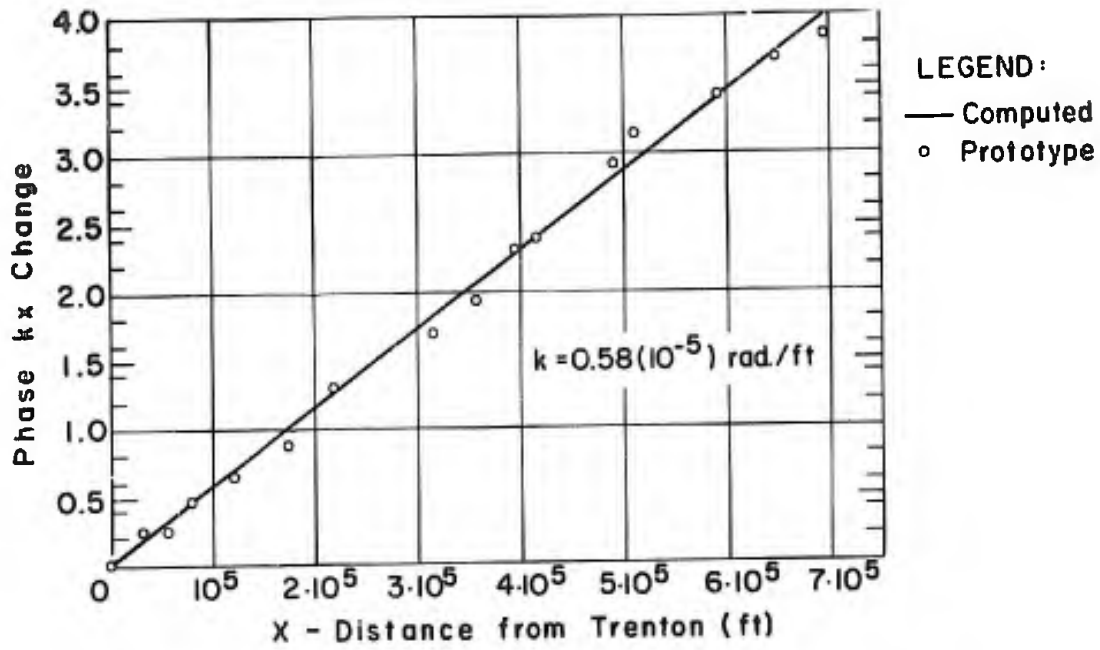


Fig. 4a Phase Change  $kx$  vs.  $x$  for Delaware Estuary

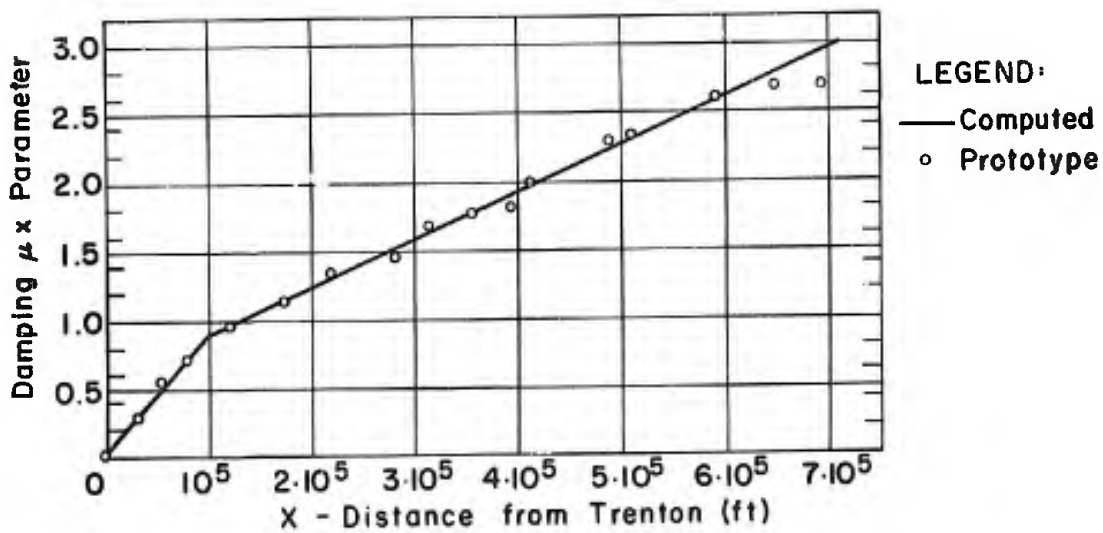


Fig. 4b Damping Parameter  $\mu x$  vs.  $x$  for Delaware Estuary

hence, with  $b$  given by equation (34),

$$Q = -b e^{\int \frac{\delta x}{e}} \frac{\partial \eta}{\partial t} dx \quad (39)$$

where  $\partial \eta / \partial t$  is obtained from equation (35).

The resulting calculation of the maximum tidal discharge as a function of  $x$  in the Delaware is shown in Figure 5. The calculations are compared with a field measurement by Miller (1960) and with discharges determined by the method of cubature (see section 4.3.1) by Pillsbury (1956) and Wicker (1955).

Similar analyses using the method of the damped cooscillating tide have been given by Redfield (1950), Ippen and Harleman (1958) for the Bay of Fundy and by Abbott (1960) for the Thames estuary.

#### 4.2 The Method of Characteristics

The application of the method of characteristics to the calculation of tides in estuaries or canals is most readily shown by neglecting friction. Hence equations (28) and (29) are applicable; setting  $Q = Au$  they become,

$$\text{(motion)} \quad \frac{\partial h}{\partial x} + \frac{1}{gA} \frac{\partial Q}{\partial t} = 0 \quad (40)$$

$$\text{(continuity)} \quad \frac{\partial Q}{\partial x} + b \frac{\partial h}{\partial t} = 0 \quad (41)$$

Multiplying equation (40) by  $\frac{c}{2}$  where  $c$  is the frictionless wave celerity  $c = \sqrt{\frac{gA}{b}}$  and eq. (41) by  $\frac{wc}{2}$  where  $w = \sqrt{\frac{1}{gAb}}$  and adding or subtracting, the following equation is obtained:

$$\frac{wc}{2} \left[ \frac{\partial Q}{\partial x} + b \frac{\partial h}{\partial t} \right] \pm \frac{c}{2} \left[ \frac{\partial h}{\partial x} + \frac{1}{gA} \frac{\partial Q}{\partial t} \right] = 0 \quad (42)$$

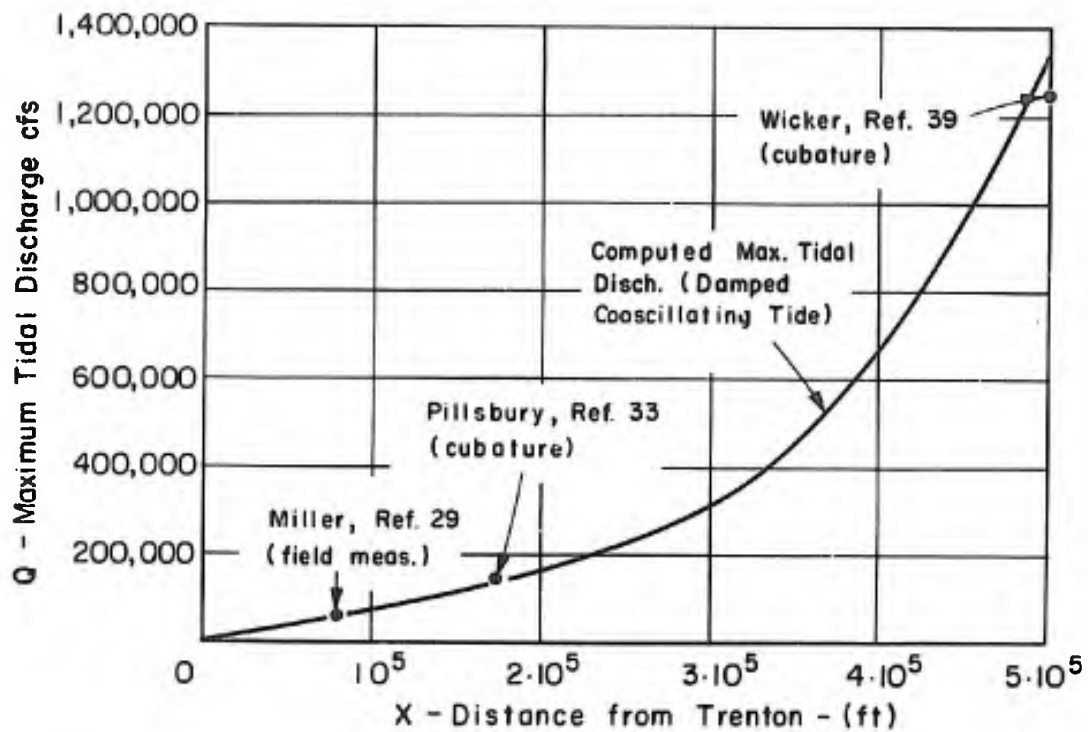


Fig. 5 Maximum Tidal Discharge vs. Distance from Trenton-Delaware Estuary

Taking the positive sign, eq. (42) is identical with

$$\frac{DF}{Dt} = \frac{\partial F}{\partial t} + c \frac{\partial F}{\partial x} = 0 \quad (43)$$

if  $F = \frac{h}{2} + \frac{wQ}{2} \quad (44)$

In a similar manner, taking the negative sign, eq. (42) is identical with

$$\frac{DG}{Dt} = \frac{\partial G}{\partial t} - c \frac{\partial G}{\partial x} = 0 \quad (45)$$

if  $G = \frac{h}{2} - \frac{wQ}{2} \quad (46)$

The functions F and G defined above may be considered as new variables in the h-Q plane and they are known as the characteristic wave components. Since both satisfy the condition that their total derivatives are zero (eqs. 43 and 45), the characteristic F is propagated in the positive sense with a velocity + c and G in the negative sense with a velocity - c. As a starting point in the analysis it may be assumed that h is known as a function of time at the mouth of the estuary and that Q is known at the landward end. Furthermore, the values of h and Q must be known (or assumed) along the estuary at an initial time  $t = t_0$ . In a short reach the geometry, given by A and b, may be considered constant. Therefore, w and c are constant and along the characteristics F and G it follows from equations (44) and (46) that h and Q are also constant. The solution may proceed in a graphical manner to find h and Q at various x and t. The modifications necessary to account for frictional effects have been discussed by Dronkers (1964); however, the graphical procedures become extremely cumbersome. It is not considered to be a practical method in the light of recent advances in machine computation.

#### 4.3 Finite Difference and Iterative Methods

The essential fact which emerges from the discussion of the various analytical methods is the difficulty caused by the non-linearity of the governing differential equations. Attempts to circumvent the difficulties by linearization unfortunately result in unsatisfactory solutions containing a high degree of mathematical complexity. A review of the various computational techniques which have attempted to deal with the non-linear realm logically divides itself into two time periods. These are the pre-computer period and the period following the development of the high speed, digital computer. The transition between the two periods occurred between 1955 and 1960.

##### 4.3.1 Pre-Computer Era

One of the early attempts to solve the problem of currents in a sea-level canal was the so-called reflected wave theory proposed by Brown (1932). Brown assumed that the effect of friction was small and developed a series approximation for the change of wave height with travel distance. As pointed out by Einstein and Fuchs (1955) many of his formulations were incorrect; however, fairly reasonable results were obtained for short canals in which the curvature of the water surface is small.

A major advance in the development of tidal computational methods in the U.S. was due to Pillsbury (1940) who prepared a monograph covering a wide range of practical applications. The essential feature of the Pillsbury approach, as applied to sea-level canals, was the development of a method of successive approximations. The magnitude of a "primary current" in the middle of a canal was estimated from the linear equations. Distortions of the primary current and tidal amplitude were then introduced which were based on the non-linear acceleration term, friction and variations in the hydraulic radius. The computations, devised for manual computation, are extremely laborious and certain errors in assumptions have been noted by Einstein and Fuchs (1955). Nevertheless, the striking fact

is that this is probably the only method existing before 1940 which was able to reproduce some of the non-linear features of tidal motion. General summaries of the methodology of the pre-computer era have been given by Einstein and Fuchs (1955) and Keulegan (1966).

In addition to the methods discussed above, another technique for the partial solution of tidal estuary problems is the method of cubature. This method was originally developed by M. Partiot of the French Corps des Ponts and was simplified for practical applications by Wicker and Rosenzweig (1950) of the Philadelphia District, Corps of Engineers. (See also Wicker, 1955.) The method is applicable to the computation of tidal velocities in estuaries in which complete observations exist on the variation of tidal stage as a function of location and time. The estuary is segmented into a finite number of reaches in which  $h = f(t)$  is known at the end of each reach. The continuity equation (6) is written in finite difference form and  $Q$  is found by numerical integration. The momentum equation is not used; hence, the method is applicable only to existing channels and cannot be used to predict the effect of future changes.

Proudman (1953) has given a finite difference formulation of the linear friction tidal equations based on the assumption of a harmonic solution. The method has been applied to the manual computation of tidal elevations and currents in the Bristol Channel. The solution depends upon the correct estimate of the linearized friction coefficient and upon the knowledge of harmonic components of the tidal elevation and current at sections near the head of tide. In practice it is expected that small errors in these boundary values or in the linear friction coefficient could cause large differences near the mouth of the estuary. A similar finite difference formulation, devised for manual computation, was proposed by Doodson (1956) for a uniform channel.

#### 4.3.2 Digital Computer Era

Probably the most significant development of the past hundred years of tidal calculations has been the introduction of the high speed digital computer. The effect of the computer on tidal calculations is

two fold: (1) the obvious and enormous increase in the speed of calculations and (2) the great simplicity of using the fundamental differential equations of continuity, eq. (6) and momentum, eq. (16) in a finite difference formulation. Here, in contrast to the analytical methods of solution, the linearity or non-linearity of the equation poses no great difficulty. The latter advantage has frequently been overlooked in the present era due to a tendency to consider only the high speed features of the computer. This has led to some unfortunate exercises in developing elaborate programs for computational methods developed in the pre-computer era. No computer program can inherently improve upon an obsolete method of formulation. Thus it should be obvious that there is little to be gained by programming the Pillsbury method or other methods based upon the linearized equations.

One of the early computer-oriented methods, developed by Baltzer and Shen (1961), is known as the power-series method. At a selected point  $x_1$ , it is assumed that the stage  $h_1$  and the discharge  $Q_1$  are known at time  $t_1$ . It is then possible to develop expressions for stage and discharge at a nearby point,  $x_2$ , at the same time, by means of Maclaurin series expansions. From known boundary conditions a unique finite difference solution for the transient flow at subsequent times is obtained.

A computer program can be developed for the method of characteristics in which the characteristic equations are written in finite difference form. Non-linear terms, including friction, can be retained (Dronkers, 1964, Ch. IX; Lai, 1967). In this method, the points at which the solution is obtained cannot be predetermined. This introduces some difficulties in the schematization of an irregular estuary. As mentioned previously, the method is best suited to situations in which the development of a tidal bore is to be expected.

In a one-dimensional tidal problem, there are only two independent variables,  $x$  and  $t$ . Therefore, if  $x$  and  $t$  are given, the value of any dependent variable can be calculated if mathematical relationships among the dependent variables and  $x$  and  $t$  exist. This implies that an  $x$ ,  $t$

diagram will constitute a solution domain and that the two dependent variables of discharge and stage can be defined at any point on the  $x, t$  diagram within the end boundaries. As it is impossible to obtain solutions for the dependent variables at all points on the  $x, t$  diagram, the task of a numerical method lies in obtaining numerical solutions only at certain points in the  $x, t$  diagram. The choice of points will depend on the features of the problem and the method to be used. If they are predetermined to be situated at regular intervals of space and time on the  $x, t$  diagram, a rectangular grid is formed. Two common numerical methods in connection with rectangular grid systems are:

- (I) Finite differences with an explicit scheme,
- (II) Finite differences with an implicit scheme.

The governing differential equations are replaced by finite difference equations, expressed in terms of the values of the unknown functions at grid points. The solution of the difference equation is carried out numerically, usually on a computer. The exact solution of the differential equation is denoted by  $S$ , the exact solution of the difference equation by  $D$ , and the numerical solution of the difference equation by  $N$ . Then  $|S - D|$  is called the truncation error, and  $|D - N|$  the numerical (or roundoff) error.

$|S - D| \rightarrow 0$  over the whole region of the solution is the condition for convergence of the finite difference scheme.  $|D - N| \rightarrow 0$  over the whole region is the condition for stability. The problem is to find  $N$  such that  $|S - N|$  is smaller than some error criterion over the whole region of interest. As

$$(S - N) = (S - D) + (D - N)$$

the total error is made up of the truncation error and the roundoff error. The truncation error is due to the form selected for the finite difference equation and is often the larger part of the total error.

The value of a quantity  $\phi$ , at a point  $x = i$ , at time  $t = n$  is

denoted by  $\phi_{i,n}$ . To illustrate some of the forms which may be selected for a finite difference solution consider the simple differential equation

$$\frac{\partial \phi}{\partial t} = K \frac{\partial^2 \phi}{\partial x^2} \quad (47)$$

One finite difference form of eq. (47), using the grid shown in Fig. 6a, is

$$\frac{\phi_{i,n+1} - \phi_{i,n}}{\Delta t} = K \left( \frac{\phi_{i-1,n} - 2\phi_{i,n} + \phi_{i+1,n}}{(\Delta x)^2} \right) \quad (48)$$

This scheme is called explicit, because the equation at each (i) includes only one unknown  $\phi_{i,n+1}$ . The solution at the new level (n+1) is computed one point at a time from three known values at time level (n). The explicit solution begins with the initial condition  $\phi_{i,0}$  (i=1, ..., I), and is propagated in time by solving for  $\phi_{n+1}$  from  $\phi_n$ . This scheme is also called forward in time.

Another possible finite difference form of equation (47) is

$$\frac{\phi_{i,n+1} - \phi_{i,n}}{\Delta t} = K \left( \frac{\phi_{i-1,n+1} - 2\phi_{i,n+1} + \phi_{i+1,n+1}}{(\Delta x)^2} \right) \quad (49)$$

This is an implicit scheme, and is shown in Fig. 6b. There are three unknowns in equation (49) for each (i). The equation is written for all i and the resulting set of equations is solved simultaneously. To solve the equations one needs the boundary conditions at i=1 and i=I for all time levels.

A detailed discussion of the application of the implicit scheme to tidal problems has been given by Lai (1965). Computational procedures using the explicit scheme have been given by Hansen (1956), Otter and Day (1960) and Dronkers (1964, Ch. X).

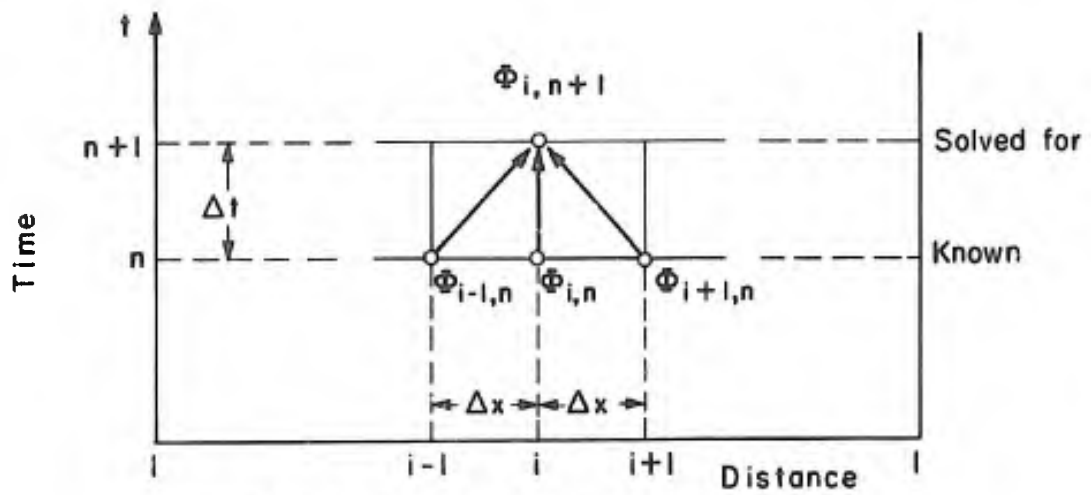


Fig. 6a Explicit Scheme

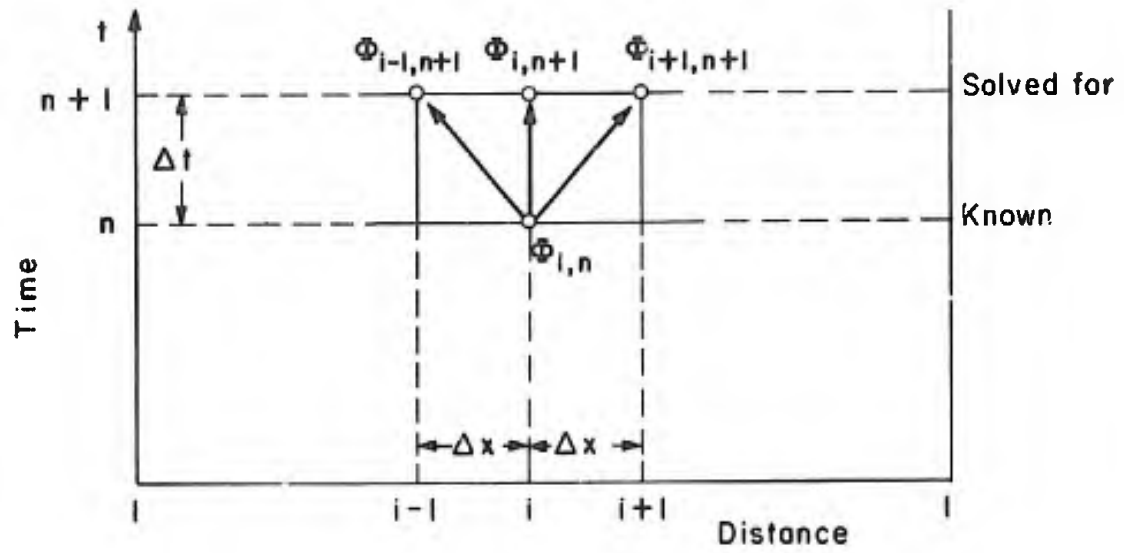


Fig. 6b Implicit Scheme

#### 4.4 Evaluation

One of the objectives of this study is to recommend methods of analysis for various tidal hydraulic problems. In the past the greatest difficulty for the practicing engineer has been to select one of the multitude of available methods which is best suited to his situation. The writers are of the opinion that the best resolution of this difficulty is the recommendation of one method which is generally applicable to a wide variety of problems. Such a method should be capable of reproducing the non-linear effects which are of great importance in many tidal channels, it should be applicable to channels of any shape and it should be capable of accepting rather complicated boundary conditions. An example of the latter is the case of an ocean tide which is non-sinusoidal and transient. Of all the methods discussed, only the finite-difference methods satisfy the above requirements.

In terms of computer time and simplicity of the computer program, the explicit scheme seems to be superior to both the implicit scheme and the method of characteristics. However, to converge to a stable solution, certain stability criteria (see Chapter 5) must be satisfied for an explicit scheme while the other two require no such criteria. Both the explicit and implicit schemes involve higher round-off errors than the method of characteristics; however, errors due to interpolations for better presentation of results may occur in the method of characteristics. In practice, Abbott (1960) has found that differences in solutions obtained by a rectangular grid and the method of characteristics amount to 2-3%. An explicit finite difference scheme is recommended as a general method. A computer program, applicable to the types of channels and boundary conditions usually encountered, has been developed. The remainder of the report will be concerned with illustrating the application of the explicit method to various estuaries and canals.

Chapter 5  
Non-Linear Solution by Finite Differences  
Using an Explicit Scheme

The method of finite differences with an explicit scheme is developed in the following sections.

5.1 Method of Schematization

The geometry of most estuaries is irregular both longitudinally and transversely while man-made tidal channels usually have a prismatic section. In a one-dimensional finite difference formulation it is necessary to divide the estuary or canal into a discrete number of longitudinal segments and to assign particular geometric characteristics to these segments. The required geometric quantities include the surface and bottom width, the cross-sectional area, mean depth, wetted perimeter, longitudinal bottom slope, etc. Since the number of segments which can be considered is limited, some degree of simplification and averaging is necessary; this process is called schematization. An excellent discussion of the technique of schematization has been given by Dronkers (1964, Ch. XI).

The longitudinal schematization of an estuary is shown in Fig. 7 where the longitudinal segment length is  $\Delta x$ . The transverse geometry assigned to section 2 can be taken as the average of the transverse geometries of sections 1b, 2 and 2a, while that for section 3 would be the average of 2b, 3 and 3a, etc. The cross sections obtained as described above should be plotted with reference to an arbitrary horizontal reference datum.

Two typical estuary cross sections are shown in Figs. 8a and 8b. The second step is to define a reference water level in the canal or estuary. The reference water level should approximate the mean water level to be expected. It need not be horizontal; however, its elevation,  $h_0$ , with respect to the horizontal reference datum must be known or assumed. In estuaries having a closed end or a well defined head of tide, the mean sea level at the open end is frequently used. In open-end estuaries joining a river, a line connecting mean sea level and the mean river level may

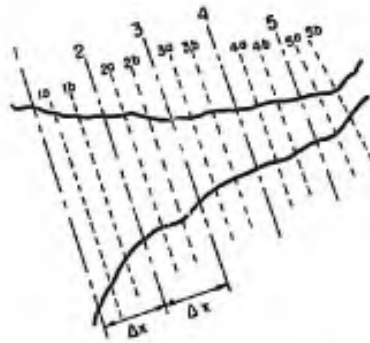


Fig. 7 Longitudinal Schematization of an Estuary

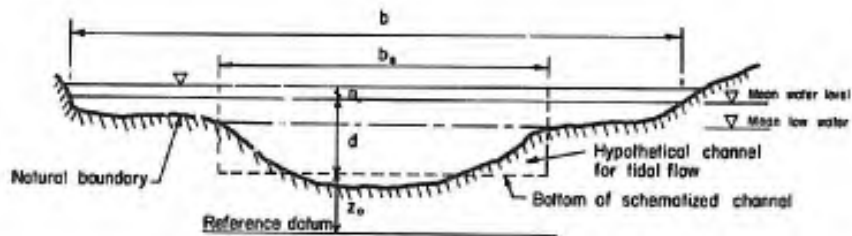


Fig. 8a Transverse Schematization of an Estuary

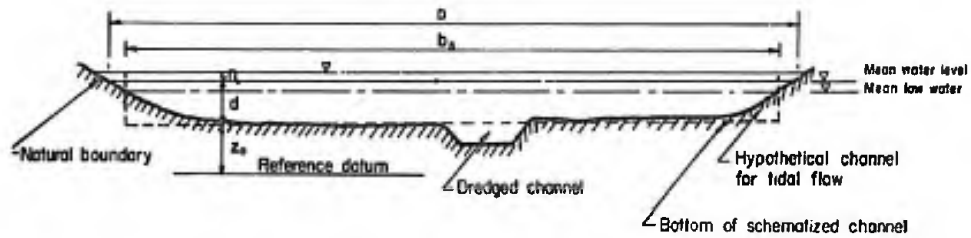


Fig. 8b Transverse Schematization of a Wide Estuary

be used.

The third step is the transverse schematization of the cross section.

#### 5.1.1 Schematization of Natural Channels

For simplicity it will be assumed that the transverse schematization of natural (irregular) channels will be one of two possible types. The first type is shown in Fig. 8(a) where the primary flow occurs in the deep channel. The shallow areas on either side contribute little to the longitudinal flow; however, they provide channel storage. For example, the primary channel width,  $b_s$ , might be defined as the width at mean low water. The instantaneous total surface width,  $b$ , is, in general, a function of  $x$  and  $t$ . The cross-sectional area,  $A'$ , of the primary flow channel is obtained graphically. The area  $A'$  includes the portion defined by the width  $b_s$ , the water surface defined by  $h_o$  and the natural bottom boundary. The depth of the schematized rectangular channel,  $d$ , is then found from the relation

$$d = A'/b_s \quad (50)$$

Since  $h_o$  is known, it follows that the elevation,  $z_o$ , of the schematized channel bottom above the reference datum is

$$z_o = h_o - d \quad (51)$$

Note that  $h$  is the instantaneous water surface elevation above the reference datum, thus

$$h = z_o + d + \eta \quad (52)$$

where  $\eta$  is the instantaneous water surface elevation with respect to the

reference water level. ( $\eta$  may be positive or negative.) The elevation  $z_0$  and the depth  $d$  are functions of  $x$  but not of time, hence

$$\frac{\partial h}{\partial t} = \frac{\partial \eta}{\partial t} \quad (53)$$

and

$$\frac{\partial h}{\partial x} = \frac{\partial z_0}{\partial x} + \frac{\partial d}{\partial x} + \frac{\partial \eta}{\partial x} \quad (54)$$

The second type of natural channel schematization is shown in Fig. 8b. In this case the width of the primary channel is approximately equal to the total width. Hence  $b_s = b$  and the schematization proceeds as in the first case.

#### 5.1.2 Schematization of Prismatic Channels

Prismatic channels of trapezoidal cross section will be considered as the general case. A typical cross section is shown in Fig. 9, where  $b$  is the instantaneous surface width,  $b_0$  is the bottom width and  $s$  the side wall slope. The rectangular section is a special case in which  $s = 0$  and  $b = b_0$ . Natural channels may also be schematized into a trapezoidal section if this fits the geometry better than the equivalent rectangular sections discussed in paragraph 5.1.1.

For reasons to be explained later, the longitudinal schematization must cover a distance of  $\Delta x$  each on either side of a particular point. Thus, values of  $b_s$ ,  $b$ ,  $d$  and  $z_0$ , representing the geometric inputs to the computer, can be taken as the numerical averages of those obtained from all the transversely schematized cross sections lying within  $2\Delta x$ , except for the two end cross sections where averages over one  $\Delta x$  are used.

All schematizations must be checked for various ocean tides and different upland discharges due to possible variations of the reference water level. In certain cases, there may be seasonal variations of the geometry of the deep channel in an estuary due to different upland discharges.

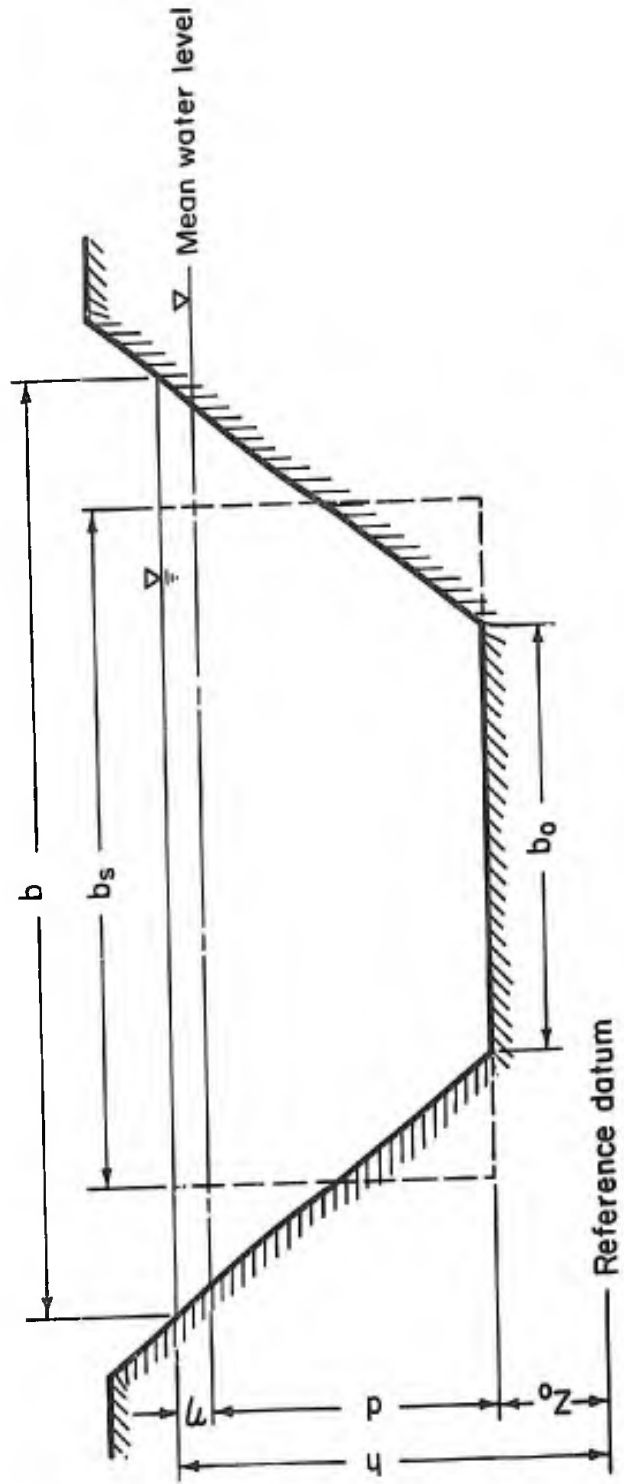


Fig. 9 Transverse Cross Section of a Trapezoidal Channel

A different schematization may also be necessary for extreme ocean tides.

## 5.2 Finite Difference Formulation of the Continuity and Momentum Equations

The basic equations used in the non-linear, finite difference formulation are the one-dimensional continuity and momentum equations for a variable area channel. These equations were derived in Chapter 3, equations (6) and (16).

In order to have a complete understanding of the significance and limitations of the proposed method a brief review of the basic assumptions is given.

1. The formulation is applicable to one-dimensional tidal flows. This implies that the velocities are average longitudinal values for the schematized flow area. Coriolis effects in the transverse direction are neglected.
2. The schematized boundary of the tidal channel is fixed so that no erosion or deposition is assumed to take place due to tidal motion.
3. The Chezy coefficient in the friction term is defined by the Manning equation.
4. Variations in fluid density due to longitudinal salinity gradients are neglected.
5. Direct astronomical tidal effects in the channel or estuary are neglected. The tidal motion is assumed to be caused by the ocean tide at the boundary or boundaries.
6. Variations of the cross section along the longitudinal axis of the tidal channel are gradual. Local energy dissipations due to sudden contractions or enlargements or flow around bends are neglected. (Eronkers, 1964, Ch. XII has discussed the incorporation of local energy dissipation into a finite difference scheme.)
7. The effect of a wind stress on the water surface of the estuary or canal may be considered by including an additional term in the momentum equation. (This is illustrated in the Delaware estuary example in a later chapter.)

The pair of differential equations for the finite difference formulation are obtained in the following manner.

If equation (53) is substituted into the continuity equation (6), the following form of the continuity equation is obtained

$$b \frac{\partial \eta}{\partial t} + \frac{\partial Q}{\partial x} - q = 0 \quad (55)$$

The momentum equation (16) contains both the tidal velocity and the discharge; it is convenient to eliminate the velocity in favor of the discharge by the relation  $u = Q/A$  and to replace  $\partial h/\partial x$  by equation (54). After expanding the derivative  $\partial(Q/A)/\partial x$  and simplifying, the momentum equation becomes

$$\frac{\partial Q}{\partial t} + \frac{2Q}{A} \frac{\partial Q}{\partial x} - \left(\frac{Q}{A}\right)^2 \frac{\partial A}{\partial x} + gA \left[ \frac{\partial z_o}{\partial x} + \frac{\partial d}{\partial x} + \frac{\partial \eta}{\partial x} \right] + g \frac{Q|Q|}{AC^2R} = 0 \quad (56)$$

Another form of the momentum equation is obtained by eliminating  $\partial Q/\partial x$  by means of the continuity equation (55) and dividing by A, thus

$$\frac{1}{A} \frac{\partial Q}{\partial t} + \frac{2Q}{A^2} q - \frac{2bQ}{A^2} \frac{\partial \eta}{\partial t} - \frac{Q^2}{A^3} \frac{\partial A}{\partial x} + g \left[ \frac{\partial z_o}{\partial x} + \frac{\partial d}{\partial x} + \frac{\partial \eta}{\partial x} \right] + g \frac{Q|Q|}{A^2 C^2 R} = 0 \quad (57)$$

The term  $\frac{Q^2}{A^3} \frac{\partial A}{\partial x}$  may be shown to be of negligible importance in most

estuaries and canals. The exception would be those cases in which a tidal bore develops. The magnitude of the above term may be readily determined for a variable area, rectangular channel in which

$$A = b(d + \eta) \quad (58)$$

In this case,

$$\frac{Q^2}{A^3} \frac{\partial A}{\partial x} = g \left(\frac{u}{c}\right)^2 \frac{\partial (d + \eta)}{\partial x} \quad (59)$$

where  $c$ , the speed of the gravity wave, is given by

$$c = \sqrt{g \frac{A}{b}} \quad (60)$$

Equation (57) can then be written as

$$\frac{1}{A} \frac{\partial Q}{\partial t} + \frac{2Q}{A^2} q - \frac{2bQ}{A^2} \frac{\partial \eta}{\partial t} + g \frac{\partial(d + \eta)}{\partial x} \left[ 1 - \left( \frac{u}{c} \right)^2 \right] + g \frac{\partial z_o}{\partial x} + g \frac{Q|Q|}{A^2 C^2 R} = 0 \quad (61)$$

For example, in the Delaware estuary the maximum value of  $(u/c)^2 = 1/150$ ; hence the final form of the non-linear momentum equation is obtained by neglecting this term:

$$\frac{1}{A} \frac{\partial Q}{\partial t} + \frac{2Q}{A^2} q - \frac{2bQ}{A^2} \frac{\partial \eta}{\partial t} + g \left[ \frac{\partial z_o}{\partial x} + \frac{\partial d}{\partial x} + \frac{\partial \eta}{\partial x} \right] + g \frac{Q|Q|}{A^2 C^2 R} = 0 \quad (62)$$

Equations (55) and (62) constitute the pair of equations for the finite difference formulation in which the surface elevation  $\eta$  and the discharge  $Q$  are the unknowns. Both equations are of first order and contain partial derivatives of  $\eta$  and  $Q$ . In theory, it is possible to eliminate either  $\eta$  or  $Q$  by combining the two first order equations into one second order equation. Each unknown may then be solved independently by means of a finite difference formulation. A more efficient method, from the standpoint of time and programming, is the explicit scheme employing a staggered arrangement commonly known as a diagonal mesh. The finite difference operators are shown in Fig. 10a in the  $x, t$  plane in which the basic rectangular grid spacing is  $\Delta x$  and  $\Delta t$ .

Two essential features of the operators should be noted:

1. Along any one line of the  $x, t$  grid, only one unknown dependent variable is defined (either  $\eta$  or  $Q$ ).

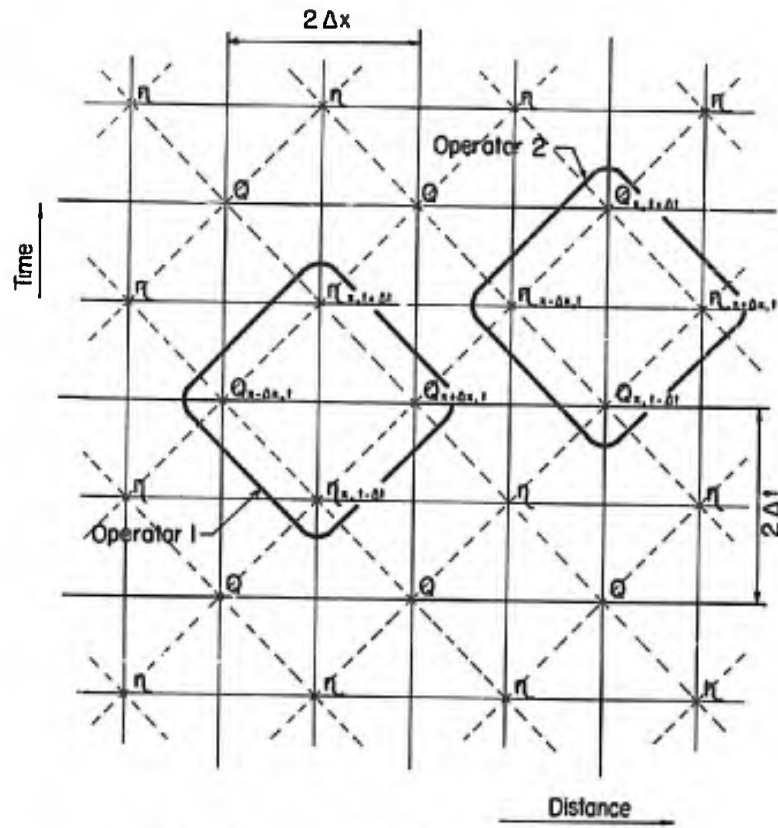


Fig. 10a Details of a Diagonal Mesh

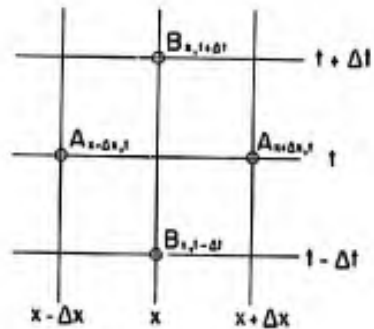


Fig. 10 b Definition Sketch for Central Differences Equations

2. The unknown variables  $\eta$  and  $Q$  are defined on alternate grid lines, both in time and distance, so that the basic space and time intervals for a diagonal mesh relating either  $\eta$  or  $Q$  are  $2\Delta x$  and  $2\Delta t$ , respectively.

The associated central finite differences equations, which define the first order partial derivatives with respect to space and time are shown in Fig. 10a, as

$$\frac{\partial A}{\partial x} = \frac{A_{x+\Delta x, t} - A_{x-\Delta x, t}}{2\Delta x} \quad (63)$$

$$\frac{\partial B}{\partial t} = \frac{B_{x, t+\Delta t} - B_{x, t-\Delta t}}{2\Delta t} \quad (64)$$

where  $A$  and  $B$  are any unknown dependent variables. For any predetermined values of  $\Delta x$  and  $\Delta t$ , the basic partial differential equations of continuity (55) and momentum (62) can be written in the finite difference form by applying equations (63) and (64) as shown in the following:

CONTINUITY EQUATION (55) [refer to operator 1, Fig. 10a]

$$\frac{b_{x, t} [\eta_{x, t+\Delta t} - \eta_{x, t-\Delta t}]}{2\Delta t} + \frac{Q_{x+\Delta x, t} - Q_{x-\Delta x, t}}{2\Delta x} - \frac{[Q_{trib}]_x}{2\Delta x} = 0 \quad (65)$$

where  $[Q_{trib}]_x$  = total inflow due to tributary streams entering the estuary or canal between sections  $(x + \Delta x)$  and  $(x - \Delta x) = q(2\Delta x)$ .

MOMENTUM EQUATION (62) [refer to operator 2, Fig. 10a]

$$\begin{aligned}
 & \frac{1}{A_{x,t}} \left[ \frac{Q_{x,t+\Delta t} - Q_{x,t-\Delta t}}{2\Delta t} \right] + \frac{2Q_{x,t-\Delta t} [Q_{trib}]_x}{[A_{x,t}]^2 2\Delta x} - \\
 & \frac{2b_{x,t} Q_{x,t-\Delta t}}{[A_{x,t}]^2} \cdot \frac{1}{2} \left[ \frac{\eta_{x-\Delta x,t} - \eta_{x-\Delta x,t-2\Delta t}}{2\Delta t} + \frac{\eta_{x+\Delta x,t} - \eta_{x+\Delta x,t-2\Delta t}}{2\Delta t} \right] + \\
 & \frac{g \left[ z_{o_{x+\Delta x}} - z_{o_{x-\Delta x}} \right]}{2\Delta x} + \frac{g \left[ d_{x+\Delta x} - d_{x-\Delta x} \right]}{2\Delta x} + \frac{g \left[ \eta_{x+\Delta x,t} - \eta_{x-\Delta x,t} \right]}{2\Delta x} + \\
 & \frac{g |Q_{x,t-\Delta t}|}{[C_{x,t}]^2 [A_{x,t}]^2 R_{x,t}} \cdot \frac{1}{2} \left[ Q_{x,t+\Delta t} + Q_{x,t-\Delta t} \right] - W_{x,t} = 0 \quad (66)
 \end{aligned}$$

where,  $W_{x,t}$  = wind stress term defined by eq. (74).

The geometric quantities  $A_{x,t}$ ,  $b_{x,t}$  and  $R_{x,t}$  are defined in finite difference form for both the rectangular or schematized section and the trapezoidal section.

1. For a rectangular or schematized section: (see Fig. 8 )

$$A_{x,t} = b_{s_x} \left[ d_x + \frac{1}{2} \left[ \eta_{x+\Delta x,t} + \eta_{x-\Delta x,t} \right] \right] \quad (67)$$

$$b_{x,t} = b_x \quad (68)$$

$$R_{x,t} = \frac{A_{x,t}}{b_{s_x} + 2d_x + \eta_{x+\Delta x,t} + \eta_{x-\Delta x,t}} \quad (69)$$

2. For a trapezoidal section: (see Fig. 9 )

$$A_{x,t} = \frac{1}{2} [b_{x,t} + b_{o_x}] \left[ d_x + \frac{1}{2} [\eta_{x+\Delta x,t} + \eta_{x-\Delta x,t}] \right] \quad (70)$$

$$b_{x,t} = b_{o_x} + 2 s_x \left[ d_x + \frac{1}{2} [\eta_{x+\Delta x,t} - \eta_{x-\Delta x,t}] \right] \quad (71)$$

$$R_{x,t} = \frac{A_{x,t}}{b_{o_x} + 2 \sqrt{1 + s_x^2} \left[ d_x + \frac{1}{2} [\eta_{x+\Delta x,t} + \eta_{x-\Delta x,t}] \right]} \quad (72)$$

The Chezy coefficient may be expressed in terms of the Manning roughness  $n_x$  (which may vary with  $x$ ) and the hydraulic radius

$$C_{x,t} = \frac{1.49}{n_x} [R_{x,t}]^{1/6} \quad [\text{ft-sec units}] \quad (73)$$

A water surface wind stress term may be added to the momentum equation (66) if it is desired to include the effect of local wind on the tidal motion. In a form similar to that suggested by Dronkers (1964) the wind term becomes

$$W_{x,t} = \frac{\beta_w \rho_a |V_x \cos \psi_x| V_x \cos \psi_x}{\rho d_{x,t}} \quad (74)$$

where,  $\beta_w$  = wind shear stress coefficient = 0.0026

$\rho_a$  = density of air

$\rho$  = density of water

$V_x$  = absolute wind speed

$\psi_x$  = angle between the direction of the wind and the longitudinal axis of the channel ( $\psi_x < 90^\circ$  for wind blowing in landward direction,  $180^\circ > \psi_x > 90^\circ$  for wind blowing in seaward direction).

In equations (65) and (66), the basic partial differential equations have been transformed into algebraic equations each containing one unknown,  $\eta_{x,t+\Delta t}$  in eq. (65) and  $Q_{x,t+\Delta t}$  in eq. (66). The two equations can be solved by a digital computer in a straightforward manner. The computational procedure can be explained by considering two regions in the interior of the  $x,t$  plane shown in Fig. 10a. Assume that from previous computations all values of  $\eta$  and  $Q$  are known along the horizontal grid lines  $n$  and  $n + 1$ . Values of  $\eta$  along the grid line  $n + 2$  can be computed explicitly, one at a time, by applying the continuity equation (65) shown by operator 1. Thereafter all values of  $Q$  along the grid line  $n + 3$  can be determined in a similar manner by use of the momentum equation (66) shown by operator 2. Thus, by consecutive advancements in time steps of  $\Delta t$  each, the tidal elevations and discharges confined within the end boundaries of the tidal channel are computed alternately by repeating the procedure described above.

In order to begin the solution, initial values of both  $\eta$  and  $Q$  are required. This requires the specification, at time  $t = 0$ , of values of  $\eta$  at intervals of  $2\Delta x$  and at time  $t = \Delta t$  of values of  $Q$  at alternate intervals of  $2\Delta x$ . In tidal problems the initial conditions are usually unknown, hence the above values of  $\eta$  and  $Q$  will have to be assumed. One of the most important properties of the proposed method is that the final solution is essentially independent of the assumed initial conditions. This will be discussed more completely in a later section.

Since the finite difference operators cannot be extended beyond the end boundaries of the segmented system, the values of  $\eta$  or  $Q$  at both boundaries cannot be calculated by the procedures described above. Therefore, two boundary conditions must be specified in order to obtain a solution. Mathematically, this is known as a mixed initial and boundary value problem. The specification of the boundary conditions is discussed in detail in a

later section.

After the magnitudes of the tidal elevations and discharges have been calculated at the grid points, the average velocity in the longitudinal direction can be calculated from the relation

$$u = Q/A . \quad (75)$$

The alternating calculation of  $\eta$  and  $Q$  using the diagonal mesh shown in Fig. 10a has some implications in the schematization of the estuary or canal. As an example, consider the estuary shown in Fig. 11a and 11b. The tidal elevation  $\eta$  is specified at the ocean boundary (section 1) and values of  $\eta$  are to be computed at all odd-numbered sections (3, 5, 7, etc.). Values of the discharge are to be computed at all even-numbered sections (2, 4, 6, etc.). In the calculation of  $Q$  at section 2, the geometric properties assigned to that section extend from section 1 to section 3. In the calculation of  $\eta$  at section 3 the geometric properties of that section extend from sections 2 to 4. Thus the basic space unit is  $2\Delta x$  and the schematized cross section at any section should be the representative average of the tidal channel geometry extended over a distance  $\Delta x$  on either side of the section. In order to reduce errors due to the schematization of a natural tidal channel, it is desirable to keep  $\Delta x$  small in relation to the irregular nature of the channel.

### 5.3 Classification of Tidal Problems in Terms of Boundary Conditions

The majority of tidal problems can be grouped into three types according to the physical characteristics of their boundaries and the availability of physical data to be used as an input to the mathematical model.

#### 5.3.1 An Estuary Having a Well-Defined Head of Tide or a Canal Closed at One End

The estuaries in this category are those with a well-defined head of tide such as a fall line or critical flow section. An example is the

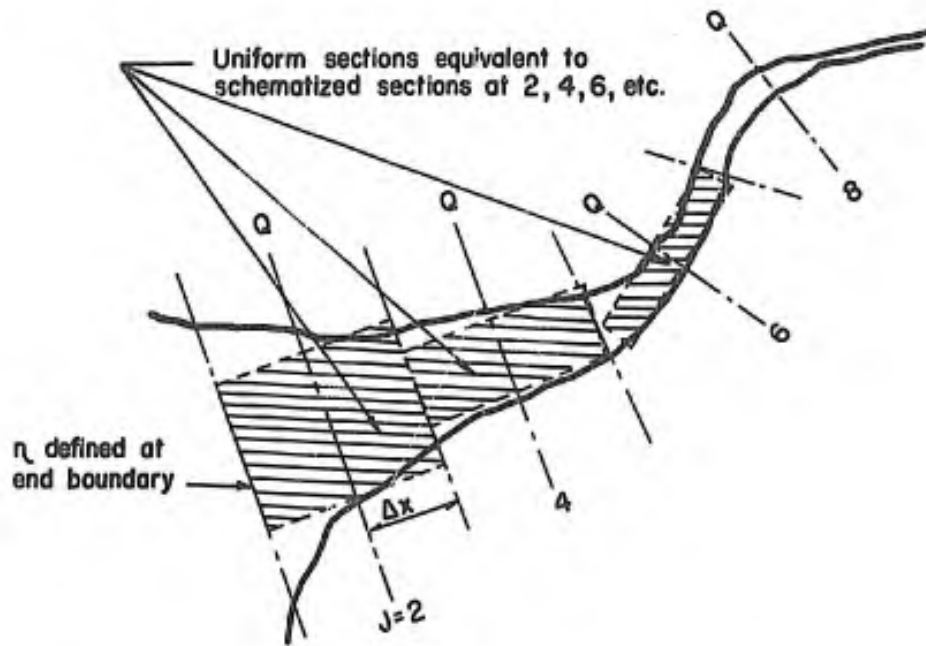


Fig. 11a Interpretation of the Geometric Schematization for Computations of  $Q$  in the Computer Solution

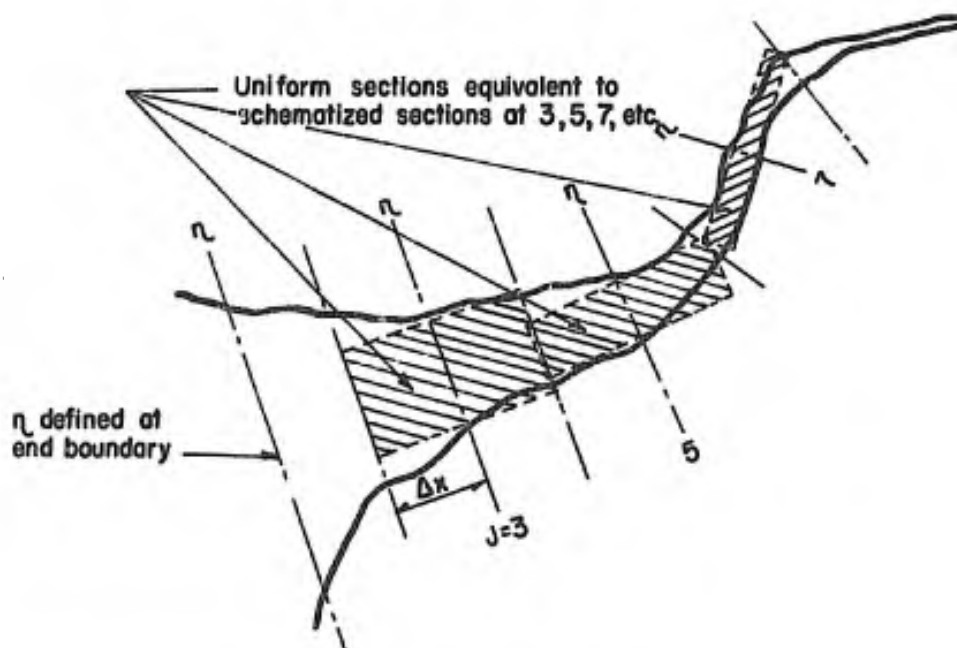


Fig. 11b Interpretation of the Geometric Schematization for Computations of  $n$  in the Computer Solution

head of tide at Trenton on the Delaware estuary. The appropriate boundary conditions are:

$$\text{ocean end: } \eta = f(t)$$

$$\text{head of tide or closed end: } Q = 0.$$

At the ocean end, the ocean tide normally can be obtained from tide tables or from prototype measurements by tide gages. It should be emphasized that the ocean tide need not be sinusoidal; any single tidal cycle record or continuous records covering from 28 days to a year may be used if desired.

At the head of tide, the condition of no upstream momentum transfer results in the boundary condition  $Q = 0$ . The fresh water inflow of the river into the last upstream segment is introduced as a lateral inflow.

Estuaries and canals in this category should be divided into an odd number of segments of length  $\Delta x$  since  $\eta$  and  $Q$  are specified at the ends of alternate segments.

### 5.3.2 An Estuary with an Open End

An open end estuary is one in which the tidal region merges gradually with the upstream river. It is characterized by a progressive reduction of tidal range in the upstream direction. The Savannah estuary is an example of this category.

The appropriate boundary conditions are:

$$\text{ocean end: } \eta = f(t)$$

$$\text{open end: } Q = f(t) \text{ or}$$

$$Q = \text{constant} = \text{fresh water discharge of upland river.}$$

The ocean end conditions are the same as in section 5.3.1. The open end boundary condition depends on available data. For example, discharge measurements may be available at an upstream location at which the current is always in the ebb direction, however there may be a cyclic variation in the magnitude, and  $Q = f(t)$  is known. A location farther upstream may be found at which the cyclic variation disappears, in this case the open end

boundary condition is  $Q = \text{constant}$  (equal to the upland river discharge). The location of this point and, therefore, the length of the segmented tidal channel will change seasonally with variations in the upland discharge. If no measurements are available it is necessary to assume a length for the tidal channel and to set  $Q$  equal to the river discharge. A check on the assumption may be made by determining whether the tidal range at the upstream end becomes small enough to be negligible.

Estuaries in this category should be divided into an odd number of segments as described in 5.3.1.

### 5.3.3 An Estuary Embayment or Canal Connecting Two Bodies of Water

In this category the two bodies of water may be two oceans, as in the case of a sea-level canal, or an ocean and a large lake without tidal fluctuations. An embayment may also be connected to the same ocean through two separate openings.

The appropriate boundary conditions are:

$$\text{water body (1): } \eta_1 = f_1(t)$$

$$\text{water body (2): } \eta_2 = f_2(t)$$

Tidal channels in this category should be divided into an even number of segments of length  $\Delta x$  since  $\eta$  is specified at both ends.

Other types of boundary conditions may arise in special cases, for example: the specification of discharge at both ends of a channel; the conditions to be applied at a junction of three tidal channels (summation of discharge equal to zero and equal values of  $\eta$  at the junction). The latter is discussed by Dronkers (1964, Ch. X).

### 5.4 Initial Conditions and Quasi-Steady State Solution

As mentioned in an earlier section, it is necessary to assume initial values of  $\eta$  and  $Q$  throughout the tidal channel in order to begin the numerical solution. Fortunately, as the solution proceeds forward in time, the property

of the hyperbolic partial differential equation is such that the effect of the assumed initial condition diminishes rapidly (Ref. 18). In the absence of any other information it may be assumed that  $\eta = 0$  at  $t = 0$  and  $Q = 0$  at  $t = \Delta t$ . Using the known boundary conditions for one tidal cycle, the finite difference solution proceeds to the end of the first tidal cycle  $T + \Delta t$  (where  $T$  is the tidal period). The values of  $\eta$  at  $t = T$  and  $Q$  at  $t = T + \Delta t$  become the new initial conditions and the tidal cycle is repeated with the same boundary conditions to the time level  $t = 2T + \Delta t$ . Thereafter, the computation is repeated to the  $(k + 1)$ th tidal cycle as shown in Fig. 12. The repeated computation ends when the tidal elevations obtained in the  $(k + 1)$ th cycle differ from those obtained in the  $k$ th cycle (i.e.,  $\eta_{x,t}^{k+1} - \eta_{x,t}^k$ ) by an amount not greater than an acceptable error (0.001 ft. or less was used in the present study). The solution obtained at the  $(k + 1)$ th tidal cycle is referred to as a "quasi-steady state solution". This solution is independent of the magnitudes of the assumed initial conditions. In other words, if the values of  $\eta$  at  $t = 0$  and  $Q$  at  $t = \Delta t$  had been chosen as other than zero, the same quasi-steady solution would have been obtained. The only difference would be in the number of cycles necessary to reach the quasi-steady state. If the assumed values are close to the final values, the number of repeating cycles would be reduced. Mathematically, it is a convergent solution for the given boundary conditions for one tidal cycle.

In the examples presented in the next chapter it has been found that usually not more than 6 cycles are necessary to reach the quasi-steady state solution. The existence of a quasi-steady usually implies that a stable solution exists, since  $(\eta_{x,t}^{k+1} - \eta_{x,t}^k)$  is magnified in an unstable solution as  $k$  increases. The determination of  $\Delta x$  and  $\Delta t$  for stable solutions is discussed in a later section.

### 5.5 Transient Solutions of Tidal Problems

In the above discussion the boundary conditions have been specified for only one complete tidal cycle. In many situations it is sufficient to determine the response of the estuary or canal to a single ocean tidal curve (i.e., mean tidal range, extreme or minimum tidal range). In other instances

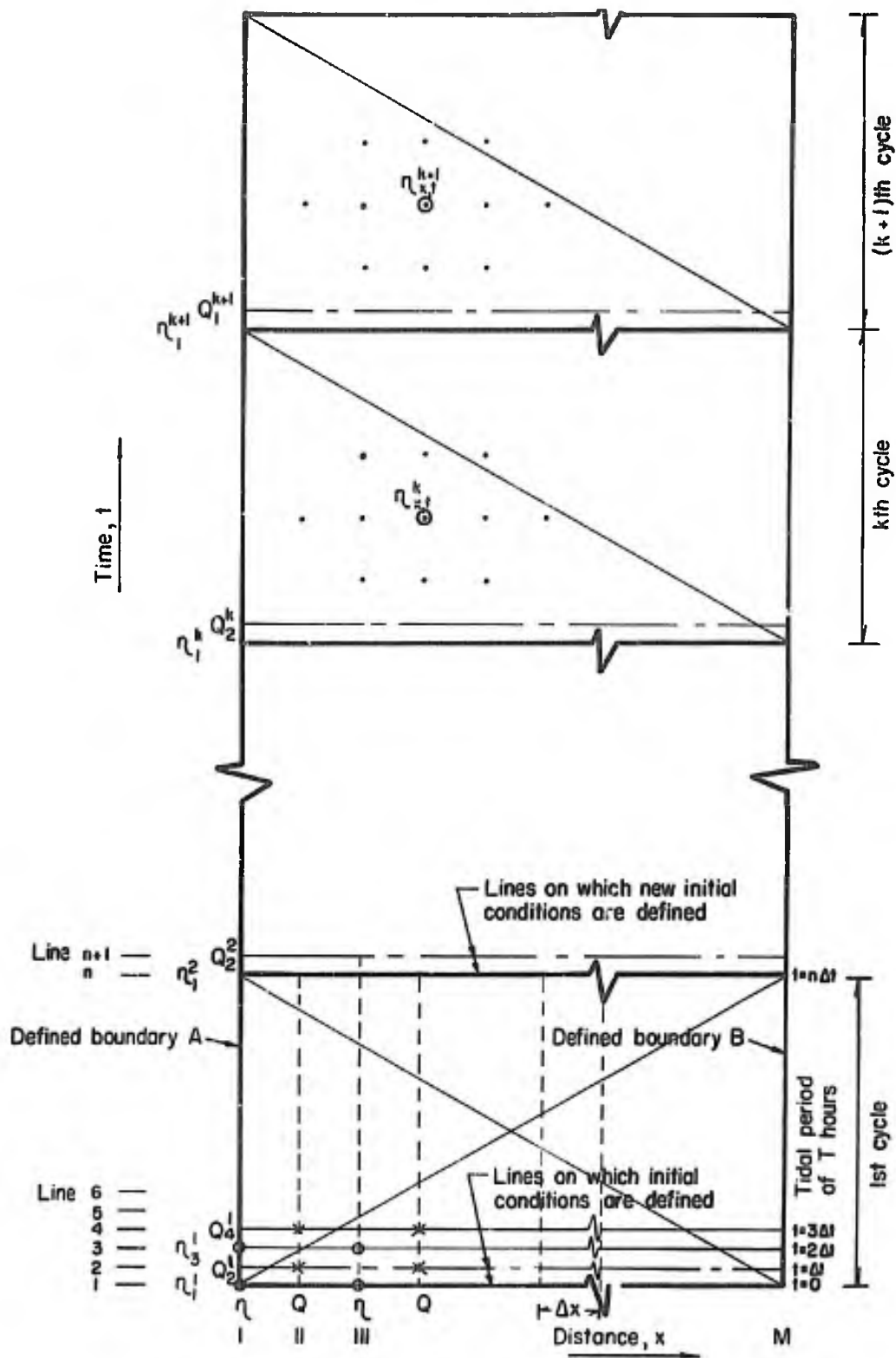


Fig. 12 Details for a Quasi-Steady State Solution

it may be desirable to obtain a transient solution as the ocean tide follows its normal biweekly variation through spring and neap ranges. This is referred to as a transient solution and it can be incorporated into the numerical scheme without difficulty.

If a continuous tidal record extending over more than one tidal period is available as an ocean boundary condition, a transient solution can be obtained by using the boundary condition of the first tidal cycle of the record to generate a quasi-steady state solution. Thereafter, the tidal conditions obtained at the end of the quasi-steady state solution can be utilized as the initial conditions for the remainder of the tidal record.

The validity of the transient solution approach was tested during a study on the prediction of tidal currents in the proposed sea-level (Panama) canal on behalf of the Jacksonville District, U. S. Army Corps of Engineers (Harleman and Lee, 1967, Ch. 3). In this investigation a complete solution for the tidal currents during a 14-day period was obtained.

#### 5.6 Additional Numerical Procedures for Computations at Boundaries

One feature of the diagonal mesh already discussed is that only  $Q$  or  $\eta$  is defined at either of the boundaries. However, it may be desirable to have a method of determining the dependent variable which is not specified at one of the boundaries. For example, at the head of tide (where  $Q = 0$  is the defined boundary condition) it may be desirable to calculate the tidal elevation; or, in the case of a sea-level canal (where tidal elevations are specified at both ends), it may be desirable to determine the discharge (or tidal velocity) at the ends of the canal. Numerical procedures, which are in principle similar to the method of cubature, have been developed for this purpose. They may be incorporated as supplements to the explicit scheme computer program. The details are given in Appendix I.

#### 5.7 Stability Criteria and Choice of $\Delta x$ and $\Delta t$

In order to obtain a stable solution in an explicit scheme one well-known stability criterion must be satisfied (Dronkers, 1964, Ch. X).

$$\Delta t < \frac{\Delta x}{|u_{\max}| + \sqrt{g(d + |\eta_{\max}|)}} \quad (76)$$

The violation of eq. (76) will usually lead to an unstable solution. Evidence of instability is shown by oscillating values of  $\eta$  and  $Q$  which reach physically absurd values. Since the maximum values of the velocity and tidal range are unknown before a solution has been obtained it is necessary to use a simplified form of eq. (76) as a first approximation for the determination of  $\Delta x$  and  $\Delta t$ :

$$\Delta t < \frac{\Delta x}{\sqrt{g(d_e + \eta_e)}} \quad (77)$$

where,  $d_e$  = depth of water below MSL at ocean end.

$\eta_e$  = amplitude of ocean tide.

The magnitude of the friction term in the momentum equation also has an influence on the stability although it is difficult to determine the effect a priori. If an unstable solution results after equation (77) has been satisfied it may be necessary to adjust  $\Delta x$  or  $\Delta t$ .

The space and time increments  $\Delta x$  and  $\Delta t$  should be chosen subject to the inequality of eq. (77) and the limitations imposed by computer storage capacity and the compiler which is used. A case study for the Panama sea-level canal is contained in Harleman and Lee (1967, Appendix VII). If  $\Delta x$  is too large, too few outputs will be available for evaluation of the tidal characteristics. On the other hand, if  $\Delta x$  is too small,  $\Delta t$  will become unnecessarily small, computer storage may be exceeded and computation time will be unnecessarily long. The time spent in the computer to obtain a solution depends largely on the total number of points contained in the rectangular grid covering the period of a tidal cycle. Decisions have to be made on an individual basis for each problem. The locations

of points of interest, where solutions should be obtained, may play a role in the choice of  $\Delta x$  as well. Ideally, all the points of interest should fall close to the grid points. Solutions for points of interest not falling on grid points can be obtained through numerical interpolations of the results obtained at the neighboring grid points, or by plotting the results in graphical form. In any event, the channel must be divided into an integral number of  $\Delta x$  segments.

As discussed previously, even integral numbers are necessarily, for the two boundary conditions, defined by the same dependent variable (either  $Q$  or  $\eta$ ), and odd numbers by different dependent variables ( $Q$  and  $\eta$ ), respectively.

After  $\Delta x$  has been chosen,  $\Delta t$  can be chosen subject to the satisfaction of equation (77). In addition, the tidal period must be divided into even integral numbers of  $\Delta t$  so that the same dependent variable ( $Q$  or  $\eta$ ) is defined at the time of the beginning of every subsequent tidal period. This is necessary for obtaining a quasi-steady state solution.

### 5.8 Computer Programs

The required input for the execution of the computer program consists of the following:

(1) Geometric Data

For a schematized rectangular section the required quantities are:  $b$ ,  $b_s$ ,  $d$  and  $z_o$  (see Fig. 8). For a trapezoidal section,  $b_o$ ,  $s$ ,  $d$  and  $z_o$  are needed (see Fig. 9).

(2) Boundary Conditions

Either  $\eta$  or  $Q$  must be specified as a function of time, for at least one tidal period, at two cross sections in accordance with the discussion in section 5.3.

(3) Initial Conditions

The surface elevation and discharge must be specified as functions of  $x$  at  $t = 0$  and  $t = \Delta t$ , respectively. In accordance with the discussion in section 5.4, both  $\eta$  and  $Q$  may be

set equal to zero initially.

(4) Resistance Coefficient

The Manning coefficient must be specified as a function of  $x$ . In an existing estuary or canal, past records of tidal elevation should be used to determine  $n$  by matching the computer solution to the field observations. In the case in which no field data is available,  $n$  must be assumed on the basis of experience with similar estuaries or canals. Meyers and Schultz (1949) have collected a table of resistance values for some rivers and canals in North America. Dronkers (1964) gives values of the Chezy coefficient for some estuaries in the Netherlands. Lai and Baltzer (1966) have made some detailed computer studies of tidal resistance for short reaches in certain estuaries.

(5) Wind Data

Wind velocity and direction observations are required if it is desired to consider the effect of local winds on the tidal motion.

The output from the computer solution consists of the tidal elevation  $\eta$ , the tidal discharge  $Q$  and the tidal velocity  $u$  at alternate grid points both in time and space. The discharge and velocity are determined for the same grid points.

The following computer programs have been developed for the non-linear, explicit scheme: The computer language is Fortran IV (E-level subset) and the computer used in this study was an I.B.M. 360 Model 40 in the Civil Engineering Systems Laboratory at M.I.T. The case studies described in the following chapter are noted under each program.

I. Estuaries and Canals Closed at One End

Case Studies:

Delaware Estuary (irregular shape)

Dominquez Channel (prismatic shape, trapezoidal)

W.E.S. Salinity Flume (prismatic shape, rectangular)

II. Estuaries with an Open End

Case Studies:

Savannah Estuary (irregular shape)

III. Estuaries and Canals Connecting Two Bodies of Water

Case Studies:

Sea-Level (Panama) Canal (prismatic shape)

Cape Cod Canal (prismatic shape)

Chincoteague Bay (irregular shape)

Complete listings of computer programs together with input formats are presented in Appendix II. In addition, a plotting program was written for use on an IBM 1130 with a Calcomp plotter to furnish nine types of graphical outputs from the main programs.

## Chapter 6

### Examples of Tidal Calculations Using the Non-Linear, Finite Difference, Explicit Scheme

Seven case studies have been made to illustrate the versatility and applicability of the non-linear, finite difference, explicit scheme. Computations have been made for two natural estuaries: the Delaware, a closed-end estuary and the Savannah, an open end estuary. Two sea-level canals have been chosen: a proposed sea-level canal at Panama and the existing Cape Cod Canal. Tidal computations for embayments were made for Chincoteague Bay, which has two tidal inlets. Two closed-end prismatic channels have been studied: the Dominquez Channel in Los Angeles (trapezoidal) and the experimental salinity flume at W.E.S. (rectangular).

These case studies represent a somewhat ambitious undertaking in terms of the time and cost limitations of the present investigation. It must be stressed that certain results, particularly those for the natural tidal channels, have been obtained on the basis of rather crude schematizations. Much more time and effort could have gone into the determination of the geometric properties, however it was decided to cover a larger number of practical situations at the expense of a high degree of geometric accuracy.

#### 6.1 Delaware Estuary (a closed-end estuary, section 5.3.1)

The Delaware is a funnel-shaped estuary extending from Capes May and Henlopen on the Atlantic Coast of the U.S. to Trenton, N.J., a distance of 132 miles inland. The width varies from approximately 1000 ft. at Trenton to 27 miles at the widest portion of Delaware Bay. Tidal action is terminated by a fall line at Trenton, beyond which the Delaware is an upland stream. It is, therefore, classed as a closed-end estuary. Since 1840 the estuary has undergone various changes due to dredging and channel training works. The mean tidal ranges along the estuary have gradually increased due to deepening of the navigation channel both above and below the city of Philadelphia. A map of the estuary is shown in Fig. 13. As the estuary is more than 20 miles wide in the vicinity of Miah Maul

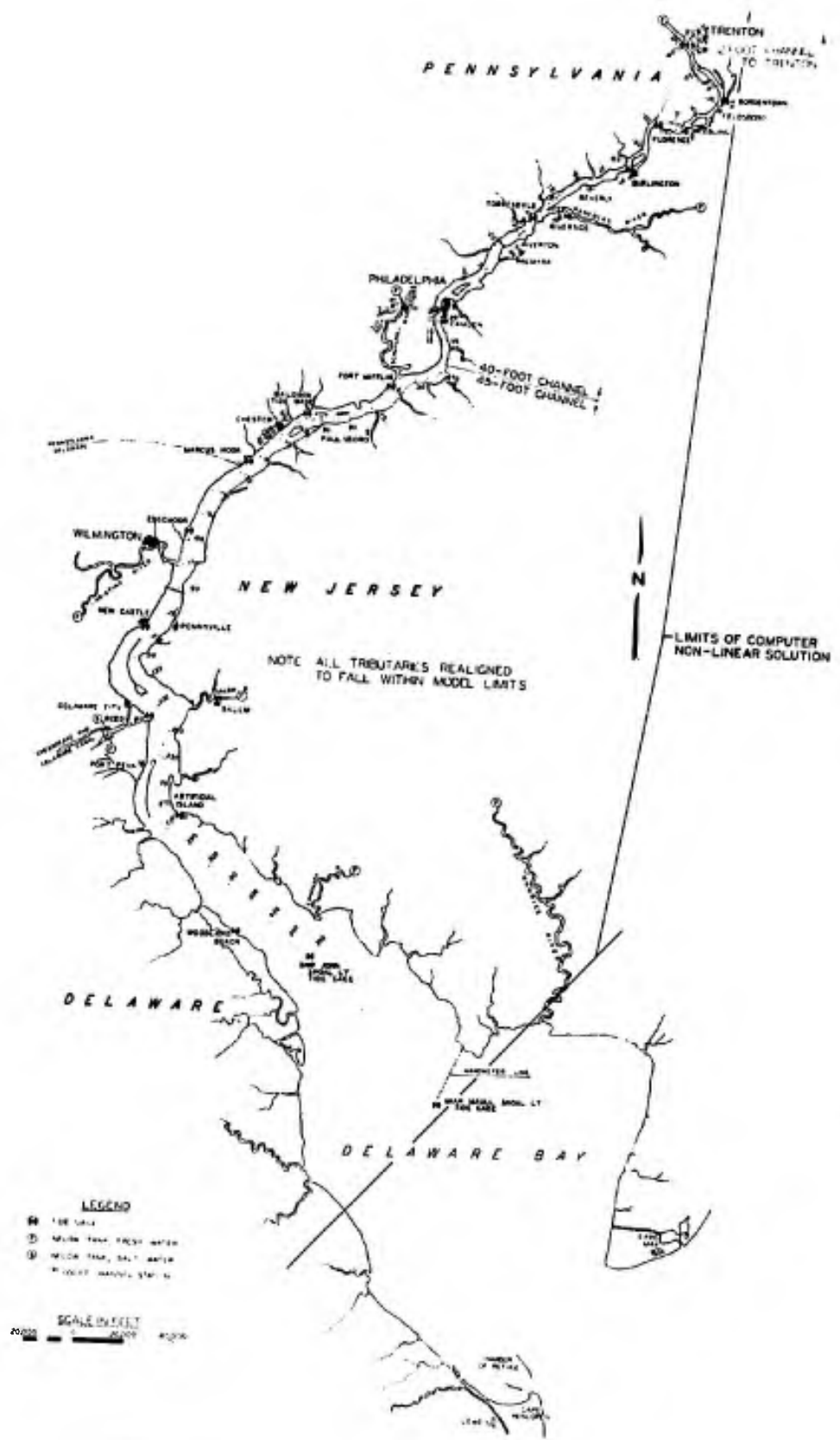


Fig. 13 Delaware Estuary - General Layout

Shoal light (about 20 miles from the Capes), the tides at Miah Maul are treated as ocean tides causing the tidal propagation in the estuary. The origin of the longitudinal axis ( $x = 0$ ) is taken at Miah Maul; at Trenton,  $x = 112$  miles.

#### 6.1.1 Schematization

Computer solutions for tidal motion in the Delaware have been obtained for three different channel geometries:

- (a) 1951 Channel Survey [based on Table of Accumulated Mid-Tide Volumes (dated 25 September, 1951) by the Philadelphia District, U. S. Corps of Engineers]
- (b) 1932 Channel Survey [based on a chart of physical characteristics (dated 24 March, 1938) according to the survey of 1932 by the Philadelphia District, U.S. Corps of Engineers]
- (c) Channel with Exponentially Varying Width and Constant Depth (used by Harleman (1966) for a linear solution with friction)

In accordance with the boundary conditions for a closed-end estuary, an odd number of segments must be used. The total length of 112 miles was divided into 33 segments giving  $\Delta x = 3.4$  miles. The stability condition is satisfied if the tidal cycle of 12.42 hours is divided into 72 time intervals of  $\Delta t = 621$  sec. The tidal elevation boundary condition at Miah Maul was taken from field observations to have a range of 5.5 ft. and a sinusoidal shape (see Fig. 17). The discharge boundary condition at the head of tide (Trenton) is taken as  $Q = 0$ . The mean fresh water inflow due to the upland river is 11, 650 cfs which is introduced as a lateral inflow into the upstream segment.

For the geometric schematization of the 1951 channel, the only available data were the cross-sectional areas at M.W.L. and the corresponding water surface widths. A rectangular channel schematization was assumed and the equivalent rectangular channel depths,  $d$ , were obtained

by dividing the cross-sectional areas by the surface widths. Since the longitudinal profile of the bottom of the estuary was not known, it was assumed as a first approximation that the reference (or mean) water level along the estuary was horizontal and equal to M.S.L. Thus the bottom profile  $z_o = f(x)$  is defined by the water depths below the horizontal surface. Except for sections close to the mouth, it was further assumed that  $b_s = b$ . The geometric data used as inputs to the computer for both the 1932 and the 1951 surveys are summarized in Fig. 14(a,b,c) and tabulated in Table I. The schematization could be improved by using transverse cross sections containing soundings related to a common datum.

The geometric data for the exponential channel approximation are as follows:

depth,  $d = 21$  ft. (constant throughout)  
width,  $b = b_s = 53,150 e^{-\delta x}$  ft.  
where  $\delta = 0.67 \times 10^{-5}$  (ft<sup>-1</sup>)  
bottom elevation,  $z_o = 0$

The accuracy of this schematization is considerably less than those based on the field surveys.

#### 6.1.2 Manning Resistance Coefficient

In this first attempt to investigate the complete one-dimensional tidal characteristics of a large estuary, by means of a non-linear method, the question of the magnitude and longitudinal variation of the Manning resistance coefficient must be answered. It was, therefore, decided to use the finite difference mathematical model initially to match the variation of the mean tidal amplitude along the estuary as determined from field measurements. This was done by a trial and error process of changing  $n$  until a reasonable agreement was obtained between the computed and observed surface elevations. The values of Manning's  $n$  along the estuary, obtained in this manner, are shown in Fig. 15 for two different channel schematizations. For the 1951 survey, the  $n$  values range from approximately 0.020 in the lower, broad reaches to slightly greater than 0.030 in the

Distance from Miah Maul (miles)	Section Number (J)	Total Width b (ft.)		Conveyance Width b <sub>s</sub> (ft.)		Elevation of Bottom below M.W.L. at Miah Maul (ft.)	
		1932	1951	1932	1951	1932	1951
0	1	106,000	106,000	-	-	-	-
3.40	2	85,000	88,200	44,000	47,120	-20.0	-21.0
6.80	3	65,000	68,700	-	-	-	-
10.21	4	50,000	46,400	34,000	37,036	-20.0	-21.0
13.62	5	36,000	35,500	-	-	-	-
17.03	6	28,000	29,000	28,000	29,000	-20.0	-21.0
20.45	7	23,000	24,500	-	-	-	-
23.85	8	19,500	20,600	19,500	20,600	-20.0	-21.0
27.20	9	16,500	17,100	-	-	-	-
30.66	10	14,500	14,800	14,500	14,800	-20.0	-21.0
34.07	11	13,500	13,200	-	-	-	-
37.47	12	11,500	12,100	11,500	12,100	-20.0	-21.0
40.87	13	10,000	11,100	-	-	-	-
44.28	14	9,000	9,900	9,000	9,900	-21.0	-21.0
47.69	15	8,000	8,450	-	-	-	-
51.10	16	7,300	7,300	7,300	7,300	-21.0	-22.8
54.50	17	6,700	6,400	-	-	-	-
57.89	18	6,100	5,800	6,100	5,800	-21.0	-22.2
61.29	19	5,600	5,500	-	-	-	-
64.69	20	5,100	5,400	5,100	5,400	-20.0	-19.4
68.09	21	4,700	5,300	-	-	-	-
71.49	22	4,300	4,500	4,300	4,500	-20.0	-20.5
74.89	23	3,500	3,500	-	-	-	-
78.29	24	3,000	3,000	3,000	3,000	-24.0	-24.0
81.69	25	3,200	3,500	-	-	-	-
85.09	26	2,900	2,800	2,900	2,800	-17.5	-19.3
88.49	27	2,500	2,700	-	-	-	-
91.89	28	2,100	1,900	2,100	1,900	-16.5	-17.3
95.29	29	1,800	1,400	-	-	-	-
98.69	30	1,550	1,300	1,550	1,300	-16.5	-19.0
102.09	31	1,350	1,300	-	-	-	-
105.49	32	1,300	1,400	1,300	1,400	-16.5	-17.8
108.90	33	950	1,000	-	-	-	-
112.31	34	860	900	860	900	-12.0	-12.0

Table I - Delaware Estuary --  
Geometric Inputs

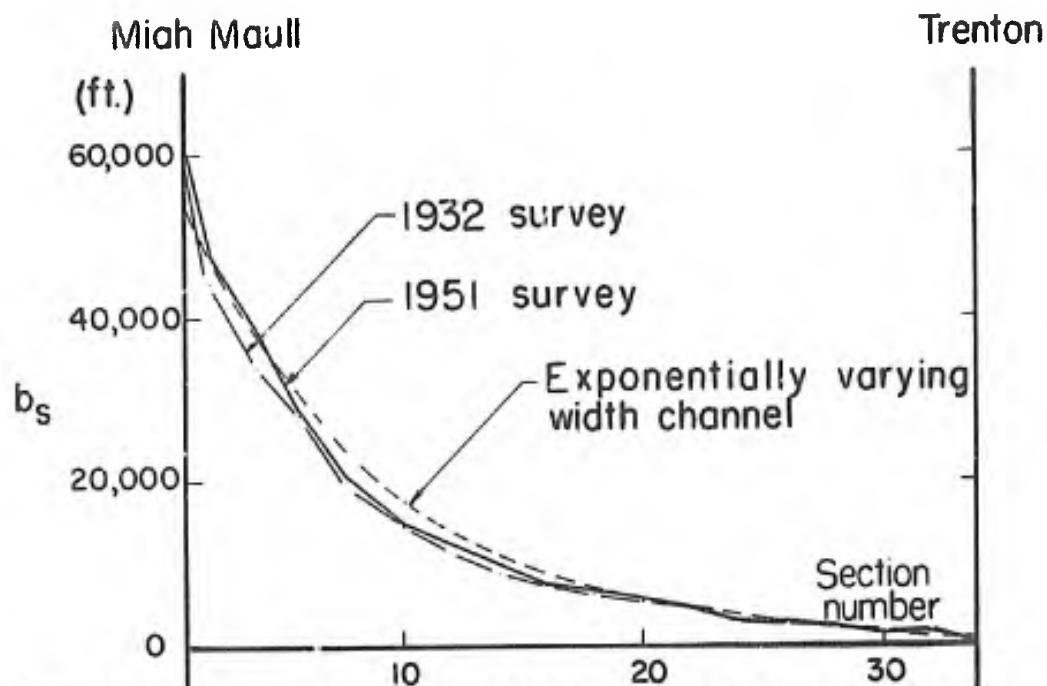


Fig. 14a Delaware Estuary -- Schematized Effective Width of Flow,  $b_s$

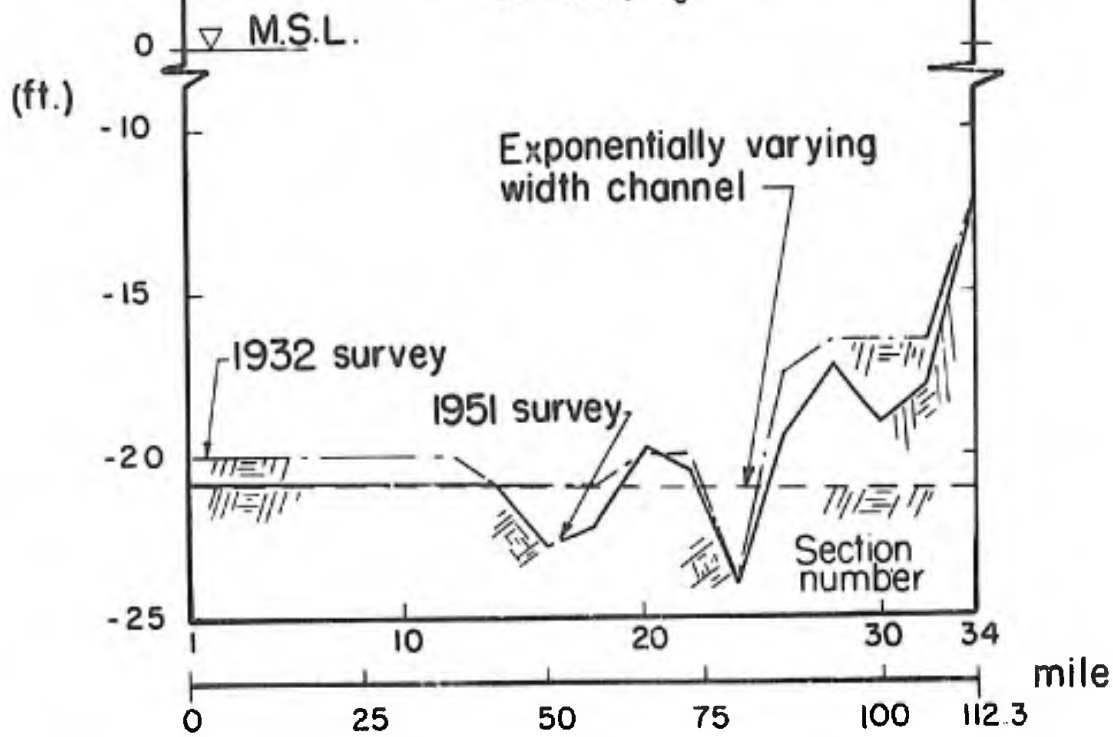


Fig. 14b Delaware Estuary -- Schematized Channel Bottom

upper, narrow portion of the estuary. These values seem reasonable in view of the experience with large rivers in steady motion. Figure 15 also shows the dependency between the Manning coefficient and the accuracy of the schematization. The corresponding curves showing the computed and observed tidal ranges are shown in Fig. 16. Using the Manning coefficients as found above, further comparisons were made between the computed (1951 survey) and observed tidal characteristics using the field data collected by Wicker (1965).

#### 6.1.3 Comparison of Computed and Observed Tidal Characteristics

The most important feature of the non-linear solution is shown in Fig. 17 where the tidal elevation versus time is plotted at the entrance, middle and end of the estuary. The progressive distortion of the tide curve from the sinusoidal shape at the entrance is clearly indicated. The agreement between the computed and observed shapes is good in view of the rather crude schematization. Other comparisons between the computer solution and the field data are given: the duration of rise and fall of the water surface and the duration of ebb flow (Fig. 18) and the times of high and low water along the estuary (Fig. 19). Also shown are the magnitude of the maximum flood and ebb velocities and tidal discharges as a function of  $x$  (Fig. 20 a,b); the time variation of velocity and discharge at two stations (Fig. 21) and the instantaneous water surfaces along the estuary at different times of the tidal cycle (Fig. 22). The latter figure shows that the mean water surface at Trenton is approximately 1.3 feet higher than at Miah Maul. The original assumption of a horizontal water surface reference plane could be corrected by this amount and the solution could be repeated if more accurate results are desired. The above figures illustrate the large amount of practical information which can be obtained from a single computer solution.

#### 6.1.4 Effect of Variation of Manning's $n$

In order to investigate the effect of the variation in the Manning coefficient along the estuary, three cases, assuming constant values of  $n$  were computed for the exponentially varying width channel. These

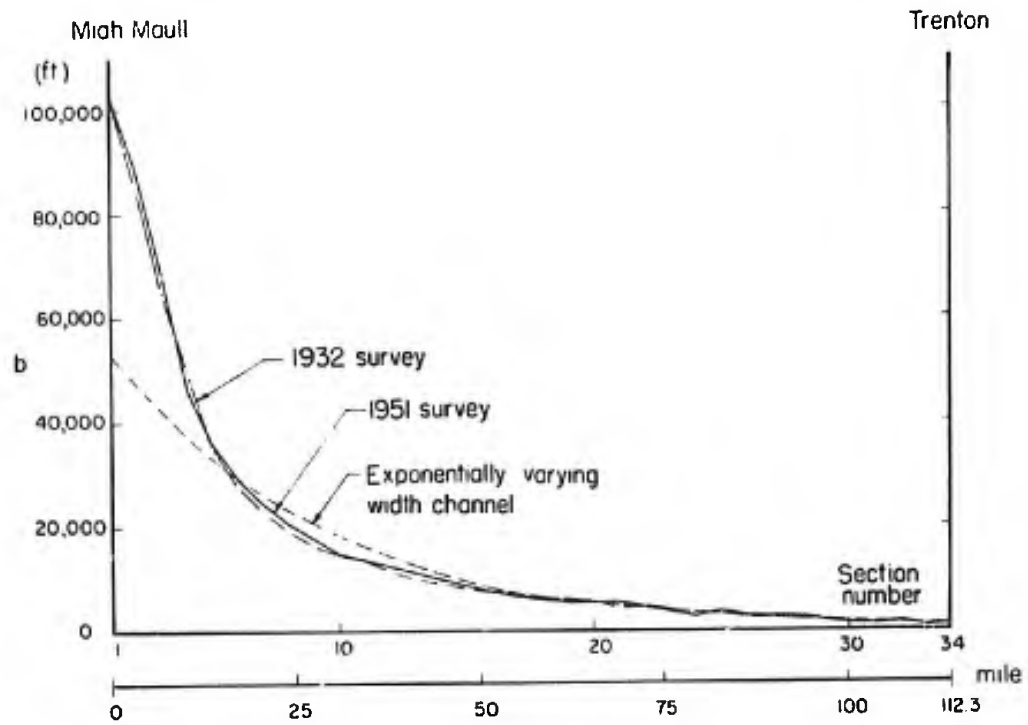


Fig. 14c Delaware Estuary -- Schematized Surface Width, b

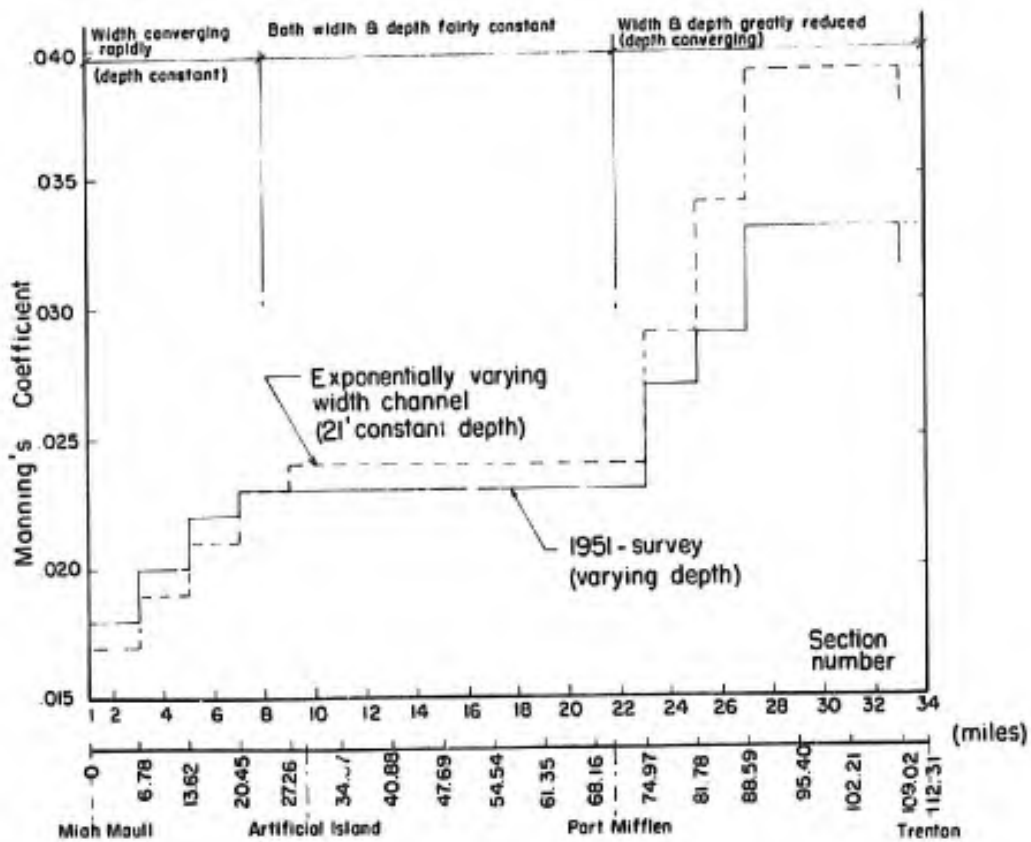


Fig. 15 Delaware Estuary -- Manning's Coefficients for 1951 Channel

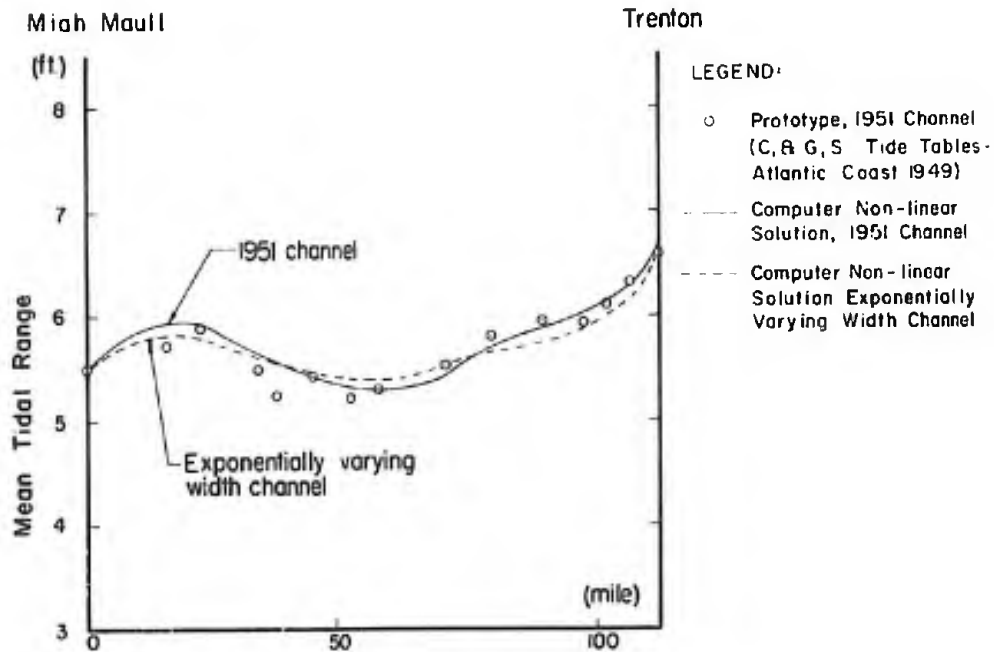


Fig. 16 Delaware Estuary -- Mean Tidal Range

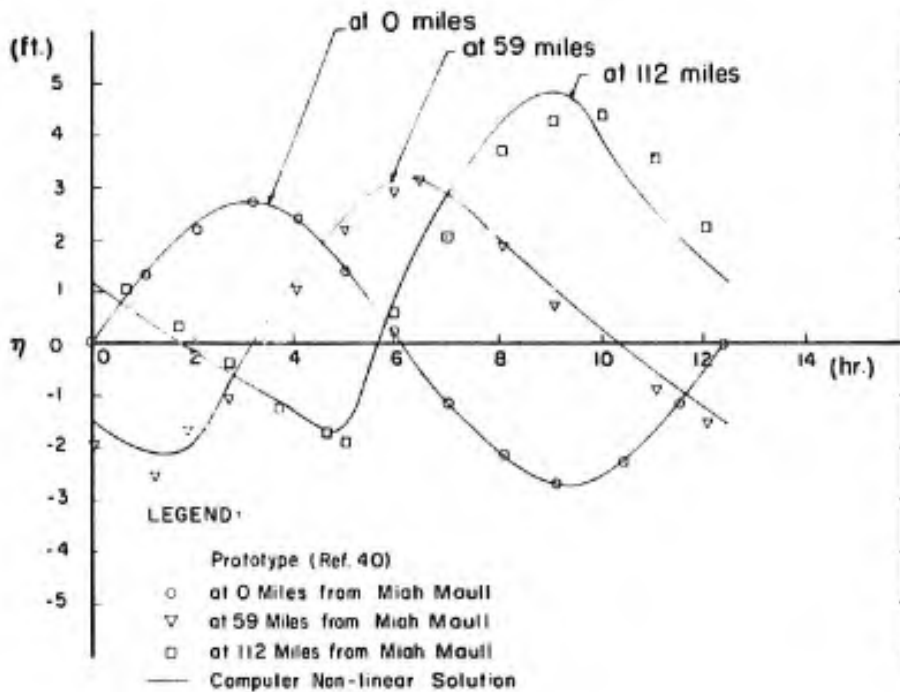


Fig. 17 Delaware Estuary (1951 Channel) -- Tidal Variations in Elevation at 0, 59 and 112 Miles from Miah Maul

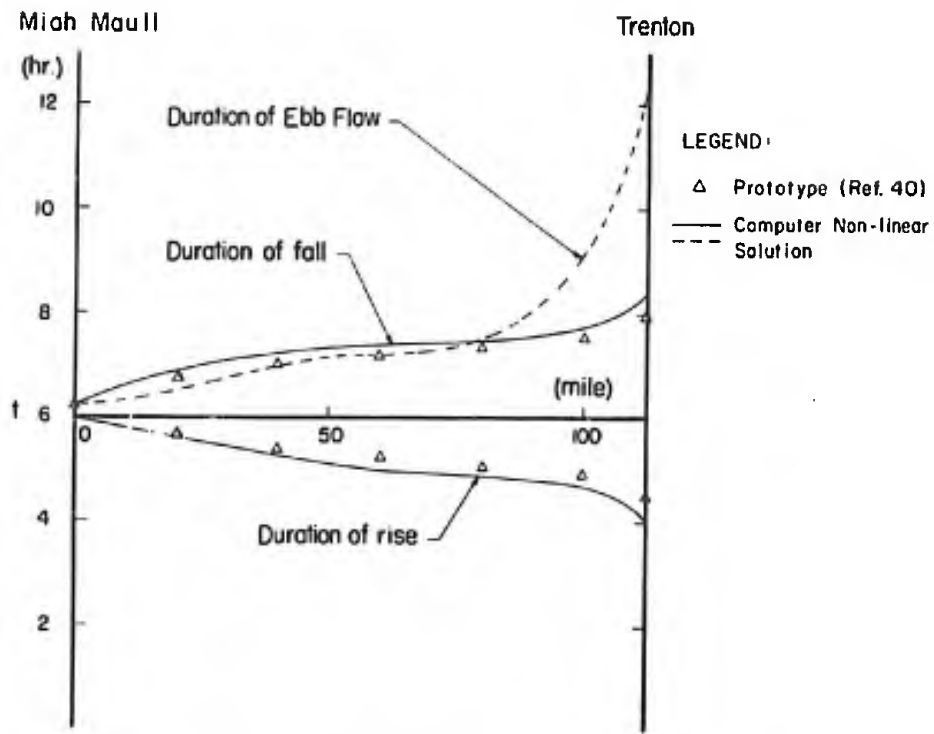


Fig. 18 Delaware Estuary (1951 Channel) -- Duration of Rise, Fall and Ebb Flow

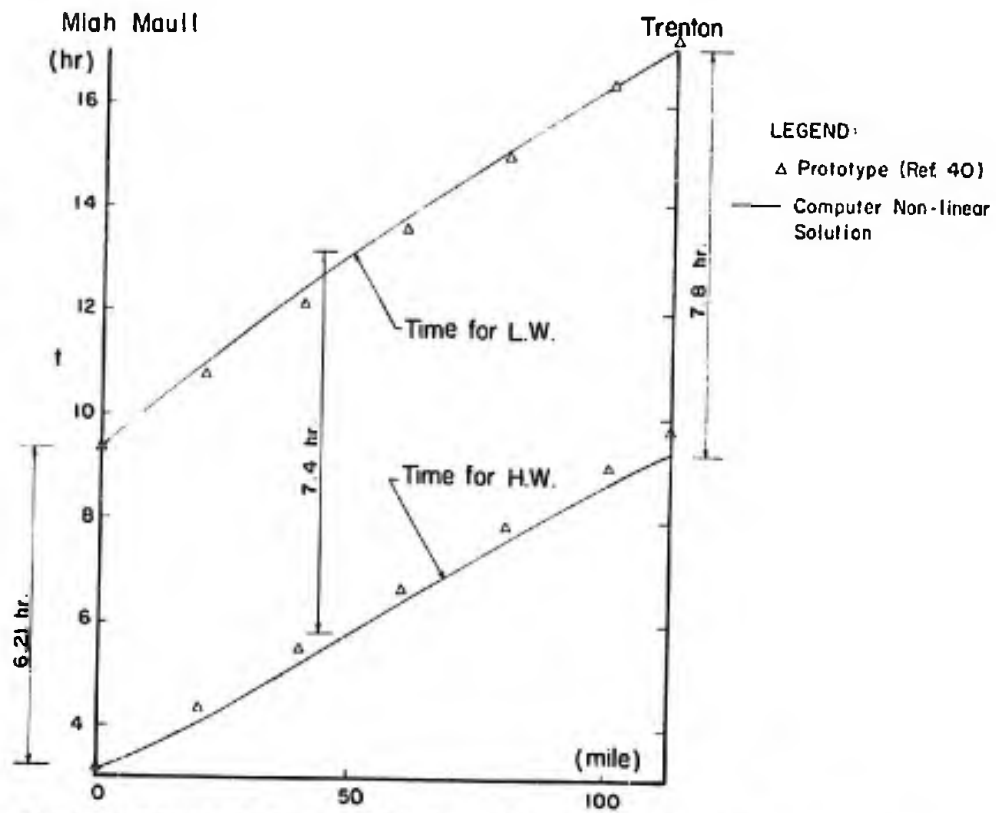


Fig. 19 Delaware Estuary (1951 Channel) -- Time for High Water and Low Water

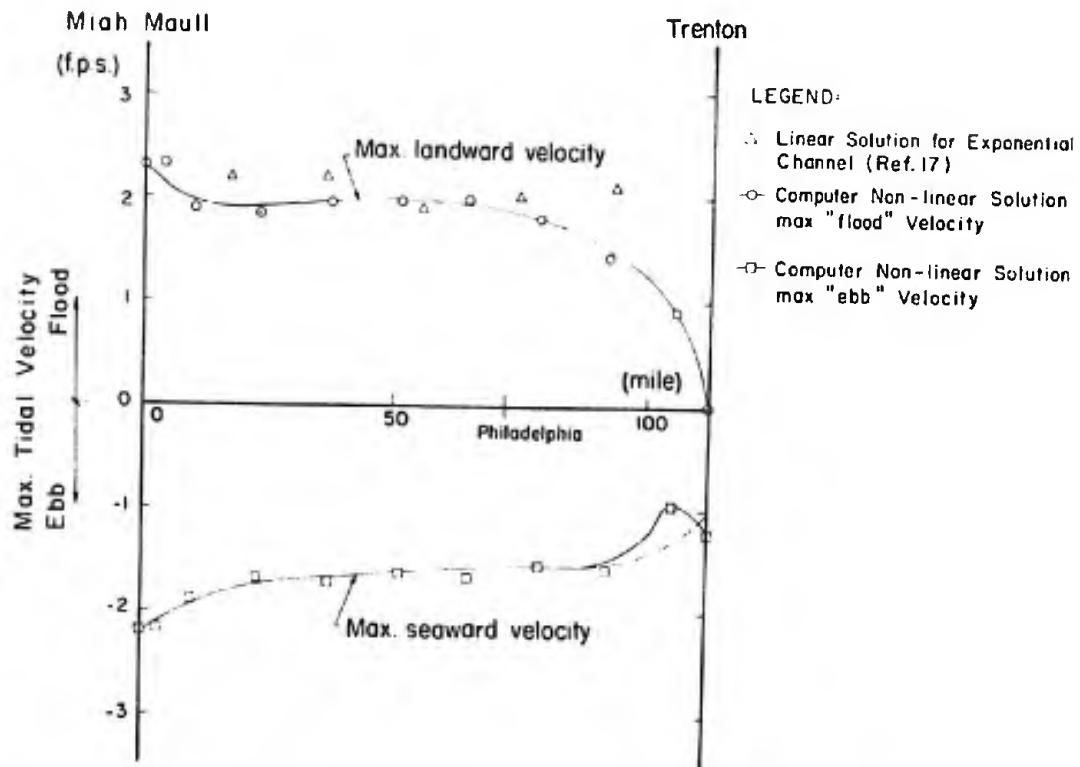


Fig 20a Delaware Estuary (1951 Channel) -- Maximum Tidal Velocities

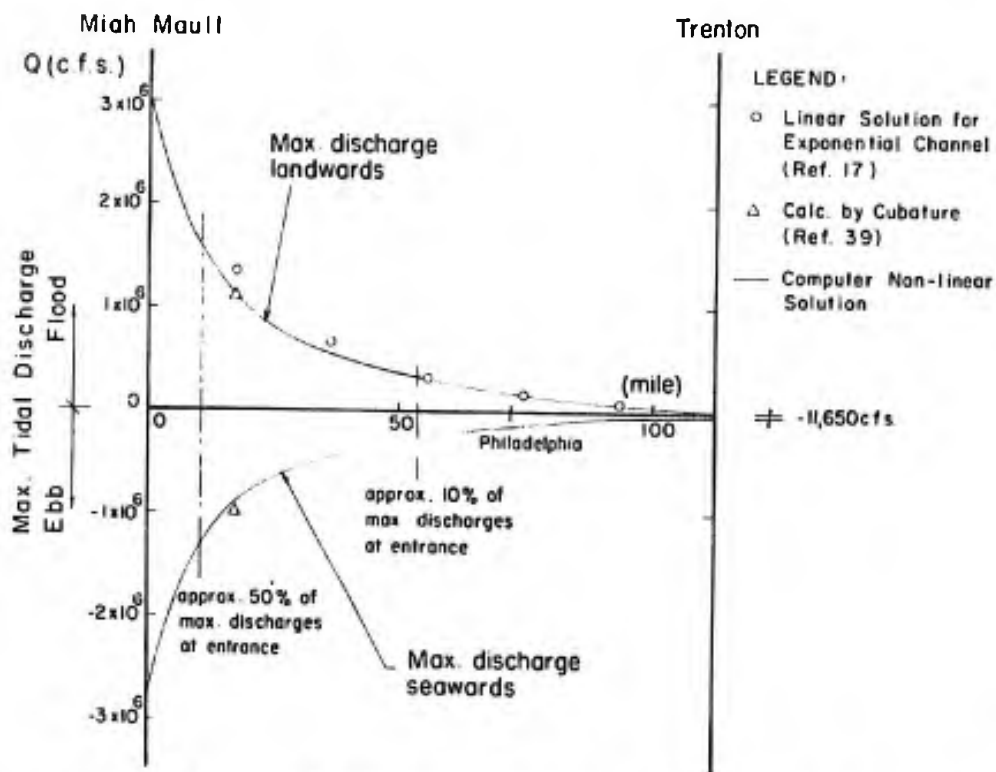


Fig. 20 b Delaware Estuary (1951 Channel) -- Maximum Tidal Discharges

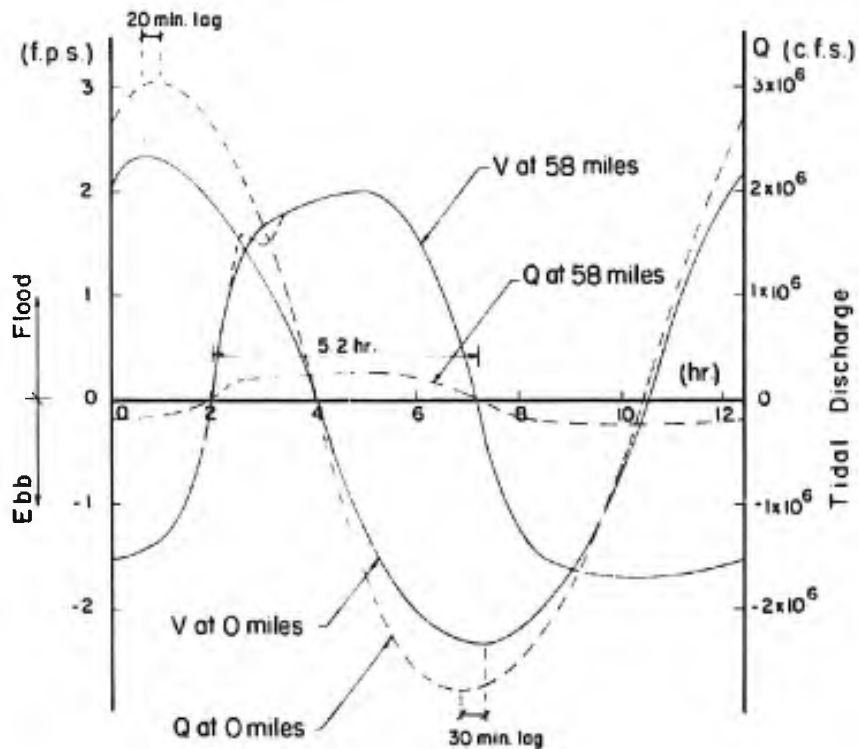


Fig 21 Delaware Estuary (1951 Channel) -- Tidal Velocities and Discharges at 0 and 58 Miles from Miah Mauli

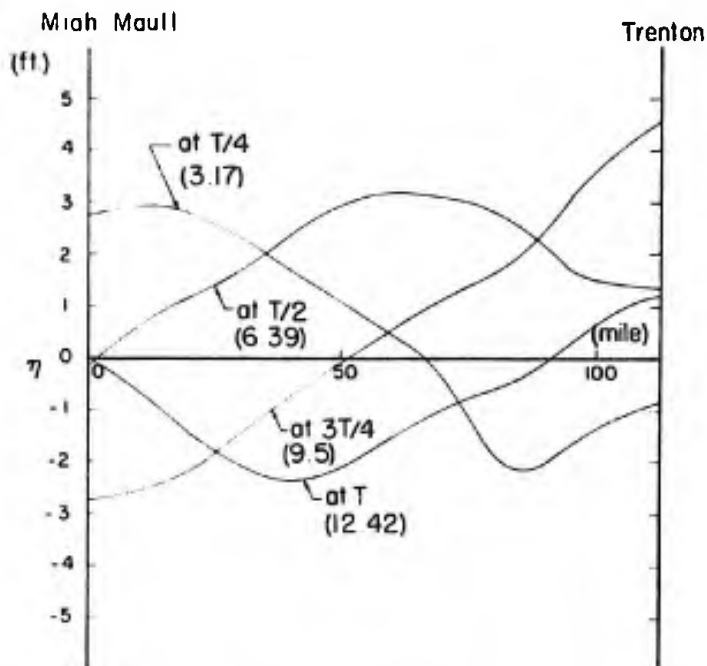


Fig 22 Delaware Estuary (1951 Channel) -- Tidal Elevations at Time of T/4, T/2, 3T/4 and T

results, together with the previous results for the variable  $n$  are shown in Figures 23, 24 and 25. The conclusion is that the variation of resistance is an important property of large estuaries. Efforts were also made to fit the corresponding field data by assuming a constant  $n$  while varying the schematization of the channel. The schematization, thus obtained, was found to be physically absurd when compared with the actual geometry of the Delaware.

#### 6.1.5 Effect of Upland Discharge

The effect of upland discharge on tidal conditions has also been investigated (Figs. 25, 26, 27 and 28) and the findings are:

- (I) The influence of upland discharge in the Delaware is limited only to the upstream half of the estuary. It is obviously so when examining once again Fig. 20 which shows that the upland discharge of 11,650 cfs is comparatively negligible to the maximum tidal discharges along the estuary, especially for the downstream half of the estuary.
- (II) Tributary discharges along the Delaware have a completely insignificant effect on tidal flows in the estuary.

#### 6.1.6 Effect of Local Winds

In one of the earliest documents describing tidal conditions in the Delaware Estuary by Zeskind and Lacheur (1926), field observations of the effect of wind have been recorded for a northwesterly wind of maximum speed of 40 m.p.h., blowing down the estuary on March 2, 1914, and an easterly wind of maximum velocity of 37 m.p.h. at the entrance, driving the ocean waters into the estuary on October 11, 1903. It is observed during storms that, corresponding to a lowering of the plane of low water, there is generally a lowering of the plane of high water; and, similarly, a rise of the plane of low water is accompanied by a rise of the plane of high water. It is also found that there are changes in tidal ranges, time of high water and low water and shapes of tidal curves along the estuary.

The value  $\beta_w = 0.26 \times 10^{-2}$  in eq. (74) is used as the coefficient of surface shear for wind, assuming that the end boundary conditions remain unchanged and that the winds are blowing over the widest part of

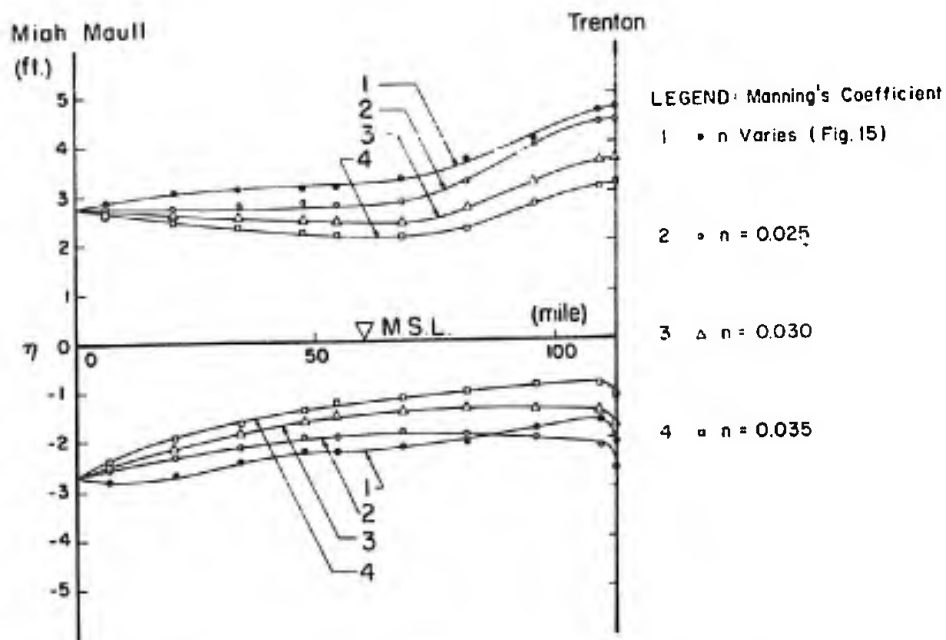


Fig. 23 Delaware Estuary (Exponential Channel) -- Effect of n on High and Low Water Planes

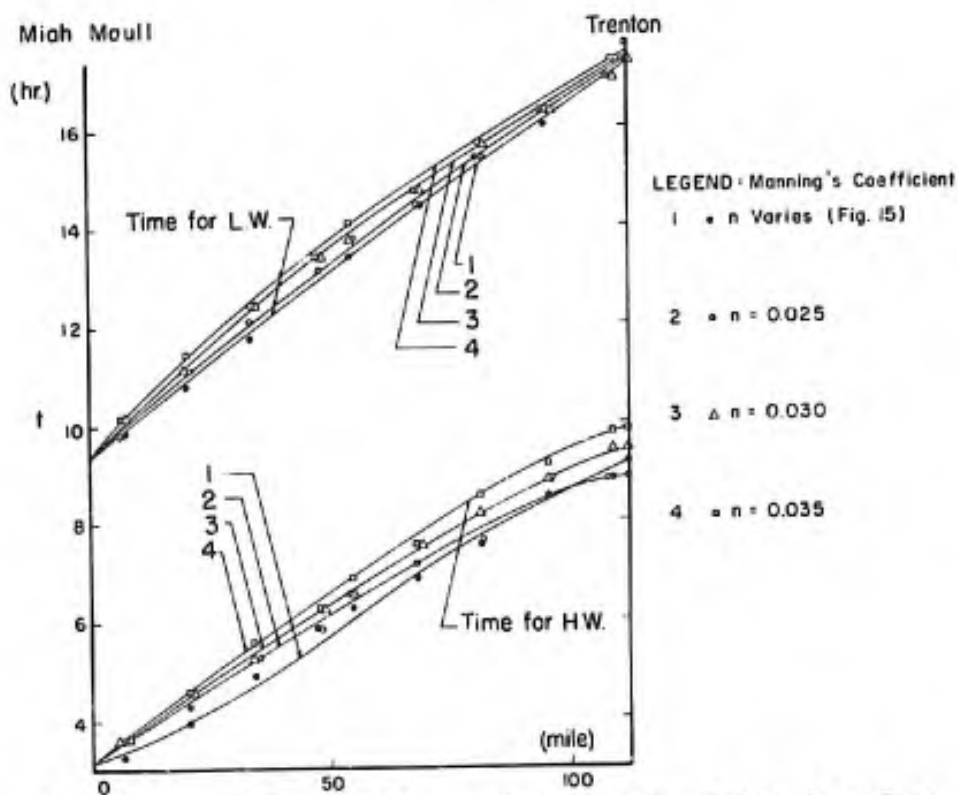


Fig. 24 Delaware Estuary (Exponential Channel) -- Effect of n on Time for High Water and Low Water

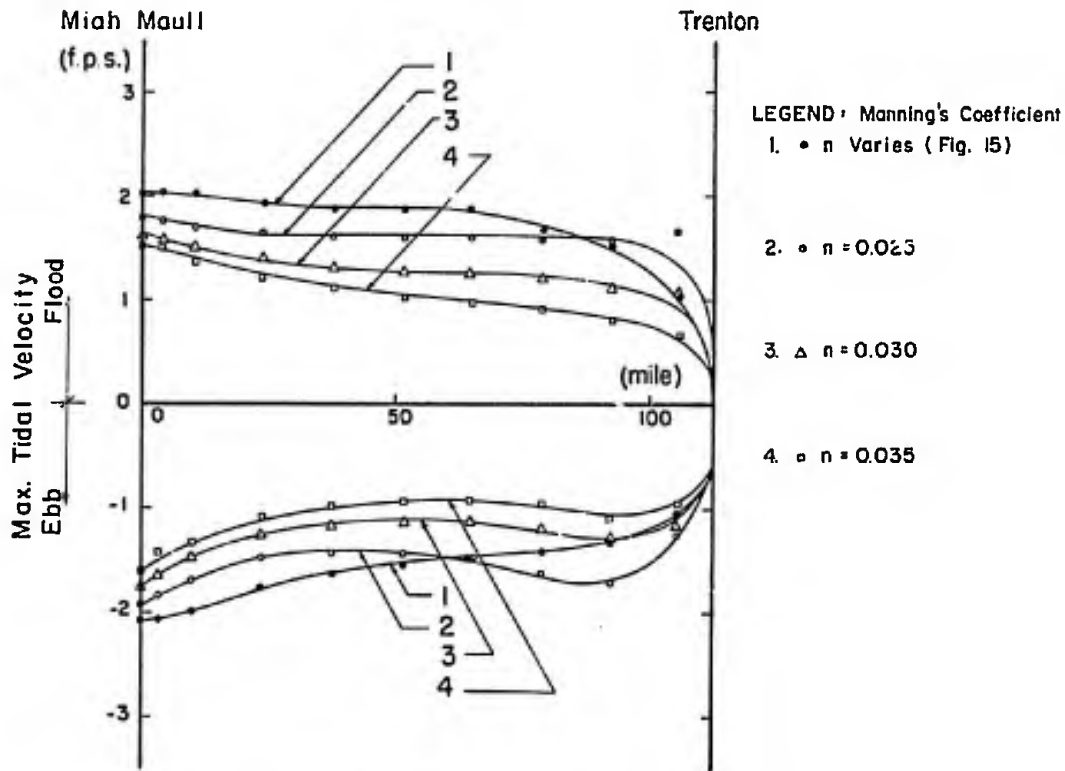


Fig. 25 Delaware Estuary (Exponential Channel) -- Effect of n on Maximum Tidal Velocities

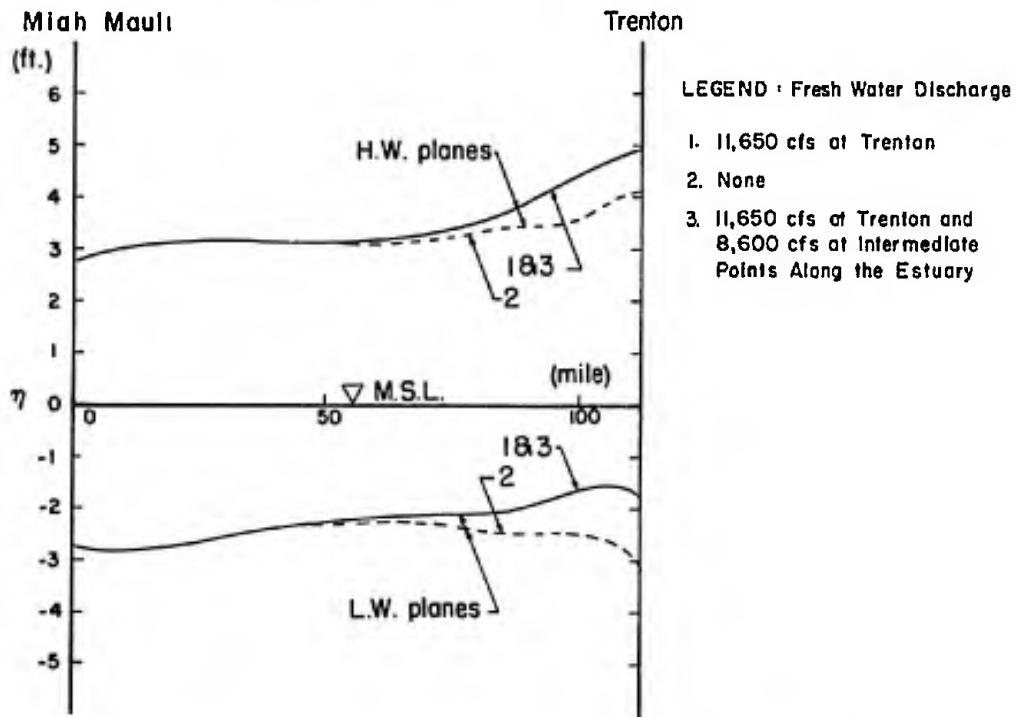


Fig. 26 Delaware Estuary (1951 Channel) -- Effect of Fresh Water Discharge on High and Low Water Planes

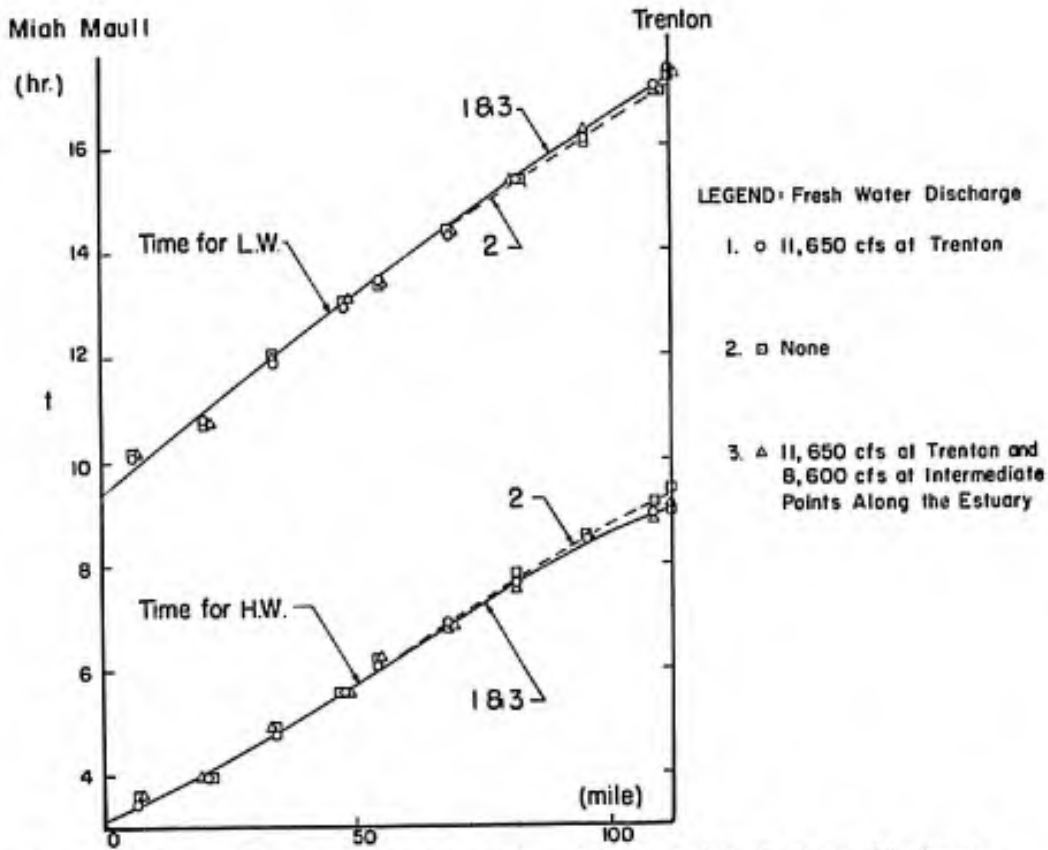


Fig. 27 Delaware Estuary (1951 Channel) -- Effect of Fresh Water Discharge on Time for High and Low Waters

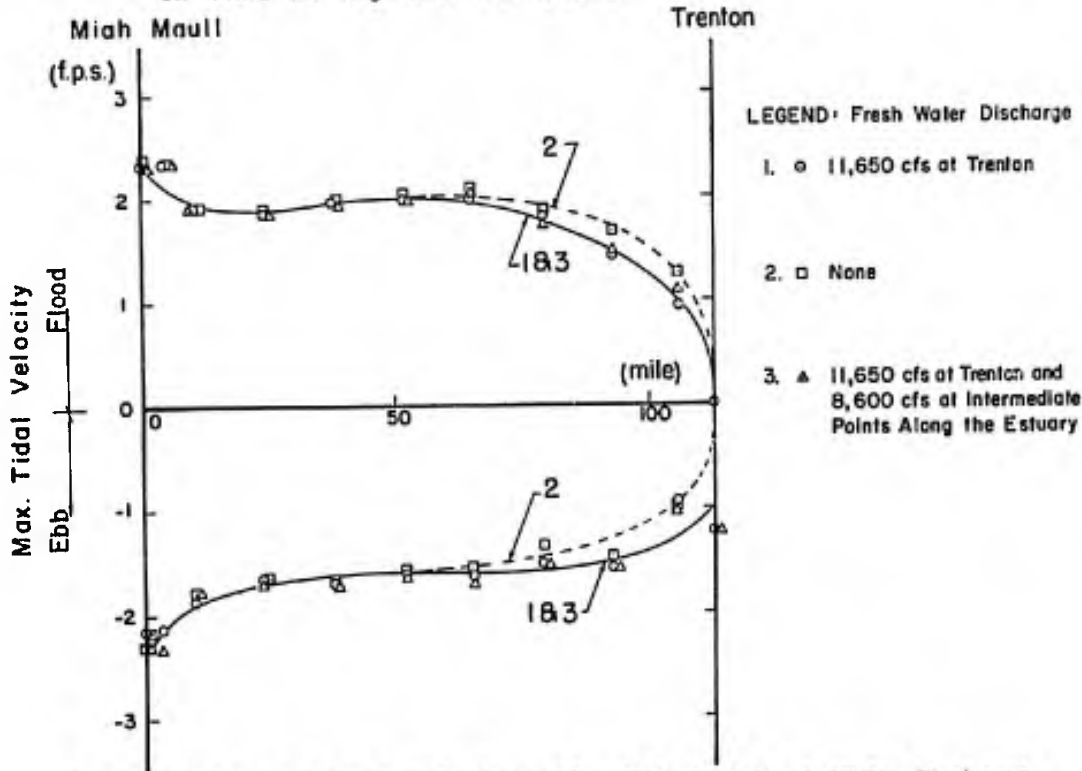


Fig. 28 Delaware Estuary (1951 Channel) -- Effect of Fresh Water Discharge on Maximum Tidal Velocities

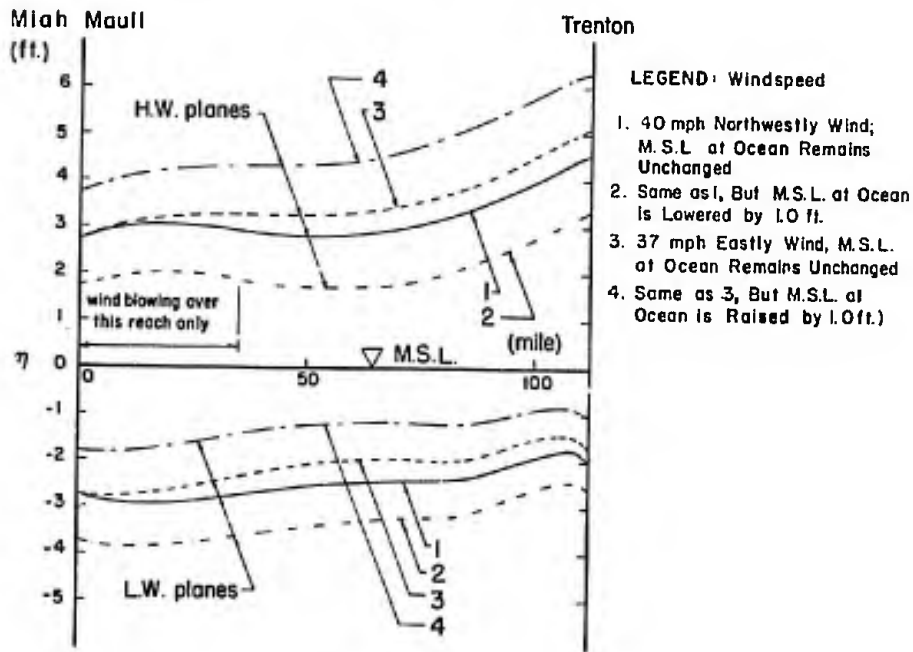


Fig. 29 Delaware Estuary (1951 Channel)-- Effect of Local Wind on High and Low Water Planes

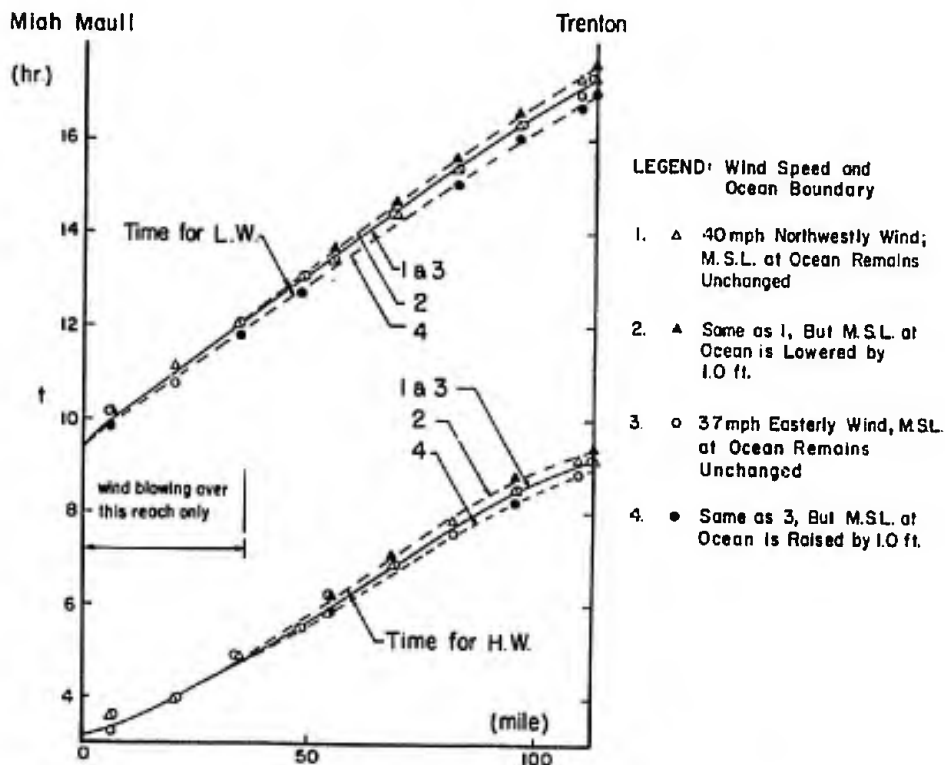


Fig. 30 Delaware Estuary (1951 Channel)-- Effect of Local Wind on Time for High and Low Waters.

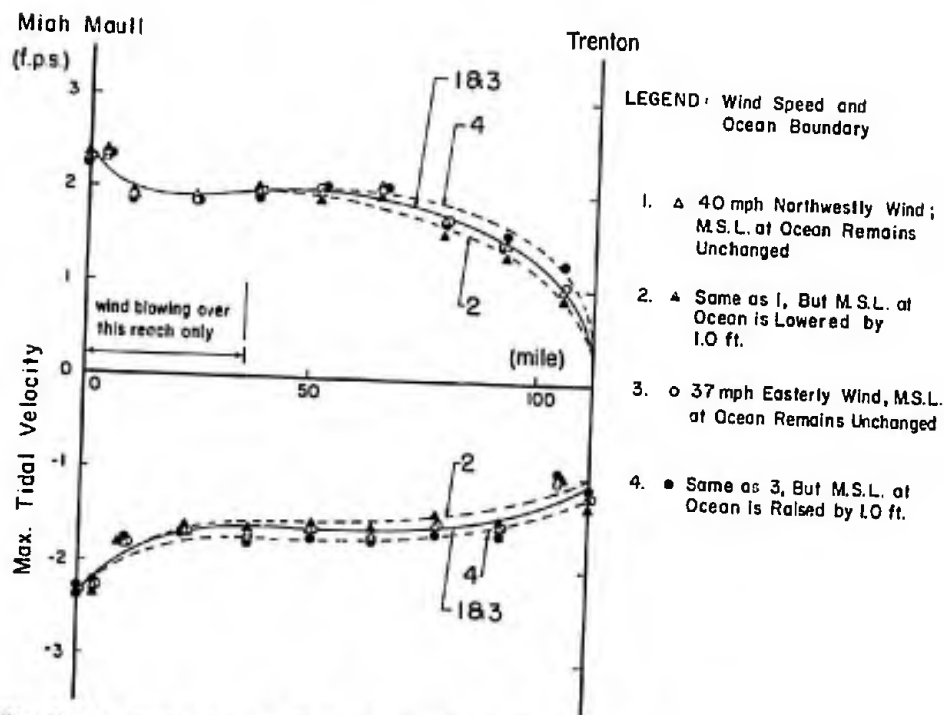


Fig. 31 Delaware Estuary (1951 Channel)-- Effect of Local Wind on Maximum Tidal Velocities

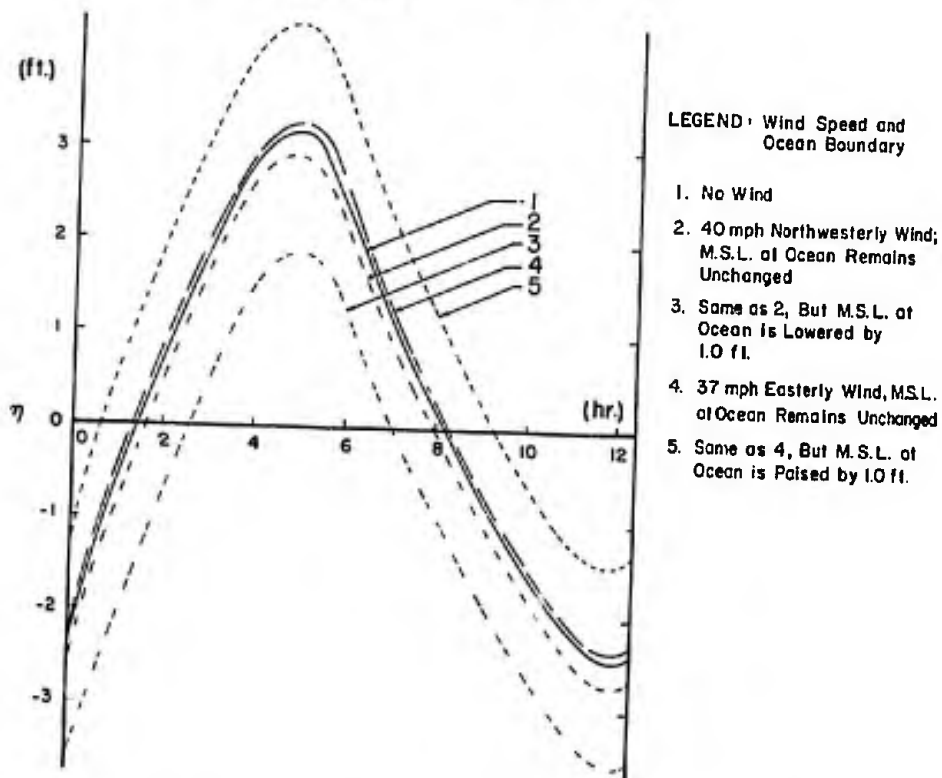


Fig. 32 Delaware Estuary (1951 Channel)-- Tidal Elevations at 34 Miles from Miah Maul under Various Conditions of Local Winds

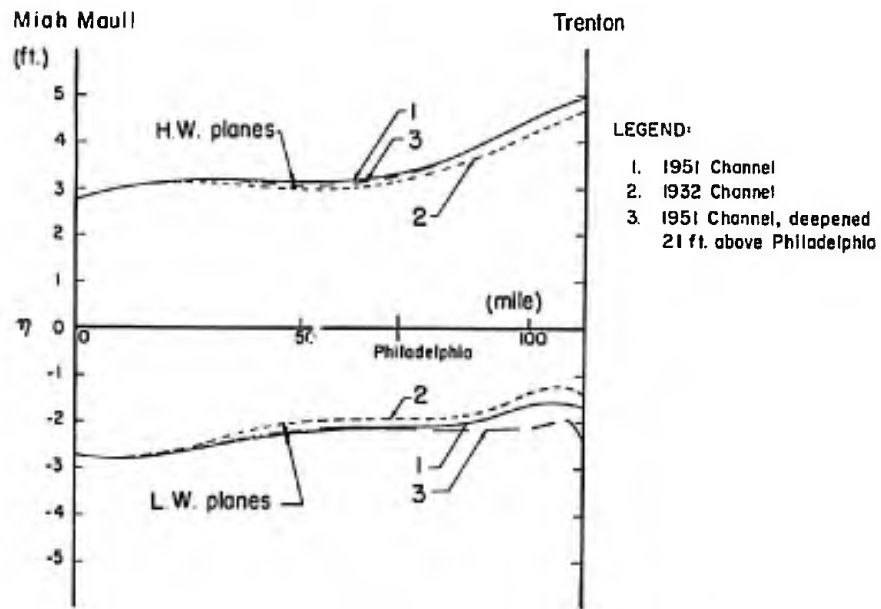


Fig. 33 Delaware Estuary -- Effect of Deepening on High and Low Water Planes

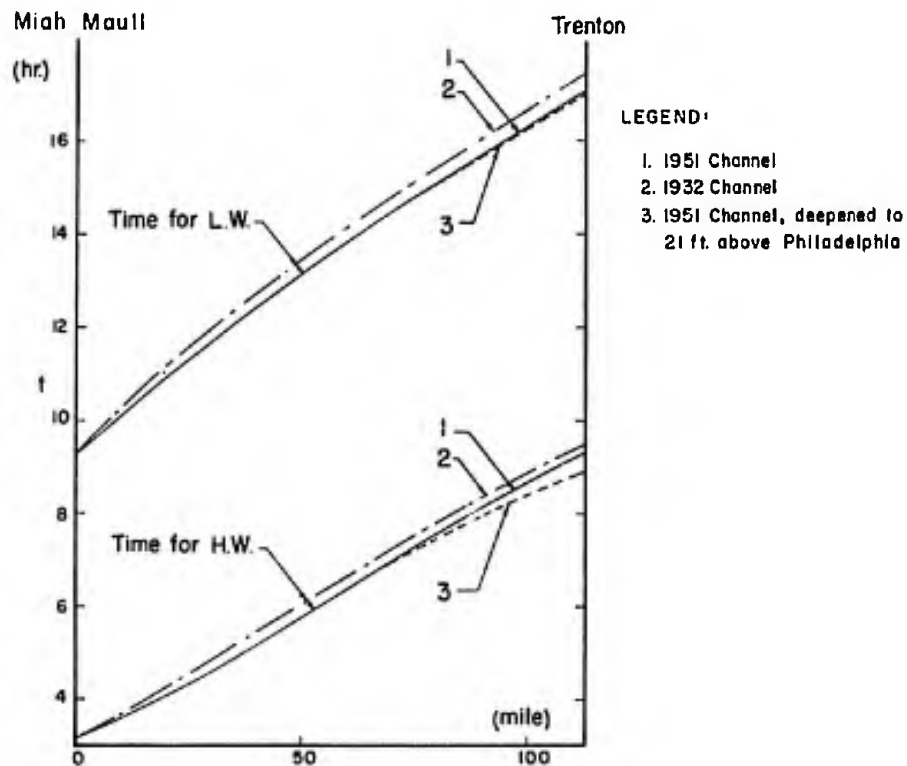


Fig. 34 Delaware Estuary -- Effect of Deepening on Time for High and Low Water Planes

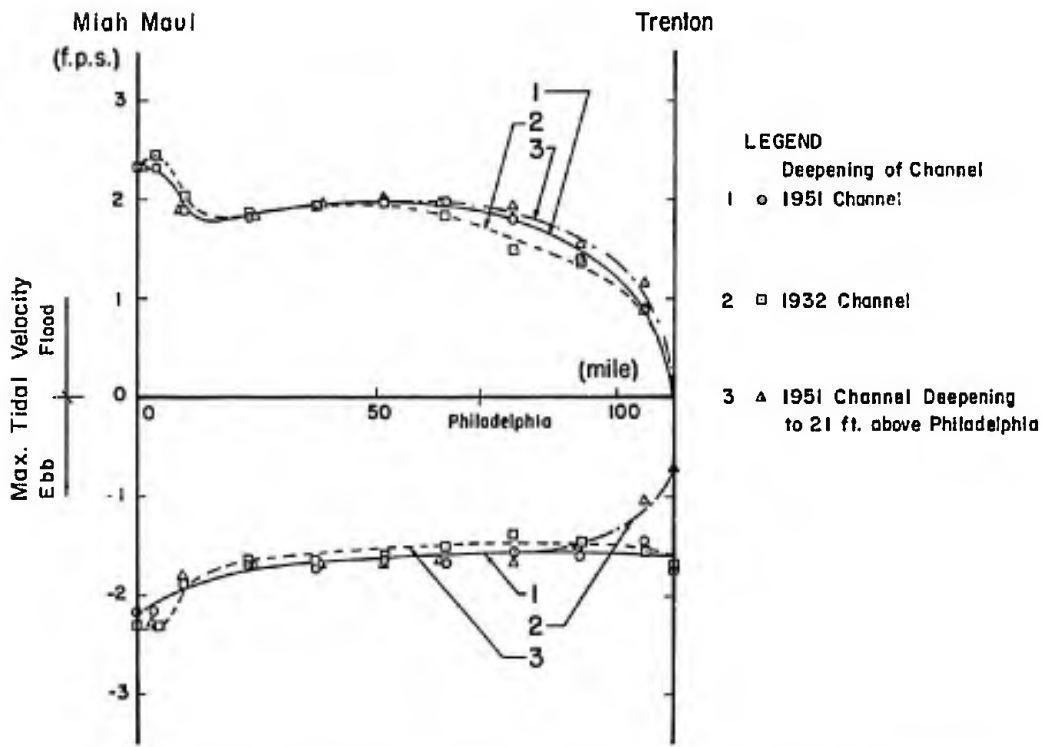


Fig. 35 Delaware Estuary - Effect of Deepening on Maximum Tidal Velocities

the estuary only, i.e., over the first 35 miles above Miah Maul. It is found that simultaneous rises and falls of the planes of high water and low water (Fig. 29) occur. There are negligible changes in tidal ranges, time of high water and low water and the shapes of tidal curves along the estuary. Additional calculations were made assuming that there are changes of mean water level at Miah Maul associated with the storms, while the corresponding tidal curve retains its sinusoidal shape. Under these conditions changes in time of high water and low water occur (Fig. 30), as well as small changes in tidal ranges (Fig. 29); however, there are no basic changes in the tidal velocity (Fig. 31) or in the shapes of tidal curves (Fig. 32). Therefore, changes in the shapes of tidal curves as observed by Zeskind and Lacheur (1926) must come from the deviation of the ocean tide from the sinusoidal form assumed in the solution. It is concluded that correct predictions of tidal conditions under extreme tides rely largely on the accuracy of the information concerning the tidal curves under such circumstances at the ocean entrance, i.e., the ocean boundary condition.

#### 6.1.7 Effect of Changes in Channel Geometry

Lastly, the effect of changes in the geometry of the estuary have been studied. In addition to the proposed schematization for the 1932 and 1951 conditions (Figs. 14a, b and c), a hypothetical schematization, assuming that the estuary is deepened to 21 ft. (over the full effective width) above Philadelphia, is included. The results obtained show that the deepening of a tidal channel due to dredging will, in general, lead to increases in tidal ranges (Fig. 33), earlier arrivals of high water and low water (Fig. 34) and increases in maximum tidal velocities (Fig. 35) along the channel.

#### 6.2 Savannah Estuary

The Savannah Estuary is a partially mixed estuary, located on the east coast of the United States between the states of South Carolina and Georgia. It is classed as an open end estuary. Due to the comparatively

steep gradient of the channel bottom, its effective length as observed by field measurements is approximately 45 to 48 miles, depending on the upland discharge. The Savannah Harbor extends as far as 20 miles above the mouth and consists of a network of tidal channels as shown in Fig. 36. The present study is limited to the reach above the harbor area, which is assumed to consist of one main tidal channel only, i.e., the effect of all minor branches is neglected.

#### 6.2.1 Schematization

The information available for schematization was a set of sounding maps based on the mean low water surface along the estuary, and a profile of the mean low water surface with respect to a reference datum. The average widths,  $b$  and  $b_s$ , and the average depths of water at the sections defined by the grid for the computer solution,  $d$ , are estimated from the sounding map. Since the profile of the mean low water with respect to a reference datum along the estuary is known, the levels of the bottom with respect to the same reference datum can be deduced from the depths of water at the corresponding sections. Due to the limited time available, no transverse cross sections were plotted from the data shown on the sounding maps.

Fig. 37 shows the proposed schematization of the Savannah Estuary starting from a point 20 miles above the entrance of the estuary. The lengths of tidal channel considered are 25 miles for a fresh water discharge of 8,620 cfs and 27.5 miles for 5,800 cfs. The corresponding  $\Delta x$ 's used are 2-1/4 miles and 2-1/2 miles.  $\Delta t$  is taken to be 298 seconds for both cases. All geometric and field data were supplied by the Savannah District, Corps of Engineers. A sinusoidal tidal curve having a range of 7.2 ft. is assumed at the downstream boundary for an upland discharge of 8,620 cfs, the corresponding tidal range is 7.8 ft. for 5,800 cfs at the upstream boundary.

#### 6.2.2 Manning Resistance Coefficient

The values of  $n$  for use in the computer solution are found by

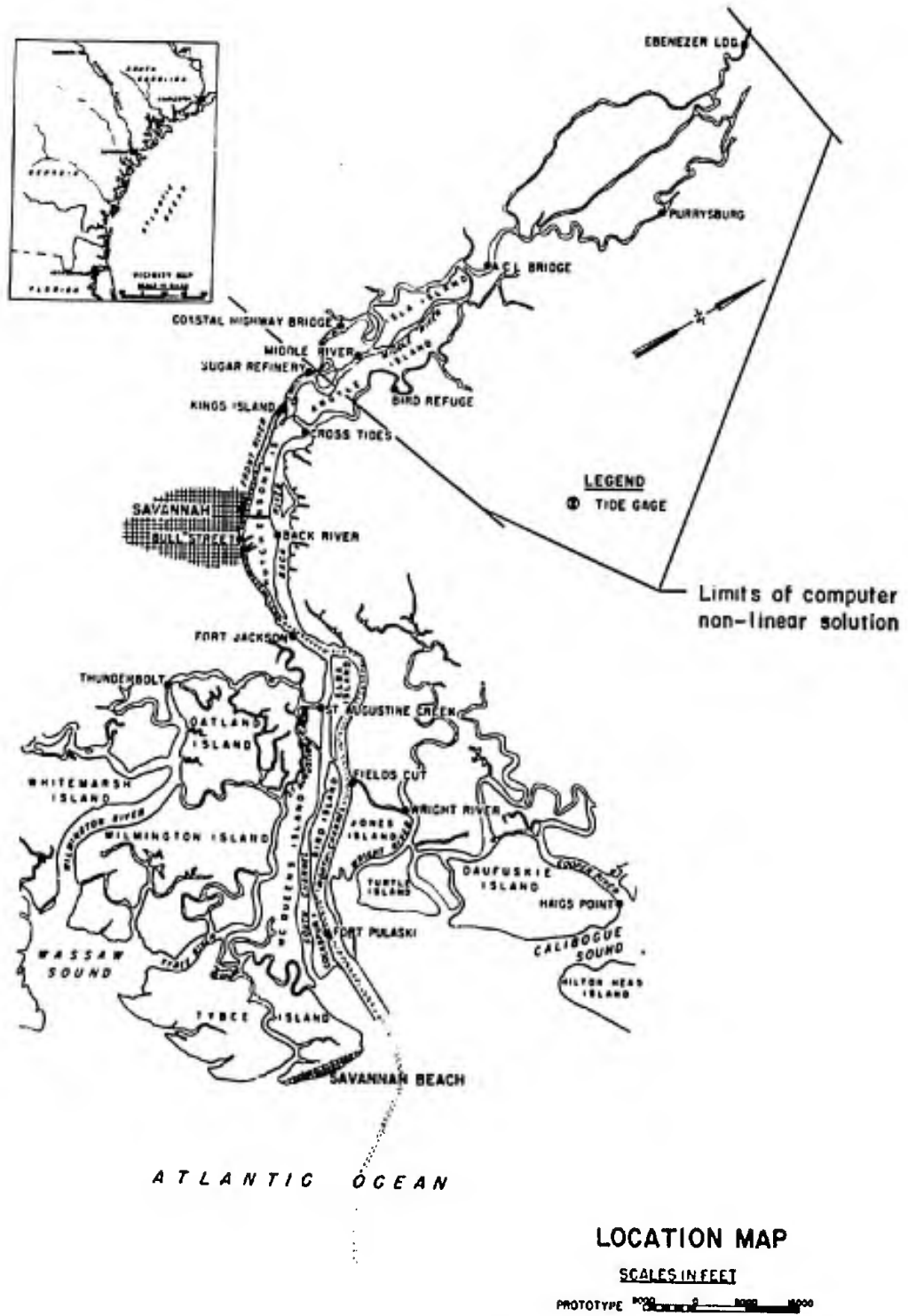


Fig. 36 Savannah Estuary - General Layout

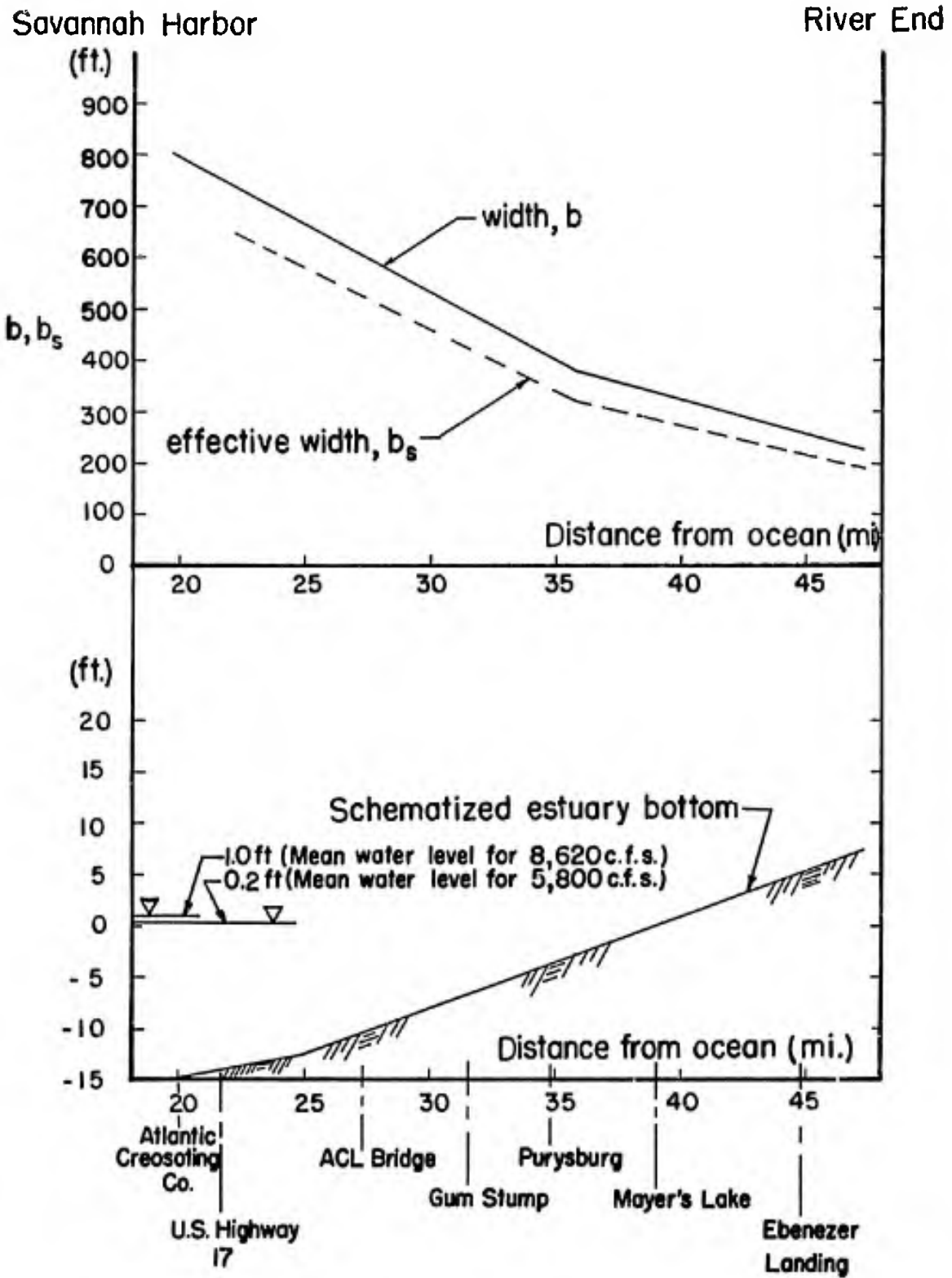


Fig. 37 Savannah Estuary - Geometry of the Schematized Estuary

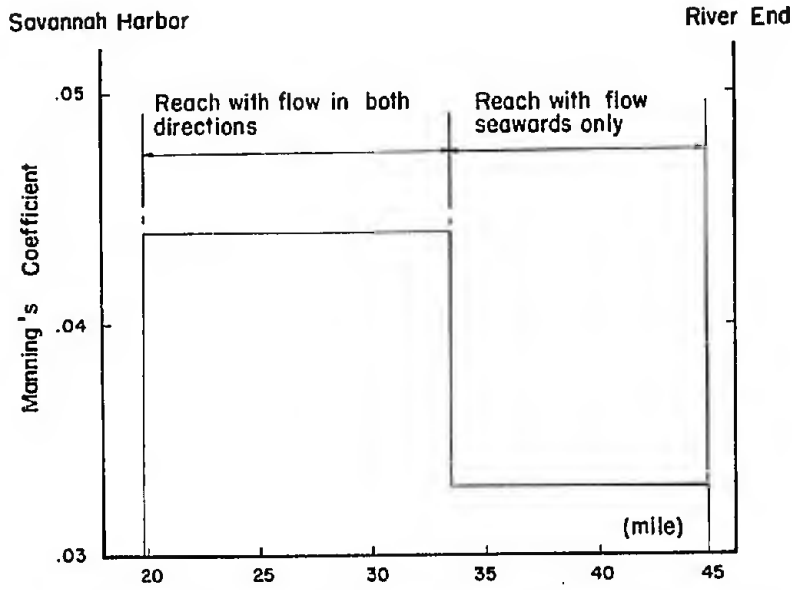


Fig. 38 Savannah Estuary (8,620 cfs) - Manning's Coefficients

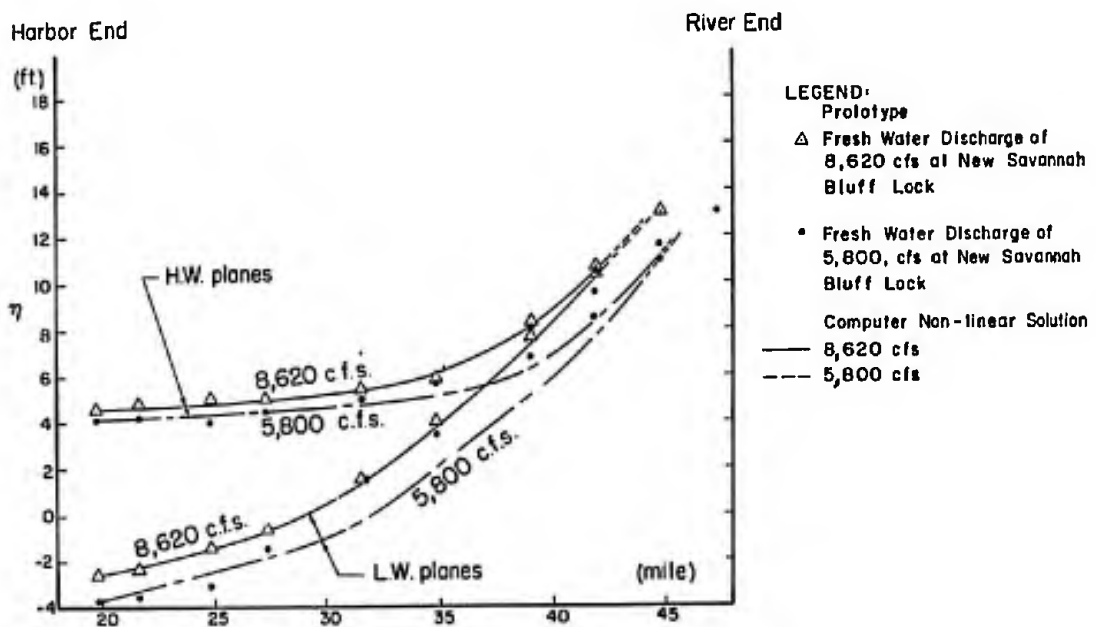


Fig. 39 Savannah Estuary - High and Low Water Planes for Different Fresh Water Discharges

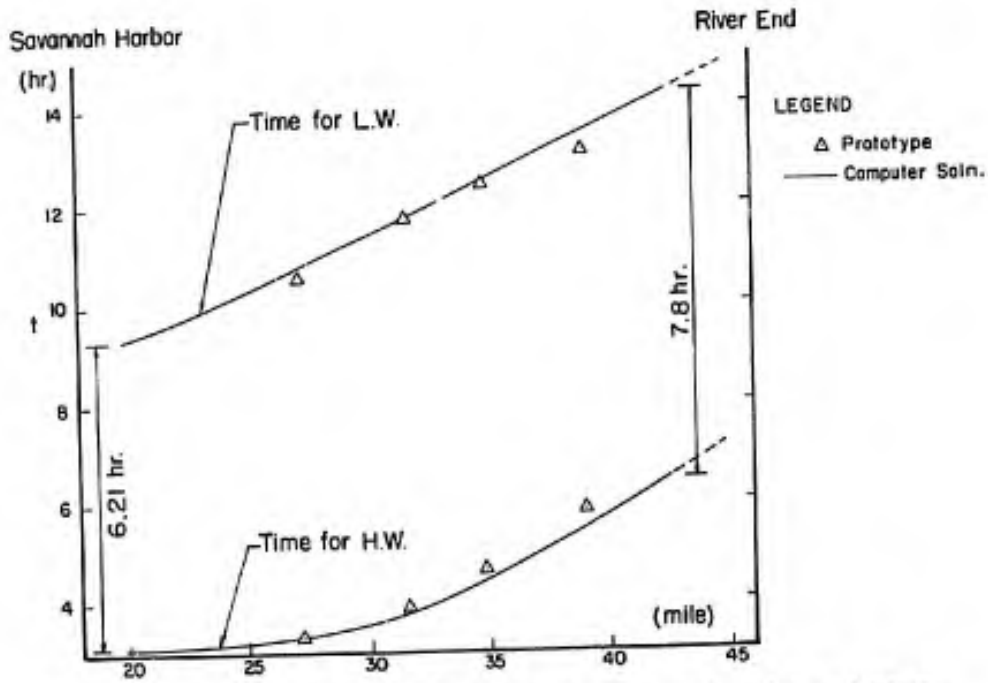


Fig. 40 Savannah Estuary (8,620 cfs) -- Time for High and Low Waters

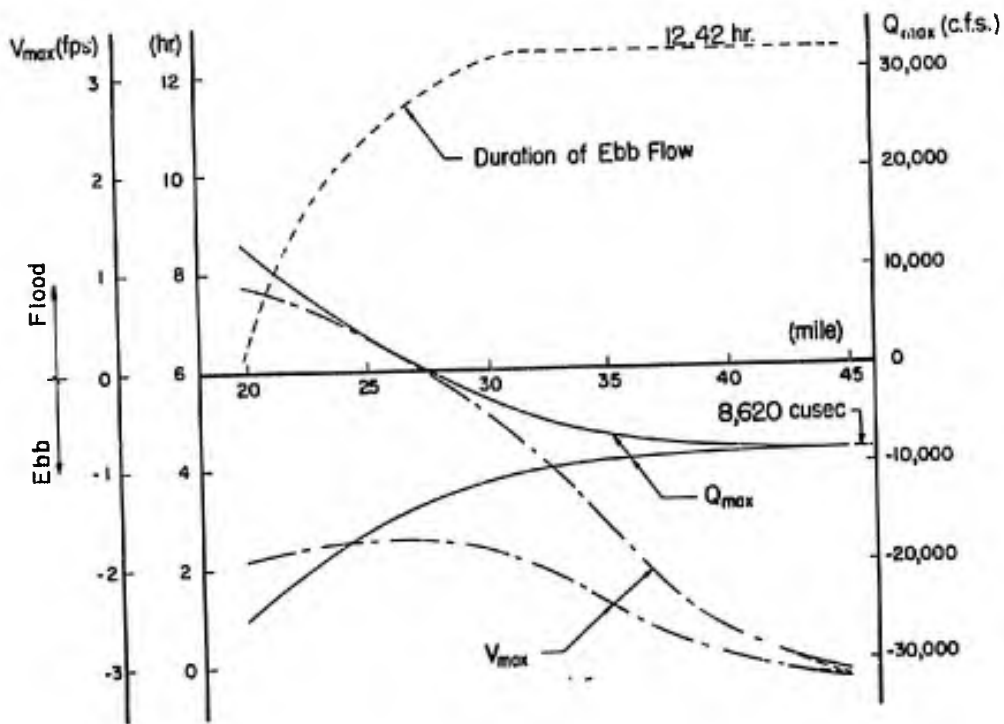


Fig. 41 Savannah Estuary (8,620 cfs) -- Maximum Tidal Velocities and Discharges, and Duration of Ebb Flow

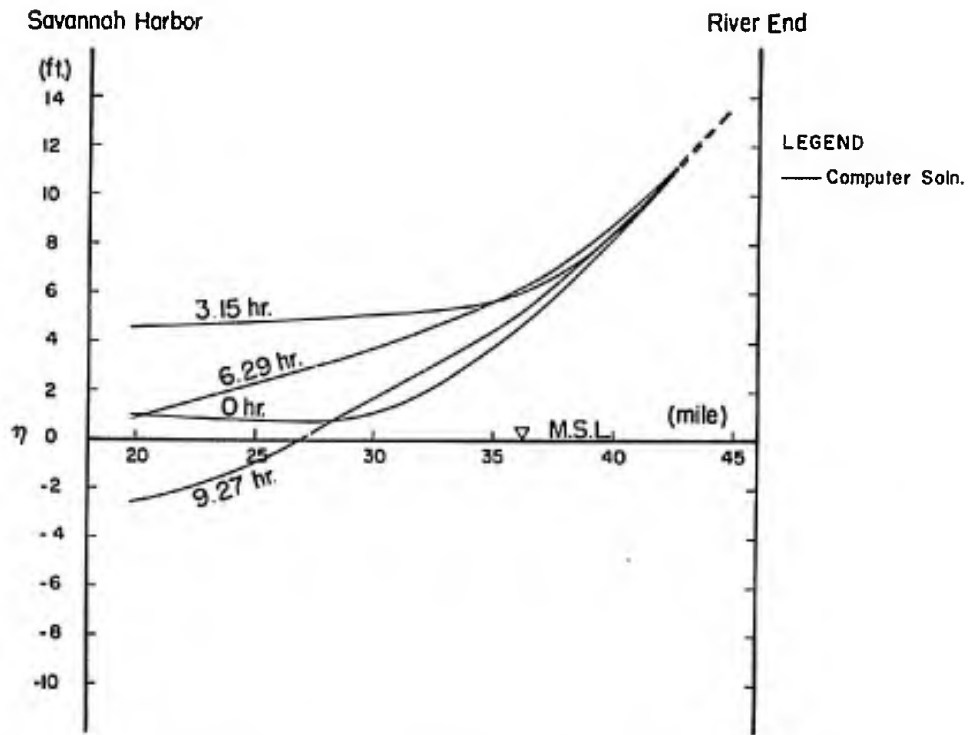


Fig. 42 Savannah Estuary (8,620 cfs) -- Tidal Elevations Approximately at Time 0, T/4, T/2, and 3T/4

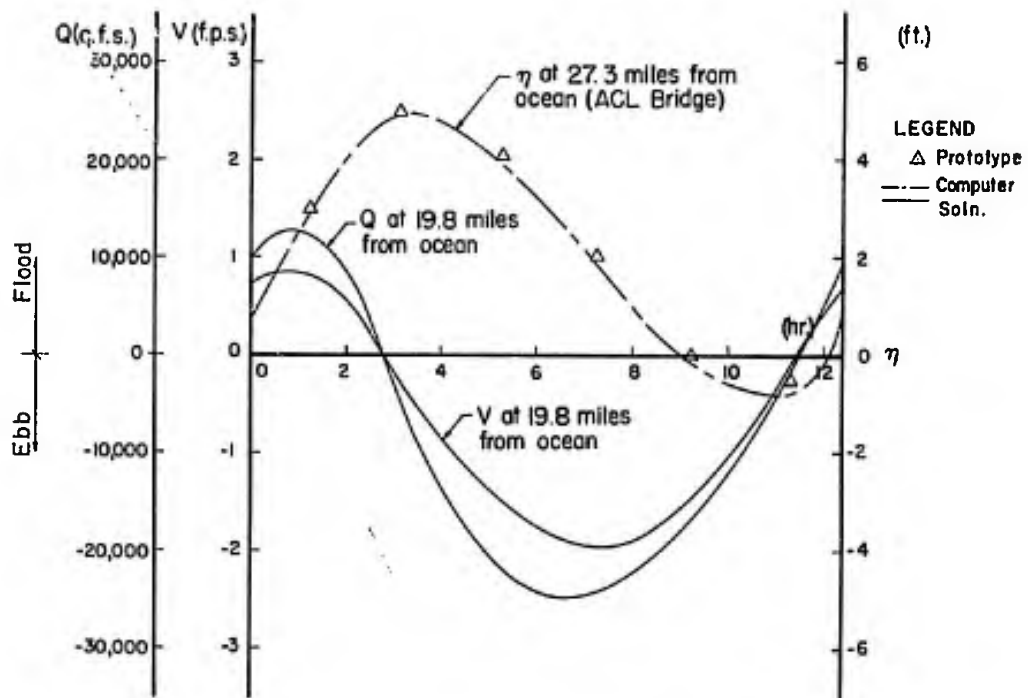


Fig. 43 Savannah Estuary (8,620 cfs) -- Tidal Curves for Tidal Velocity, Discharge and Elevation

matching the field data on tidal elevations at a fresh water discharge of 8,620 cfs. A resistance change from  $n = 0.044$  to  $n = 0.033$  appears to occur near the section (mile 34) at which the flood component of the tidal velocity disappears as shown in Fig. 38. Using these values of  $n$ , a close agreement was obtained between the computed solution and the field data as shown in Figures 39, 40 and 43. The agreement between computed and observed values at the fresh water discharge of 5,800 cfs is not as good as in the previous case. This is probably due to the crude transverse schematization which was used for this study.

### 6.2.3 Tidal Characteristics

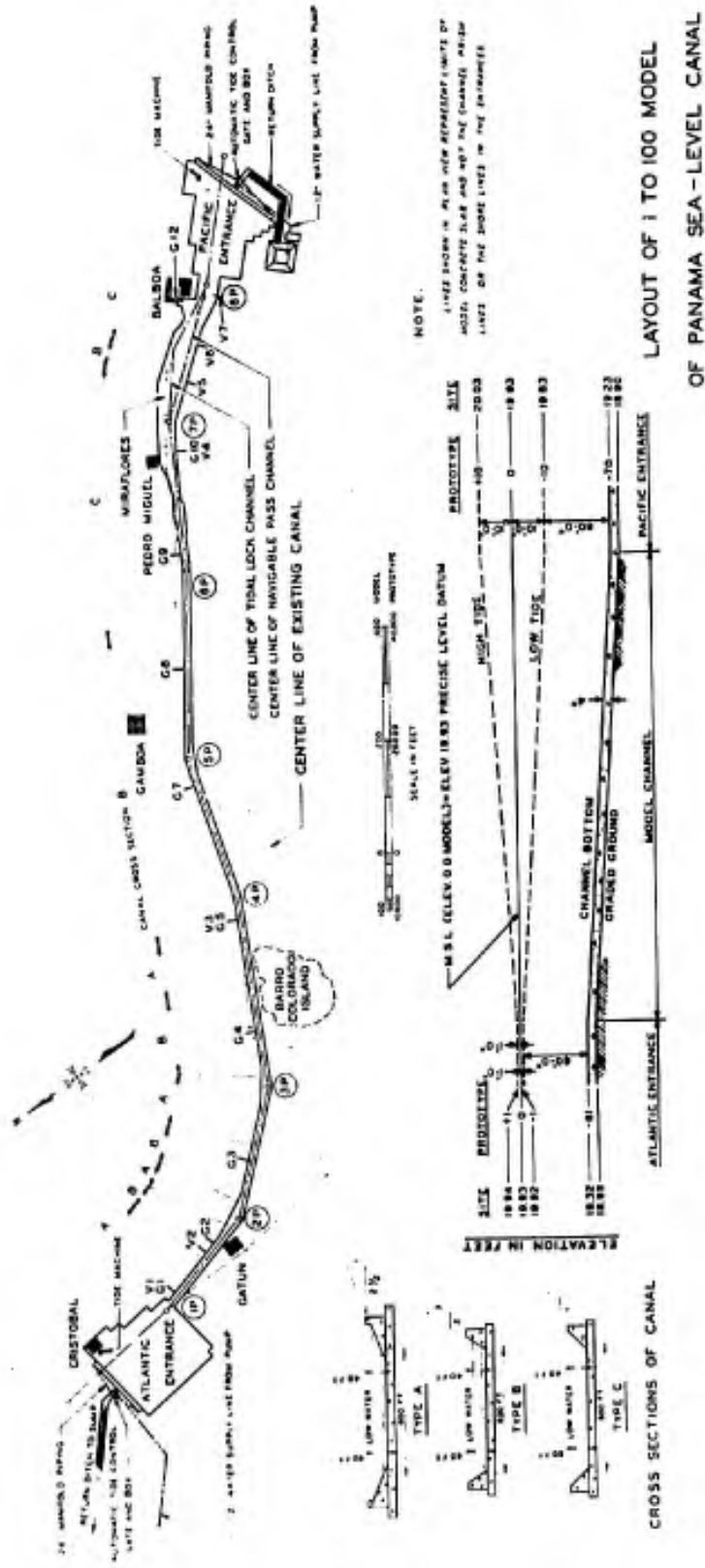
Figure 41 shows the computed values of maximum tidal velocity, maximum discharge and the duration of ebb flow for this portion of the open end estuary. The upland discharge is not negligible when compared to the downstream tidal discharges, as in the case of the Delaware estuary. Thus relatively small changes in the fresh water discharge cause significant changes in the downstream tidal characteristics. Instantaneous water surface elevations computed at different times in the tidal cycle are shown in Fig. 42.

### 6.3 Proposed Sea-Level Panama Canal

After World War II, feasibility studies were made by the U. S. Corps of Engineers for a sea-level canal at Panama. A final report on sea-level canal model tests (Ref. No. 43) was submitted in 1948. A series of articles concerning various problems of the present and the proposed Sea-level Panama Canal (Ref. No. 28) were published in 1949.

#### 6.3.1 Schematization

A general layout with typical cross sections of the proposed sea-level Panama Canal is given in Fig. 44. The geometric inputs are prepared from Fig. 44 with the exception that the Type C cross section is adopted, for simplicity, as the typical cross section throughout the Canal. The channel used for solution is 35.35 miles long. In accordance with the boundary condition for a sea-level canal it is divided into



Longitudinal cross section of Canal  
 Fig. 44 Proposed Sea-level Panama Canal - General Layout

12 equal segments of 2.95 miles each.  $\Delta t$  is equal to approximately 344 seconds. Sinusoidal ocean tides are assumed at both ends. The various ocean tidal boundary conditions which are similar to those performed in the hydraulic model studies are summarized in Table II.

In the hydraulic model, it was decided to adopt a Manning's coefficient of 0.024 (Ref. No. 28). Since the schematized canal is of constant cross section, better agreement between results obtained from the hydraulic model tests and the computer solutions were found using a constant Manning's coefficient of 0.025 (except for the case of a 6' Pacific tide and a 1' Atlantic tide, where a value of 0.014 was used).

### 6.3.2 Tidal Characteristics of the Sea-Level Canal

The computed and measured tidal elevations and velocities are shown in Figs. 45 and 46 for the case 1 (Table II) boundary conditions. The distribution of maximum tidal currents and discharges along the canal for the various boundary conditions is shown in Figs. 47 and 48. Tidal velocities versus time at both the Atlantic and Pacific ends are given in Figs. 49 (a) and 49 (b). The high and low water planes and the time of the maximum current along the canal are shown in Figs. 50 and 51. A summary of the computed values of the maximum tidal currents at both ends of the canal, for all the boundary conditions, is given in Table III. For comparison, the measured values obtained in the hydraulic model tests are tabulated and the agreement is very close. Computations made by the Pillsbury method and by Bakhmeteff's (Ref. No. 28) method are also tabulated. A significant factor is the economy and speed of acquiring the solutions by means of the non-linear, finite difference method. The compilation of the computer program by an IBM 360 - model 40 computer takes about 1-1/2 minutes and the solution for each boundary condition takes an additional 1-1/2 minutes of computer time.

### 6.3.3 Currents During a Ship Transit of the Canal

The ease with which solutions to special problems may be obtained on the computer is demonstrated by calculations relating to the transit of ships through the canal. A ship is assumed to enter the canal from

Case	Tidal Range (ft.)		Phase Difference between Tides at Both Ends	Mean Water Level in Pacific Ocean with Respect to Reference Datum	Manning's Coeffi- cient used for Computer Non- linear Solution
	Pacific End	Atlantic End			
1	20	2	Atlantic Tide Pre- cedes Pacific Tide by 3 Lunar Hours	+0.77	0.025
1a	20	2	0	0	0.025
2	16	1	0	0	0.025
3	13	1	0	0	0.025
4	10	1	0	0	0.025
5	6	1	0	0	0.025
5a	6	1	0	0	0.014

Table II - Proposed Sea-level Panama Canal -  
Data Used for Computer Solutions

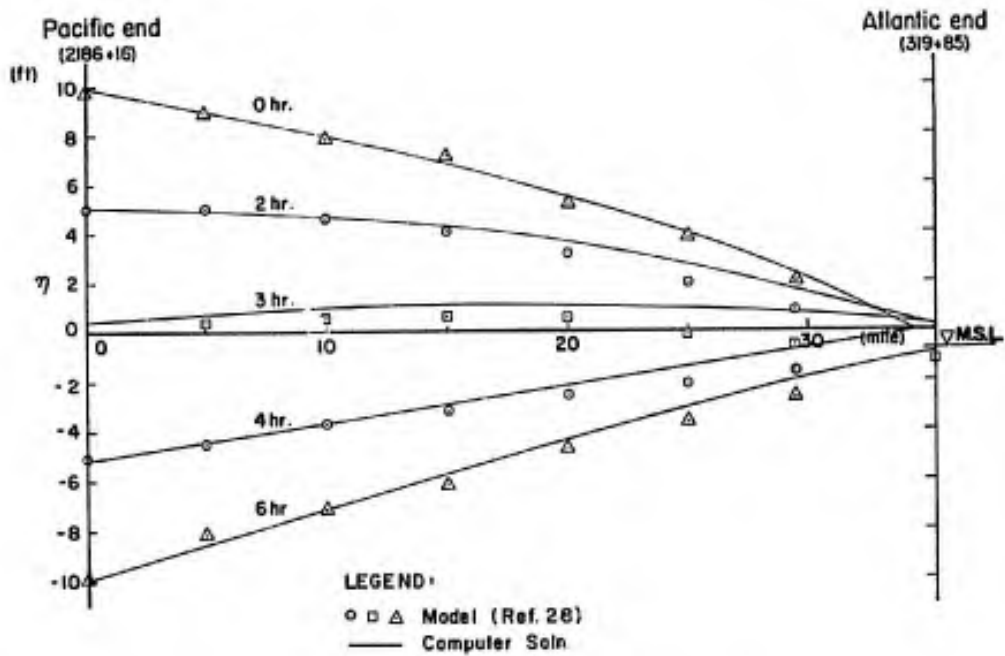


Fig. 45 Proposed Sea-level Panama Canal (Case I) -- Tidal Elevations at Time 0, 2, 3, 4, and 6 Hours, After High Water at Pacific Ocean

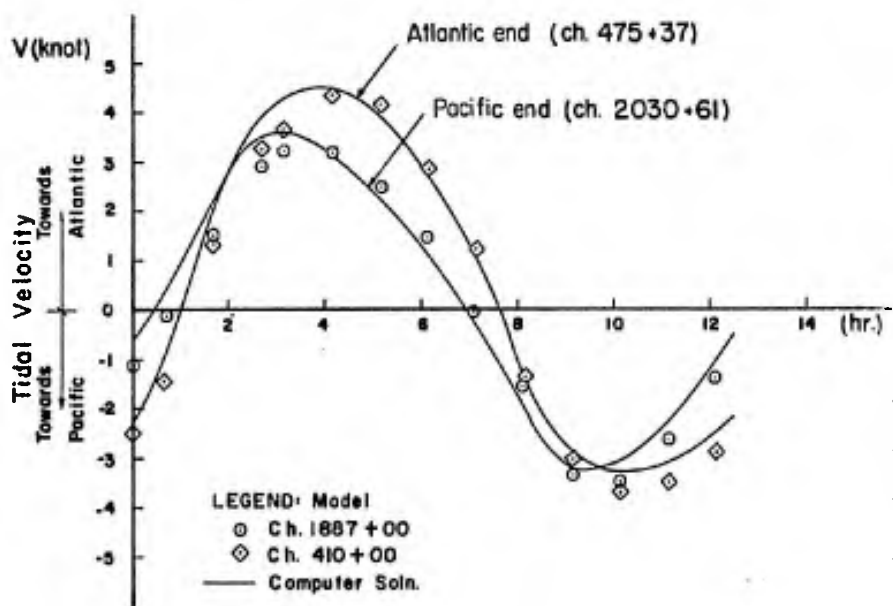


Fig. 46 Proposed Sea-level Panama Canal (Case I) -- Tidal Curves for Tidal Currents

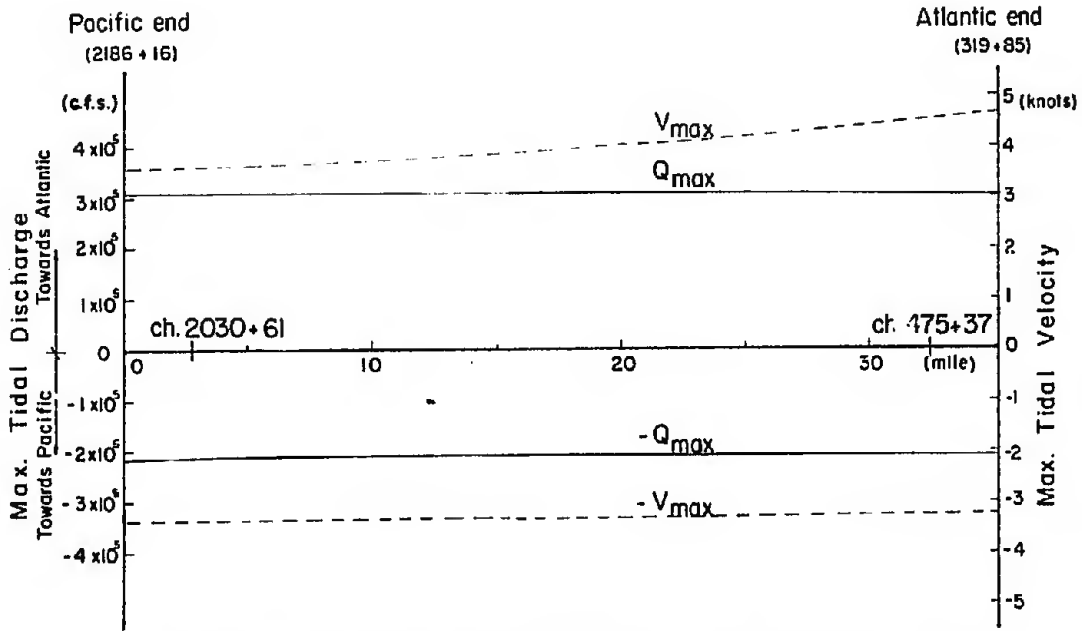


Fig. 47 Proposed Sea-level Panama Canal (Case 1) -- Maximum Tidal Currents and Discharges

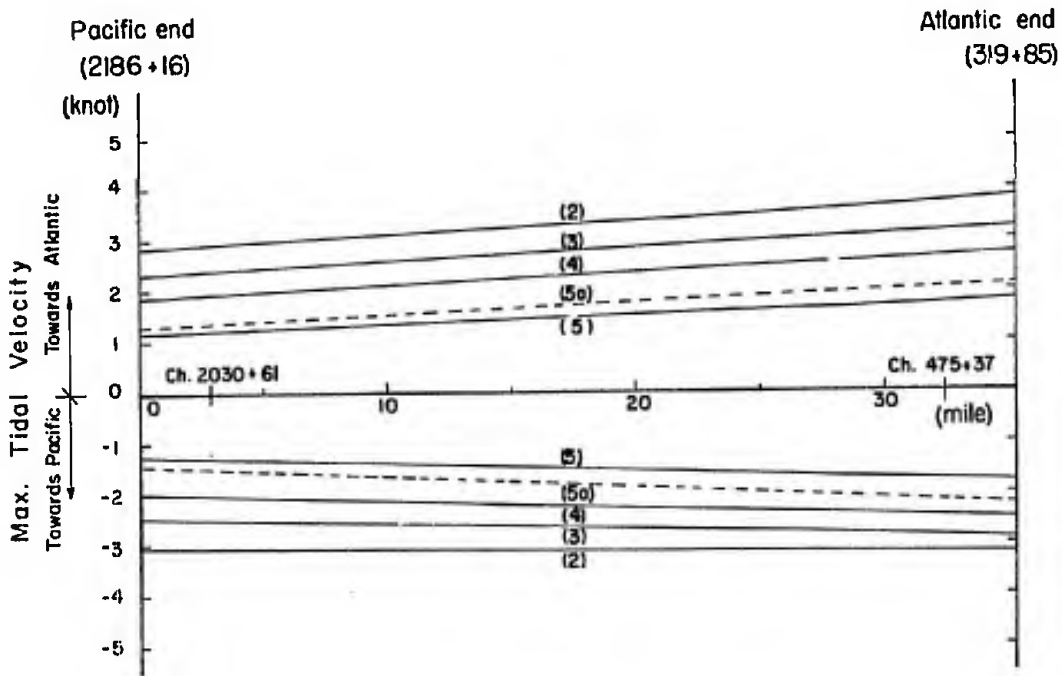


Fig. 48 Proposed Sea-level Panama Canal (Cases 2-5) -- Maximum Tidal Currents

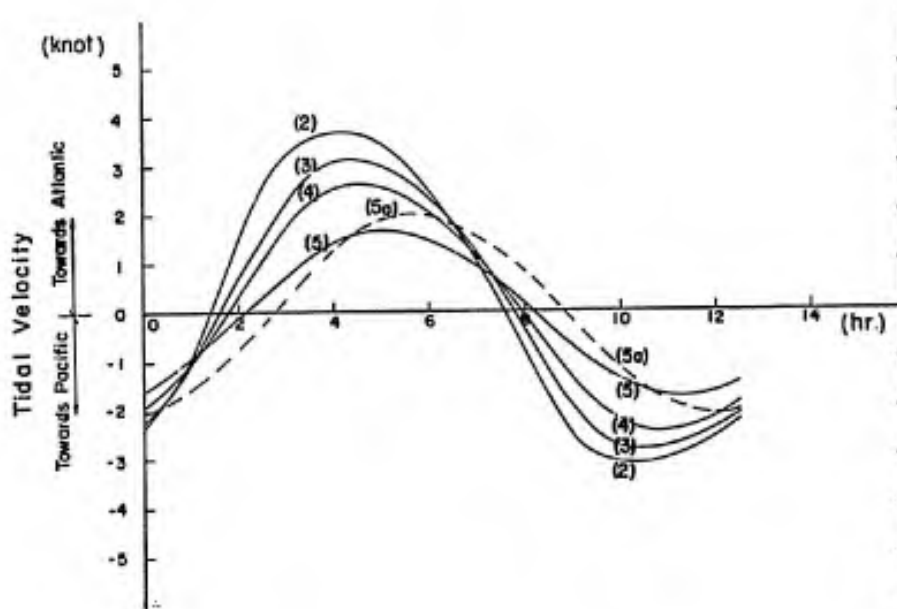


Fig. 49a Proposed Sea-level Panama Canal (Cases 2-5)-- Tidal Curves for Tidal Currents at Atlantic End (ch. 475+37)

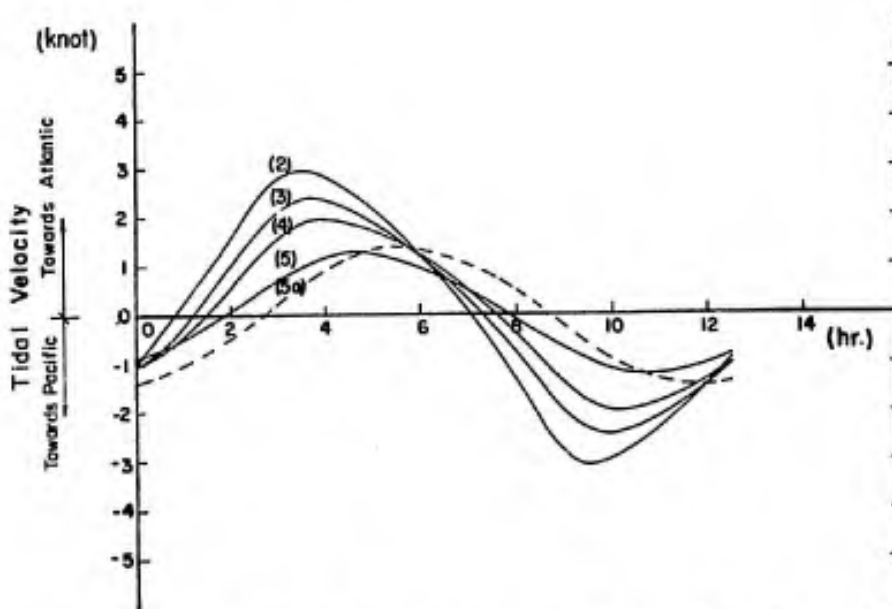


Fig. 49b Proposed Sea-level Panama Canal (Cases 2-5)-- Tidal Curves for Tidal Currents at Pacific End (ch. 2030+61)

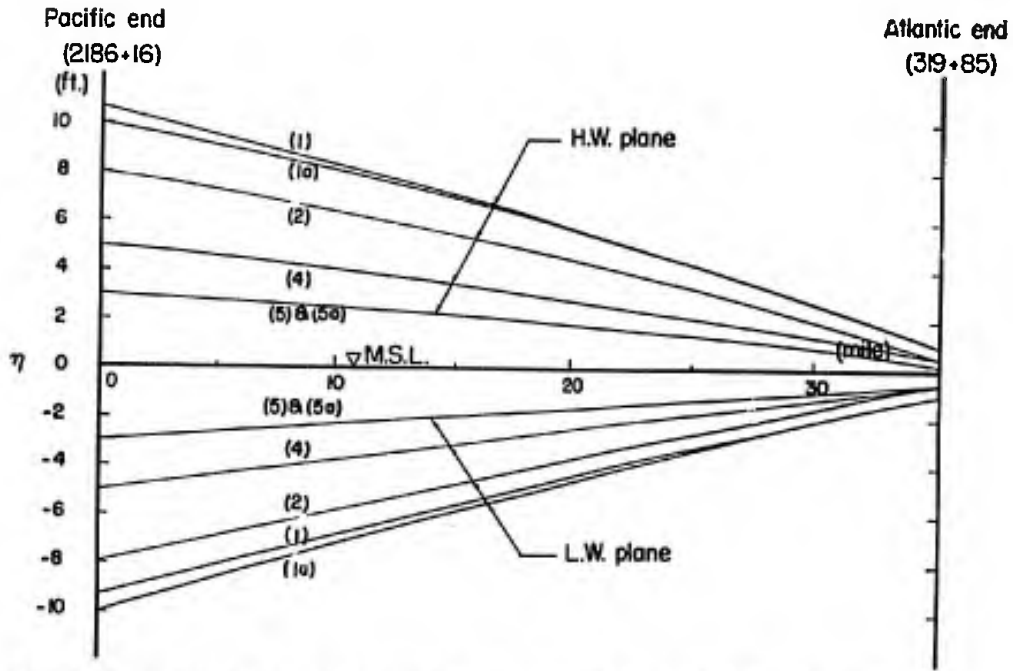


Fig. 50 Proposed Sea-level Panama Canal -- High and Low Water Planes

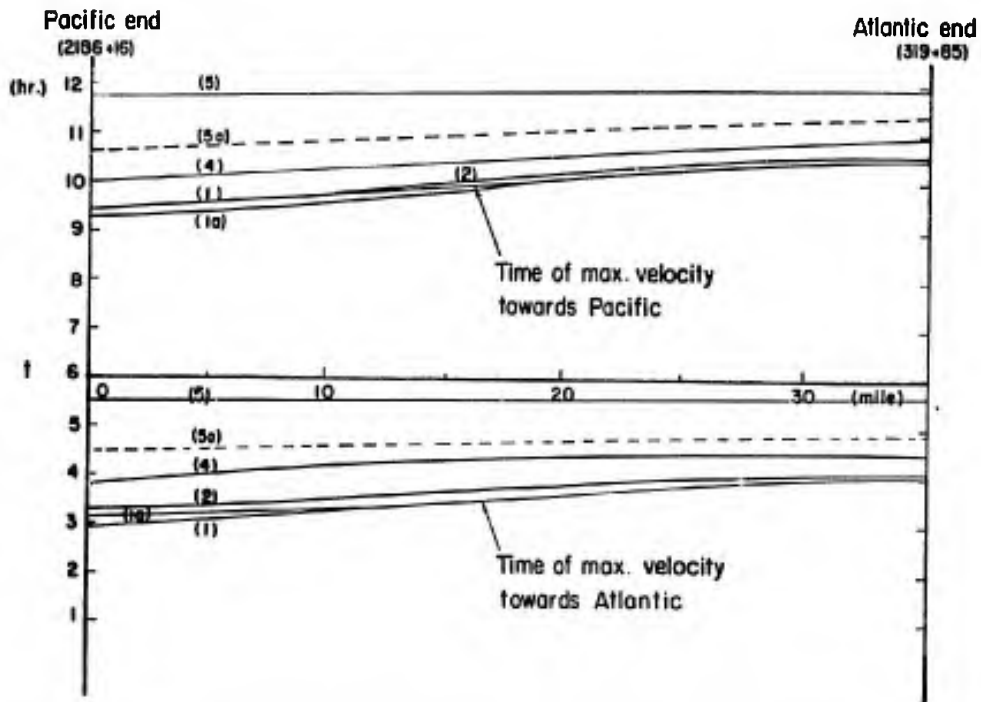


Fig. 51 Proposed Sea-level Panama Canal -- Time at Maximum Tidal Currents

		MAXIMUM CURRENT (Knots)										
Case	Tidal Ranges (ft.)		Atlantic End					Pacific End				
	Pacific Ocean	Atlantic Ocean	Pillsbury's Method	Bakhtmeteff's Method	Hydraulic Model	Computer Non-linear Solution	Bakhtmeteff's Method	Hydraulic Model	Computer Non-linear Solution	Bakhtmeteff's Method	Hydraulic Model	Computer Non-linear Solution
1	20	2	4.5	4.6	4.4	4.52	3.8	3.7	3.62			
1a						4.31			3.59			
2	16	1	4.0	3.7	3.8	3.68	3.4	3.0	2.88			
3	13	1	3.5	3.3	3.3	3.19	3.0	2.5	2.48			
4	10	1	3.0	3.0	2.7	2.64	2.6	2.0	2.02			
5	6	1	2.1	2.4	2.1	1.75	2.0	1.5	1.28			
5a						2.10			1.44			

Table III - Proposed Sea-Level Panama Canal --  
Summary of Maximum Currents

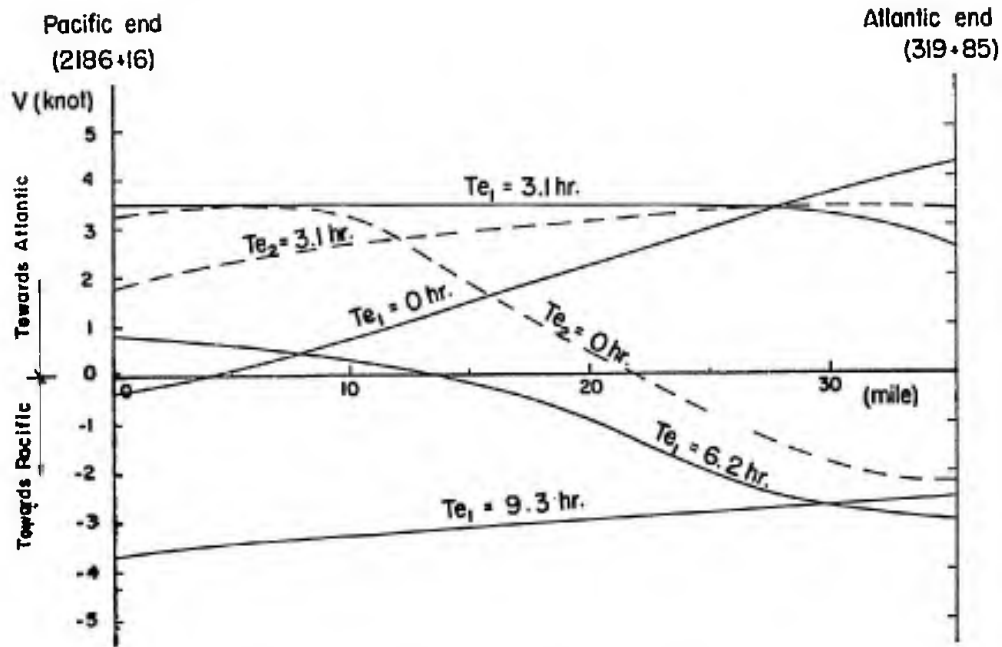


Fig. 52 Proposed Sea-level Panama Canal (Case I) -- Currents Experienced by Ships Traveling at a Net, Constant Speed of 10.2 Knots

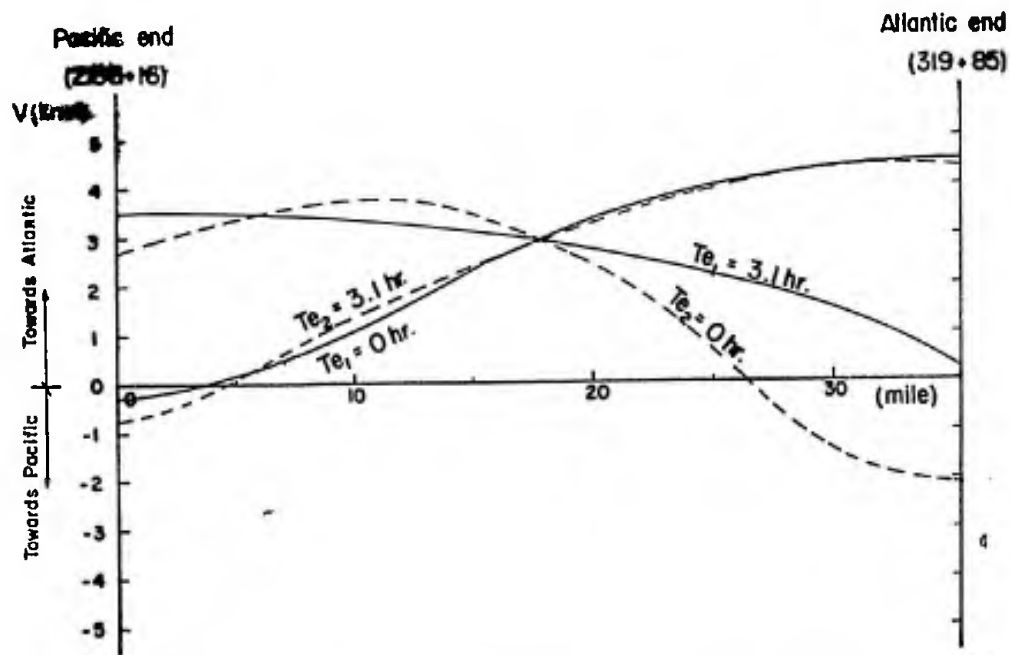


Fig. 53 Proposed Sea-level Panama Canal (Case I) -- Currents Experienced by Ships Traveling at a Net, Constant Speed of 7.65 Knots

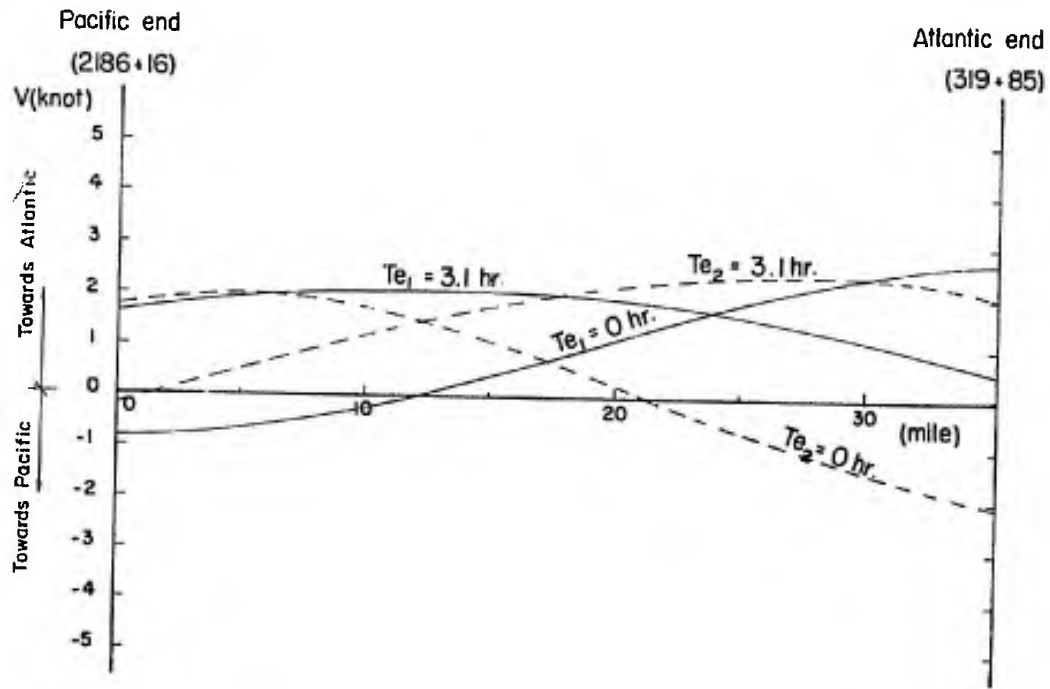


Fig. 54 Proposed Sea-level Panama Canal (Case 1a) -- Currents Experienced by Ships Traveling at a Net Constant Speed of 7.65 Knots

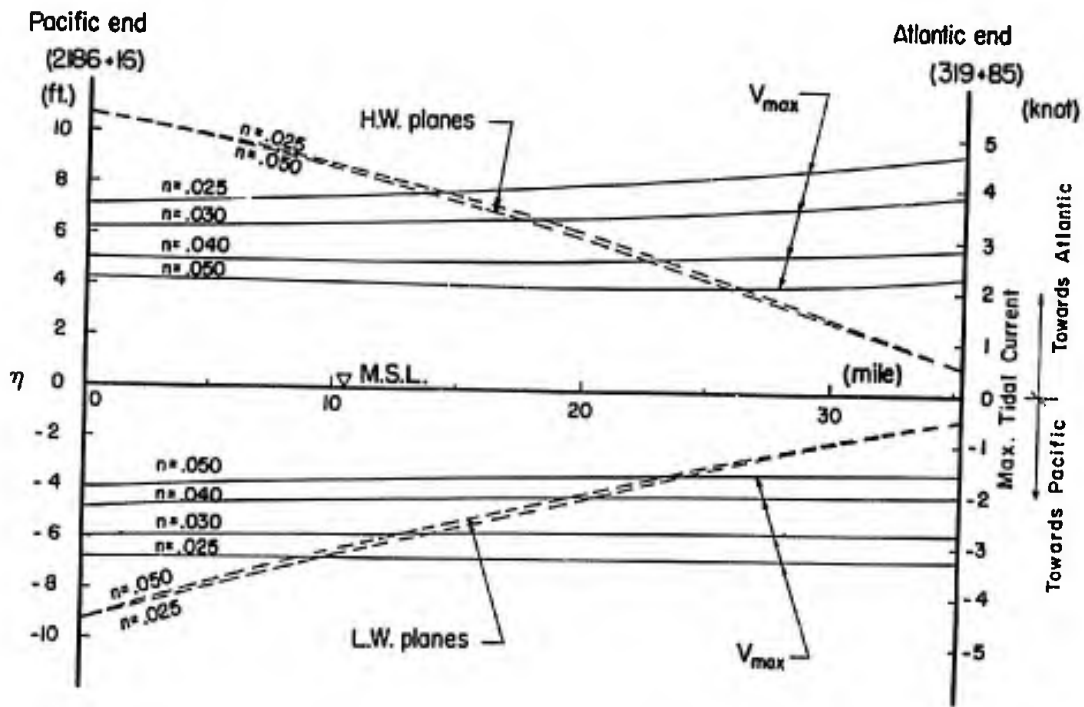


Fig. 55 Proposed Sea-level Panama Canal -- Effect of Manning's Coefficient,  $n$ , on Maximum Currents and Tidal Elevations

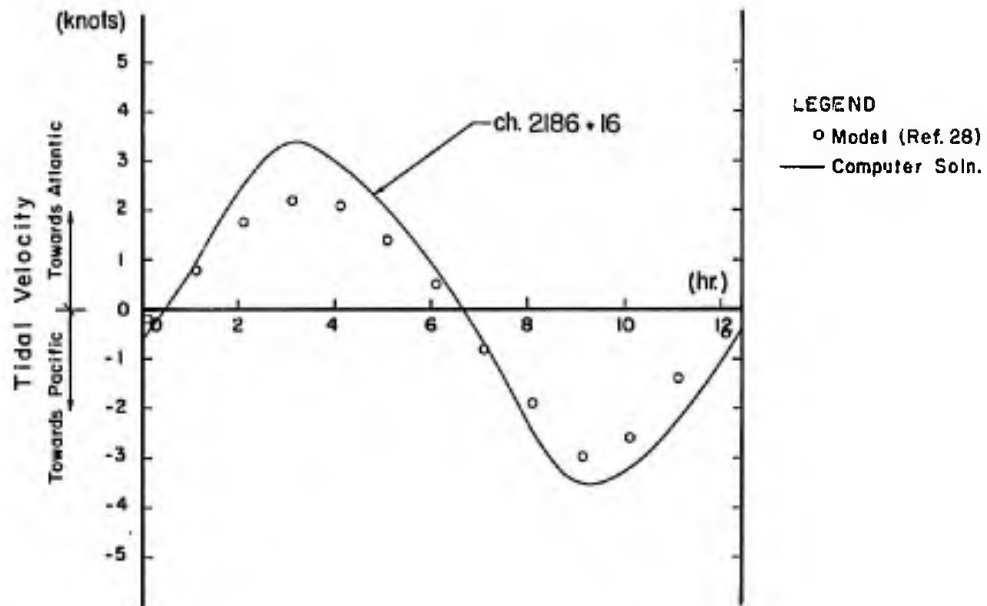


Fig. 56 Proposed Sea-level Panama Canal (Case I) -- Local Effect on Tidal Currents at Pacific Entrance to the Canal

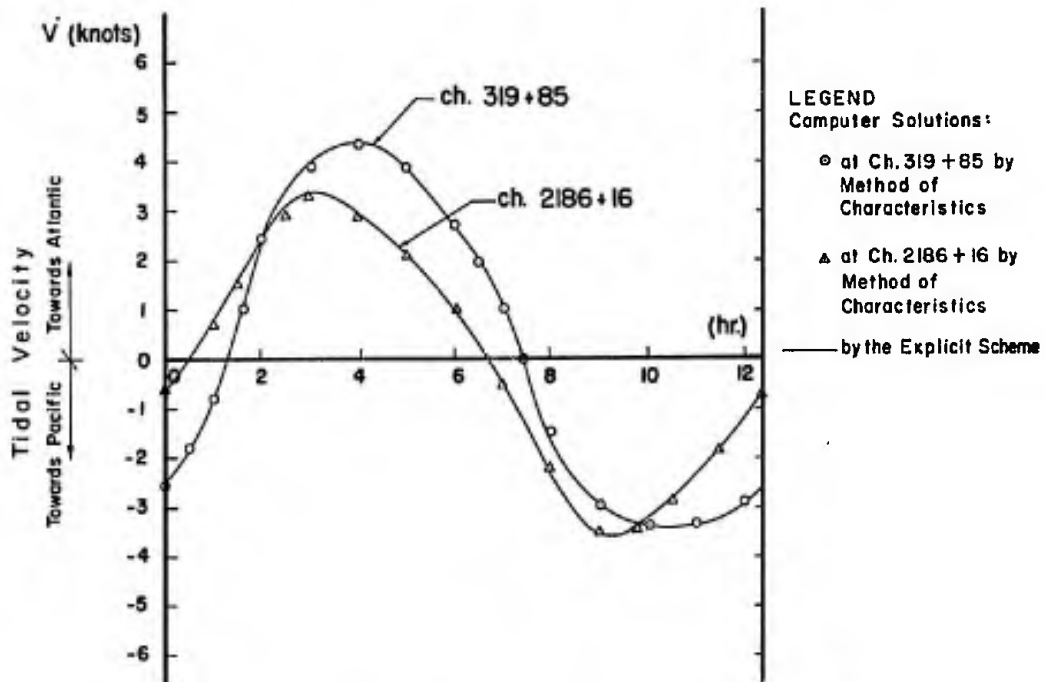


Fig. 57 Proposed Sea-level Panama Canal (Case Ia) -- Comparison of Tidal Currents Between Results Obtained Through the Explicit Scheme and the Method of Characteristics

either end at a certain instant,  $T_e$ , where,

$T_{e1}$  = time at which the ship enters the canal from the  
Pacific end

$T_{e2}$  = time at which the ship enters the canal from the  
Atlantic end.

The time of 0 hr. is defined as the time at which the tidal elevation in the Pacific ocean is at mean sea level during a rising tide. The speed of the ship is assumed to be constant and the boundary conditions for the canal are for those for case 1. The actual speed of the ship, at any time, which is necessary to maintain the desired constant speed is the sum of the respective constant speed and the tidal current. The currents experienced by the ship during transit are shown in Figs. 52, 53 and 54.

#### 6.3.4 Other Tidal Calculations

The effect of arbitrary changes in the value of the resistance coefficient is shown in Fig. 55. Computed values of tidal elevation and current are given for  $n = 0.025, 0.030, 0.040$  and  $0.050$ . The effect on the high and low planes is negligible; however, the tidal current is reduced by 50% for  $n = 0.050$ . A comparison of computed and observed (model) tidal currents near the Pacific entrance of the canal is shown in Fig. 56.

An existing computer program designed for the solution of unsteady, open channel flow problems by the method of characteristics was modified to obtain a solution for the sea-level canal (case 1a). As shown in Fig. 57, the differences between the explicit scheme and the method of characteristics are insignificant.

#### 6.4 Cape Cod Canal

The Cape Cod Canal is a sea-level canal located 50 miles south of Boston, Massachusetts, at the narrow neck of land joining Cape Cod to the mainland. The canal principally serves coastwise shipping to and from Boston and other coastal states south of Massachusetts. A complete

description of its case history was written by Allen (1952).

#### 6.4.1 Schematization

A general layout of the canal with the cross sections used in the computer solution can be found in Fig. 58.

Hydraulic model tests of the canal were carried out for the U. S. Corps of Engineers at the Massachusetts Institute of Technology in 1936 (Ref. No. 42). The purpose was to investigate the feasibility of widening and deepening the Cape Cod Canal from a cross section of 170' x 25' to 500' x 40'. Prototype measurements and data obtained from hydraulic model tests are used for the evaluation of the present study. The length of the canal in the computer solution is 38,035 ft., and an even number of segments are required.

Since the depths of the canal are different for the two channels concerned,  $\Delta x$  and  $\Delta t$  are used as follows:

For the 170' x 25' channel:

$\Delta x = 4,754$  ft. (80 segments)

$\Delta t = 174.5$  sec.

For the 500' x 40' channel:

$\Delta x = 6,339$  ft. (60 segments)

$\Delta t = 163.2$  sec.

The end boundary conditions of ocean tides for the two different cases are obtained from the report on the model study and are shown in Figs. 59 and 60. Since the ocean boundary tidal curves are not sinusoidal, they are incorporated as discrete point inputs in the computer solution.

#### 6.4.2 Tidal Characteristics of the Cape Cod Canal

The computed high and low water planes and the time for high and low water for both cross sections are compared with model and field measurements in Figs. 61 and 62. It was found that the computer solutions were insensitive to the value of Manning's  $n$ , as in the case of the Panama Canal. However, a variation in  $n$  from 0.020 to 0.040 produces a large variation in the maximum tidal currents and discharge as shown in Fig. 63. Owing to the crude instruments available for velocity measurements in 1936, only one maximum velocity was obtained for each channel. It is therefore difficult to choose the best value of  $n$ . However,  $n = 0.035$

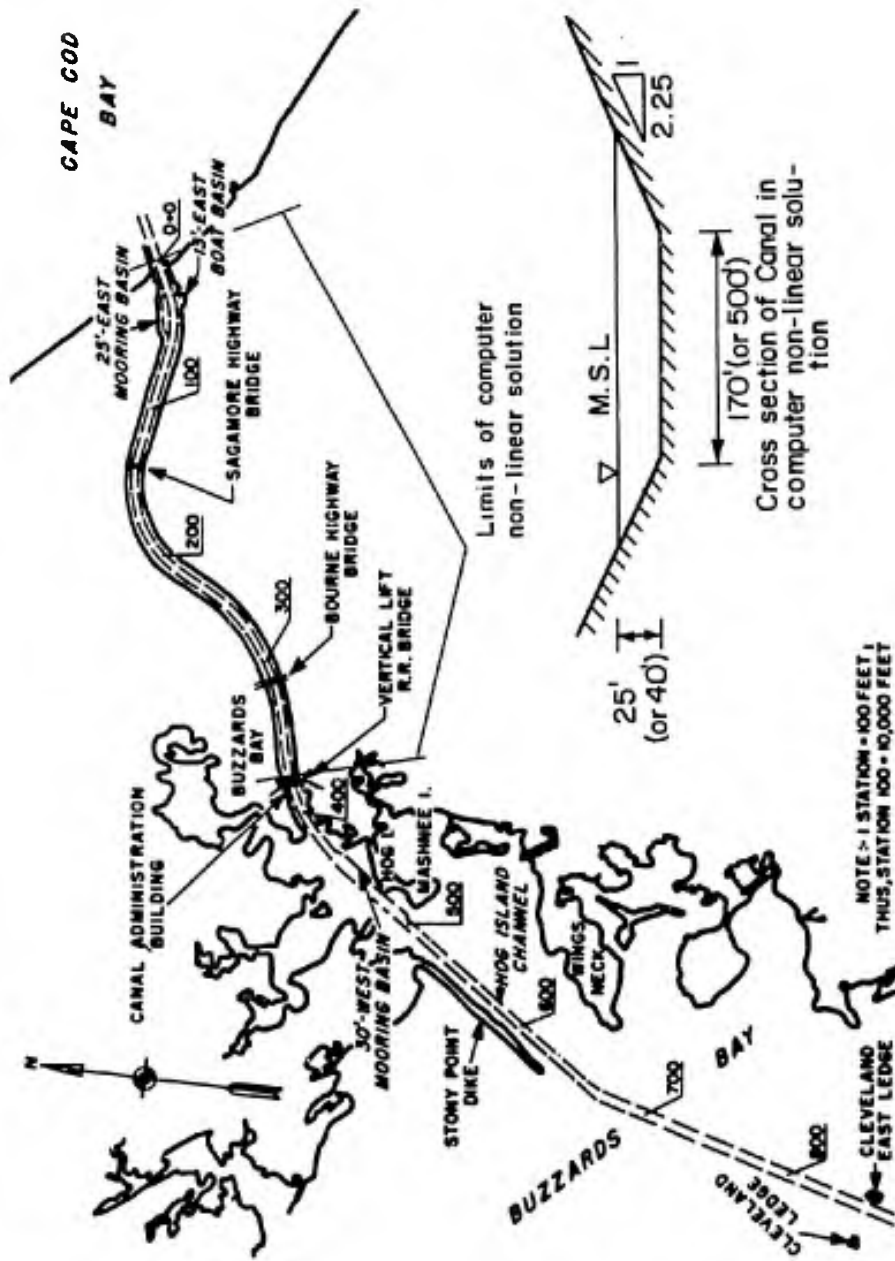


Fig. 58 Cape Cod Canal - General Layout

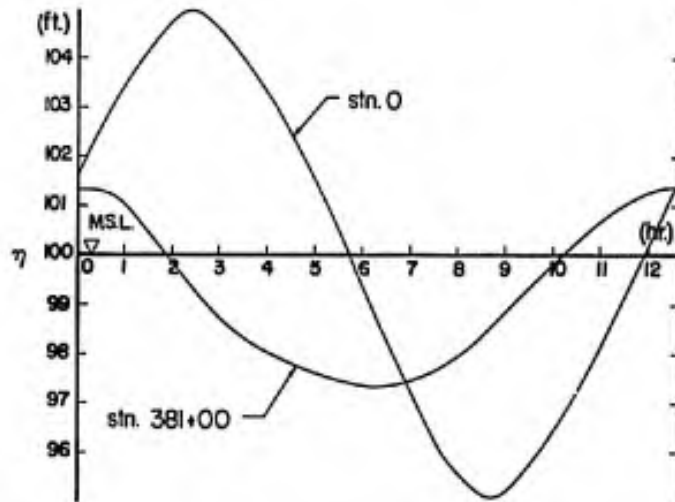


Fig. 59 Cape Cod Canal (170' x 25') Boundary Conditions  
 (Tidal Curves for Elevation on Dec. 21, 1934;  
 Tidal Period = 12.7 hrs)

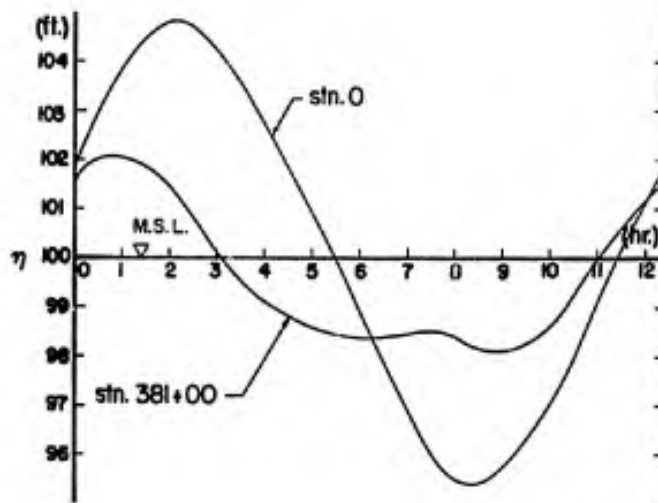


Fig. 60 Cape Cod Canal (500' x 40') - Boundary  
 Conditions (Tidal Curves Obtained from  
 Ref. No. 42; Tidal Period = 12.42 hrs)

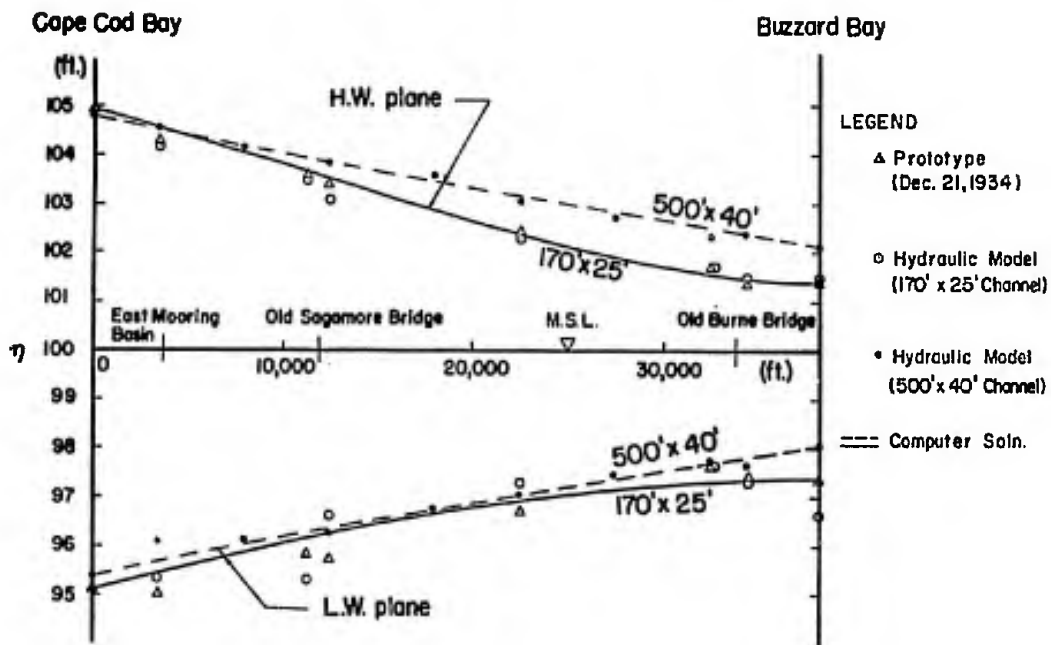


Fig. 61 Cape Cod Canal -- High and Low Water Planes

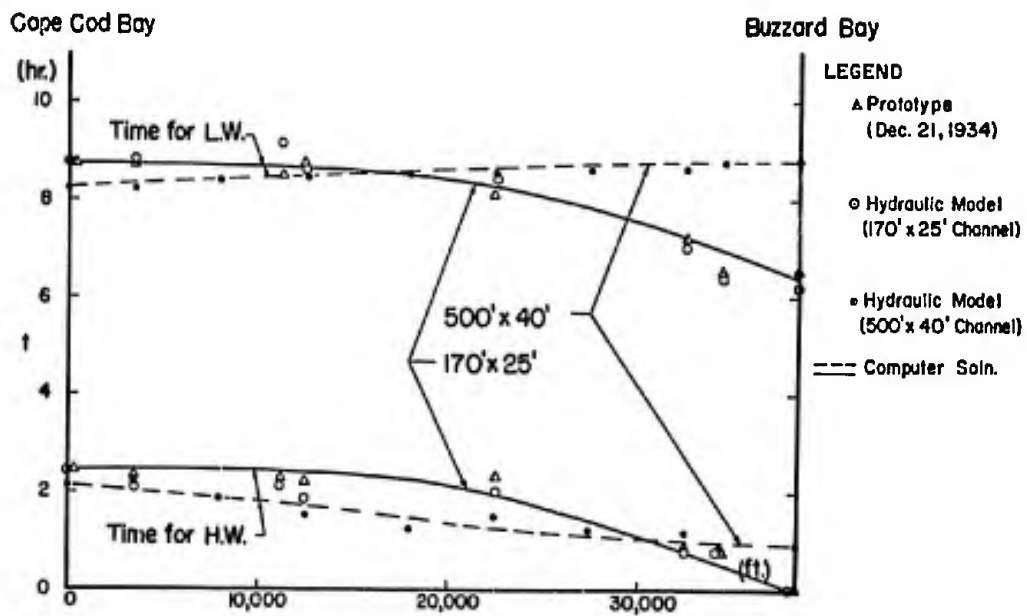


Fig. 62 Cape Cod Canal -- Time for High and Low Waters

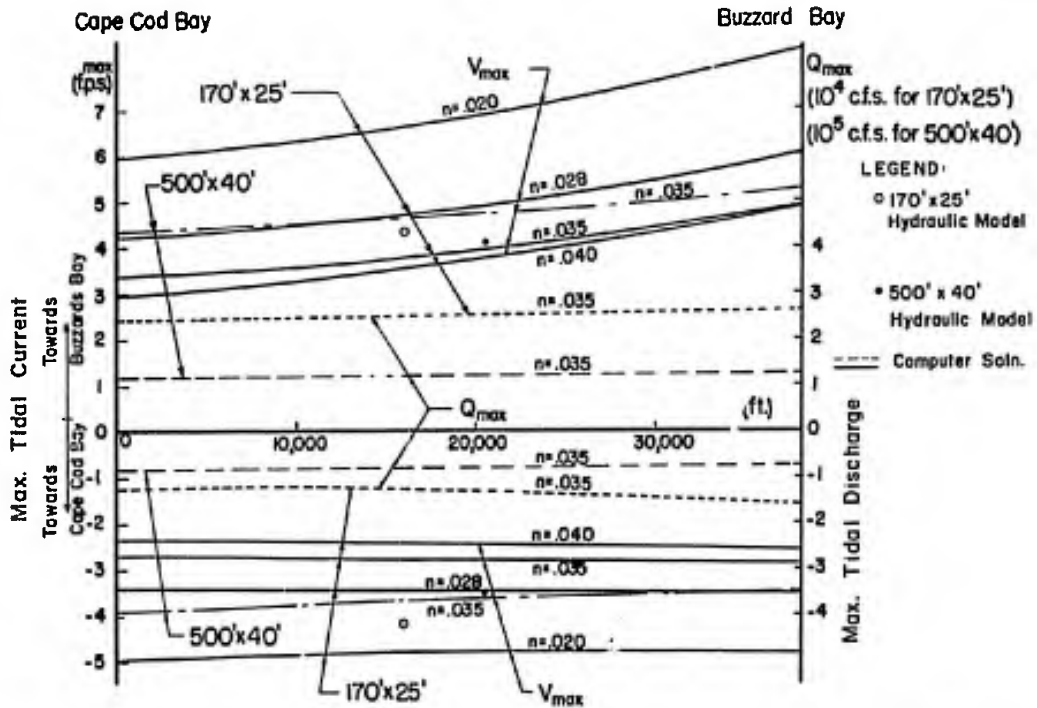


Fig. 63 Cape Cod Canal — Effect of Manning's Coefficient on Maximum Currents and Discharges

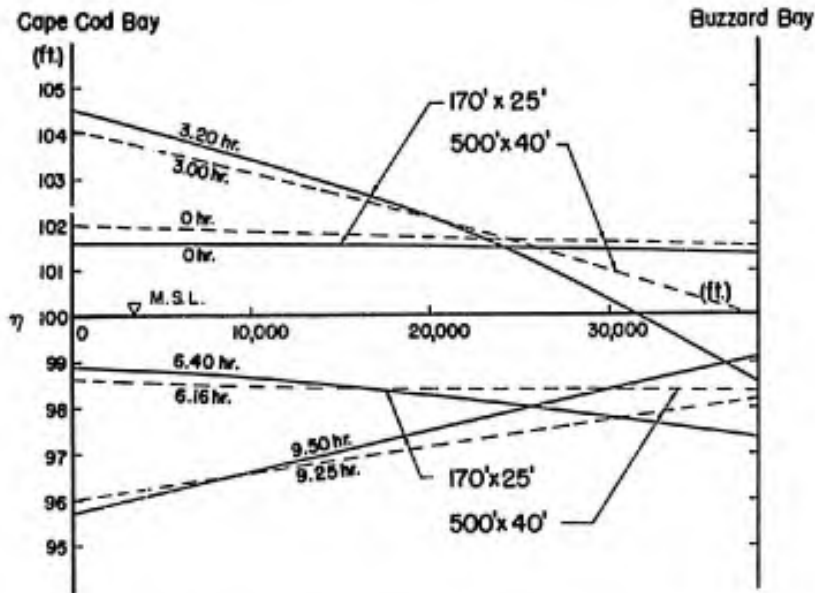


Fig. 64 Cape Cod Canal - Tidal Curves for Tidal Elevations, at Different Time, in the Canal

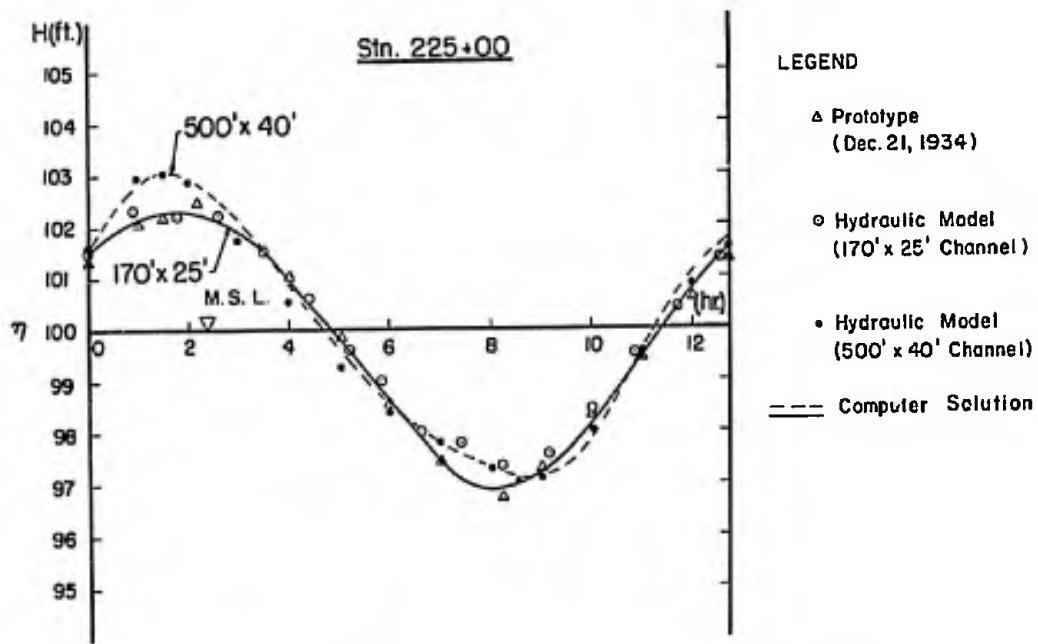


Fig. 65 Cape Cod Canal -- Tidal Variations in Elevation at Station 225 + 00

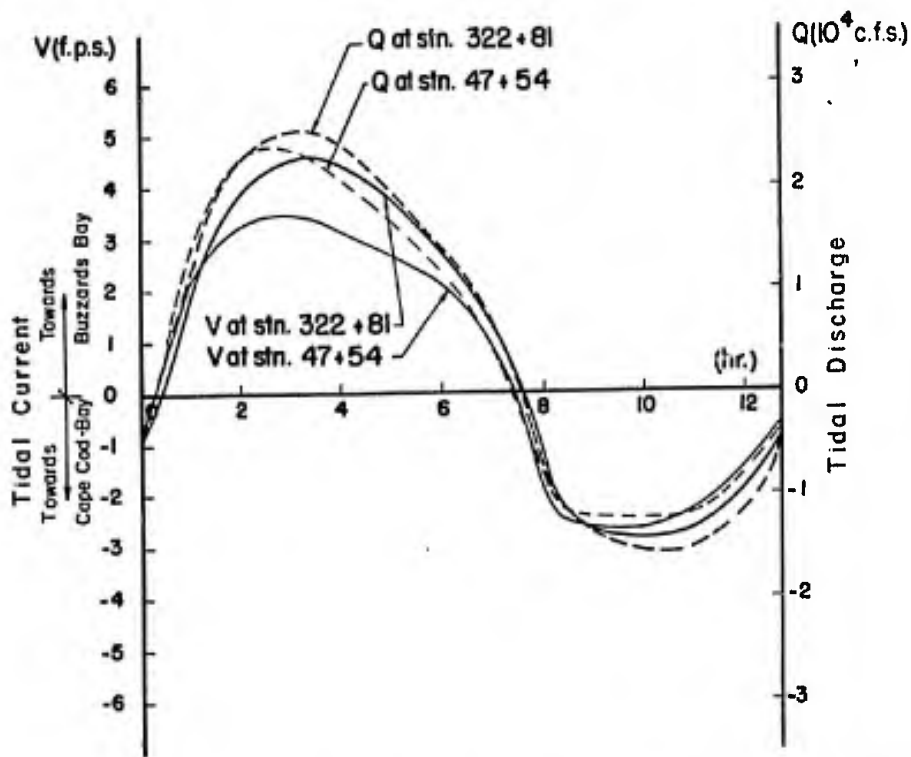


Fig. 66 Cape Cod Canal (170' x 25') -- Tidal Currents and Discharges

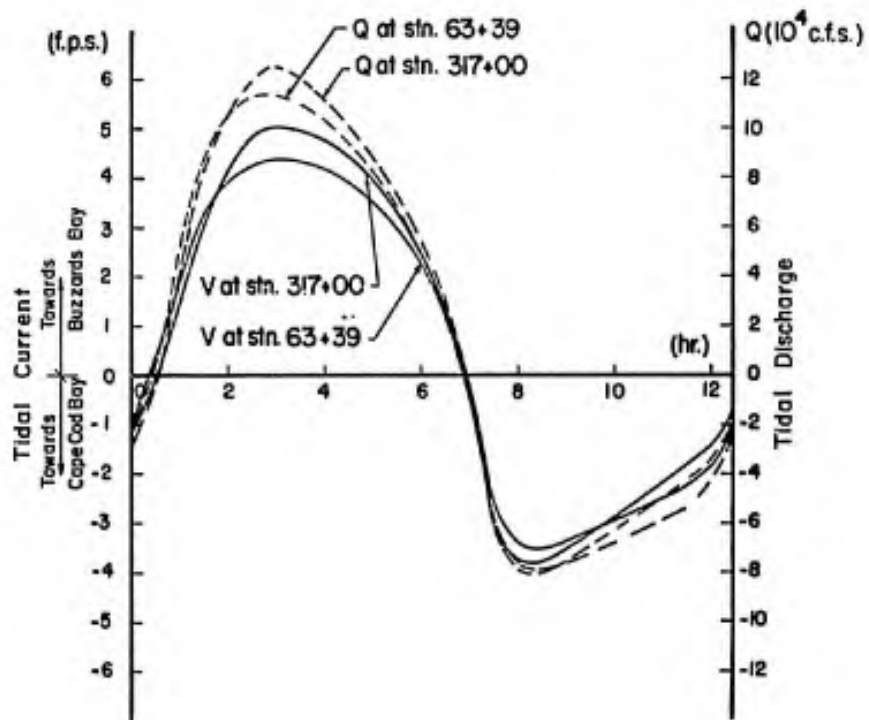


Fig. 67 Cape Cod Canal (500' x 40') - Tidal Currents and Discharges

seems to result in the best agreement. On this basis, the other tidal characteristics shown in Figs. 64, 65, 66 and 67 were calculated.

Some general conclusions regarding the effect of enlarging the cross section of the canal can be gained from the above calculations:

- (a) Due to the rise of the planes of high water and low water, the net gain in water depth available for navigation is not only the increase in depth due to deepening, but also an additional increase owing to the rise of mean water level throughout the tidal channel.
- (b) The maximum currents in the canal are increased after deepening.

## 6.5 Chincoteague Bay

Chincoteague Bay is a bar-built, tidal bay located in the State of Maryland on the east coast of the United States. The bay has two tidal inlets from the Atlantic Ocean -- one at Ocean City and the other some 30 miles south at Chincoteague Inlet. The bay is geometrically very irregular as shown in Fig. 68 and has comparatively shallow depths of water.

### 6.5.1 Schematization

Geometric and field data were collected by Pritchard (1963) for the study of the salt balance and exchange rate in the bay. The schematization of the bay is shown in Fig. 69.

The average cross section areas at mean low water for different zones, defined on the map (Fig. 68), are given in Ref. No. 34. This data is used to estimate the average areas at mean low water at the sections defined by the grid for the computer solution. The average widths,  $b$ , are estimated from the map and are assumed to be equal to  $b_g$ . The average depths of water are computed from the average areas and the average widths obtained. The mean low water surface in the bay is assumed to be horizontal and the bottom profile is then defined by the average depths of water. The length of the reach for zone VII is taken to be longer than the distance between the partition lines at both ends

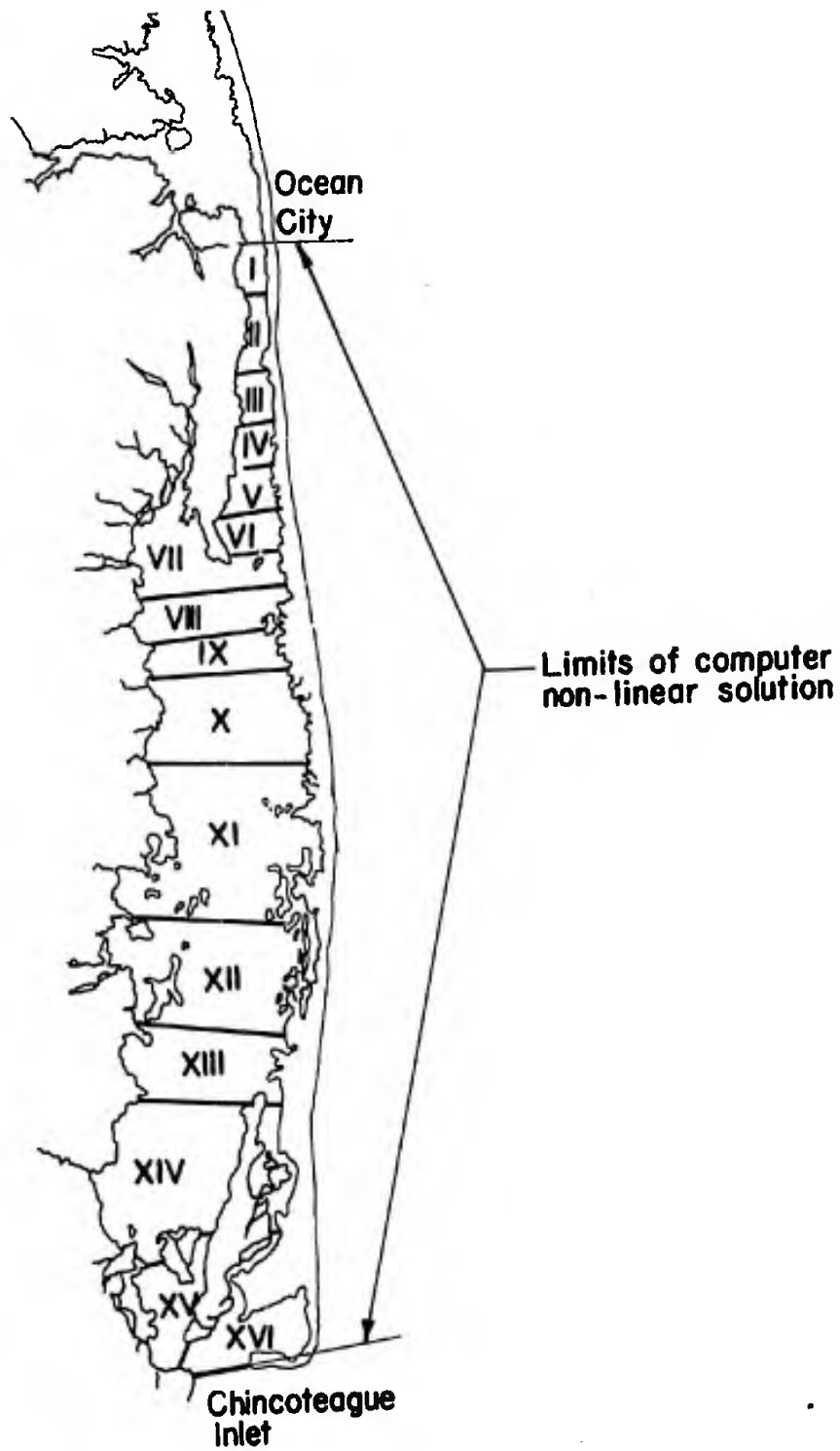


Fig. 68 Chincoteague Bay – General Layout  
(Reproduced from Ref. No 34)

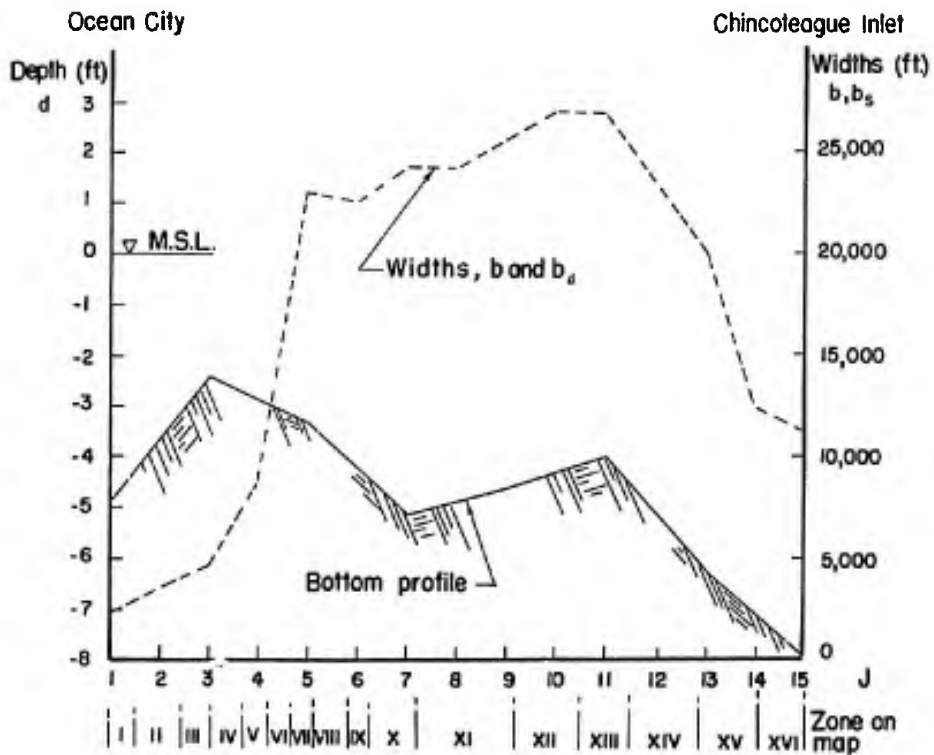


Fig. 69 Chincoteague Bay - Geometry of the Schematized Tidal Channel

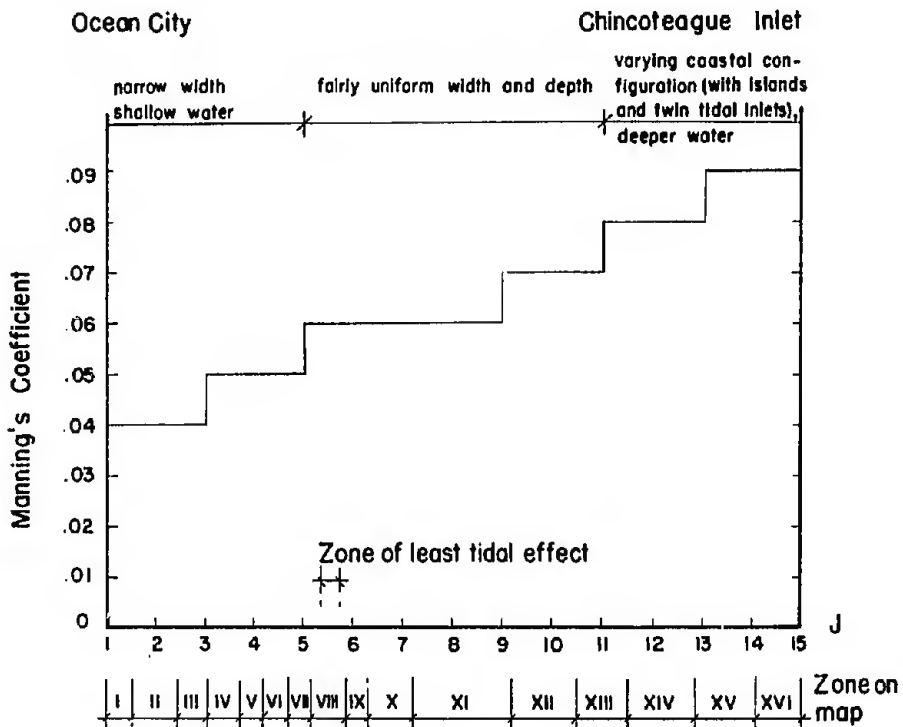


Fig. 70 Chincoteague Bay -- Manning's Coefficient

of the zone.

The boundary conditions are the same as those for a sea-level canal, hence an even number of segments are required. The input data are as follows.

Total length = 37 miles

$\Delta x = 2.65$  miles (14 segments)

$\Delta t = 324$  sec.

Mean tidal range at Ocean City = 3.4 ft.

Mean tidal range at Chincoteague Bay = 3.8 ft.

Both ocean tides are sinusoidal and there is no phase lag between them. Also, the mean sea levels at both inlets are the same.

#### 6.5.2 Tidal Characteristics of Chincoteague Bay

Comparisons between the mean tidal ranges and the time of high water for the prototype and computer solutions were made to determine the variation of  $n$  throughout the waterway. The results are shown in Fig. 70, together with the tidal range and phase in Table IV and Fig. 71. It was not possible to reproduce the observed tidal elevations with a constant value of  $n$  in the bay. The values of  $n$  obtained are quite high, ranging from 0.040 to 0.090, this may be due to the fact that the average water depth is only 5 feet and that the southern portion of the bay is very irregular.

The high and low water planes given in Fig. 72 show the rapid decay of tidal range inside the bay. The mean water surface inside the bay is always above M.S.L. Tidal velocities and discharges as functions of distance and time are shown in Figs. 73 and 74. The latter figure shows that, during a significant portion of the tidal period, the velocities at different sections are in opposite directions.

Tidal elevations throughout the bay at various times in the tidal cycle are shown in Fig. 75. The computed tidal velocities as a function of time at the two entrances to the Bay are shown in Fig. 76. During the computation of the velocity at Chincoteague Inlet it became evident

Section	Mean Tidal Range (ft.)		Time of High Water (hrs.)	
	Prototype	Computer Solution	Prototype	Computer Solution
Ocean City I	3.4	3.4	0	0
III	0.7	0.79	2	1.62
VII	0.3	0.58	6	6.12
X	0.4	0.58	6	5.4
XI	0.4	0.58	5	4.7
XIII	0.7	0.60	3	3.2
XIV	1.2	1.26	2	1.8
XVI Chincoteague Inlet	3.8	3.8	0	0

Table IV - Chincoteague Bay -- Comparisons of Data  
Between the Prototype and Computer Solution

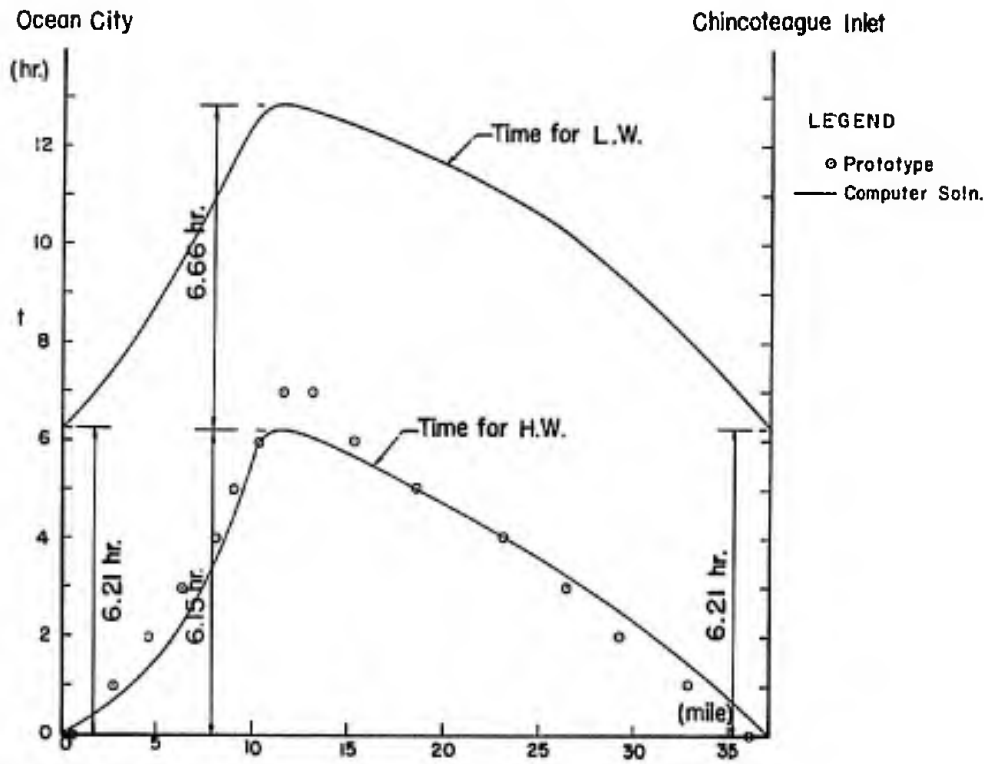


Fig. 71 Chincoteague Bay -- Time for High and Low Waters

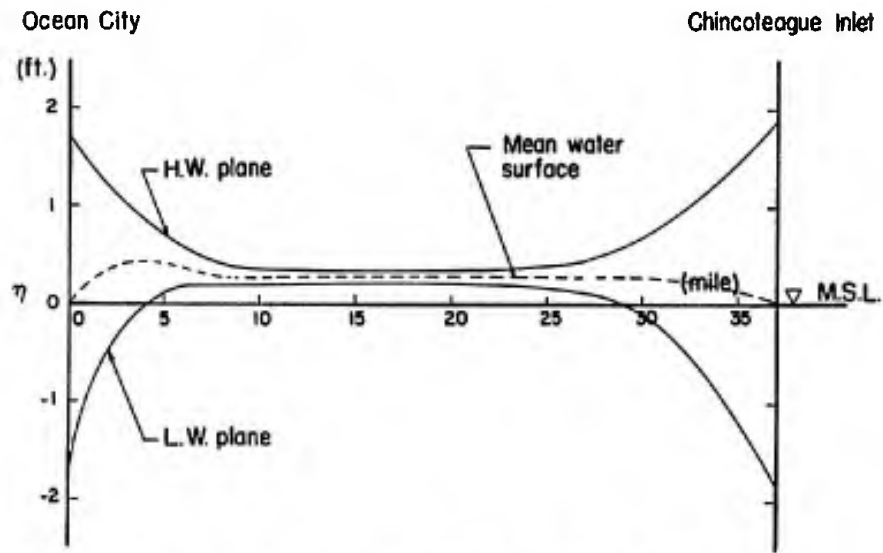


Fig. 72 Chincoteague Bay -- High, Low and Mean Water Planes

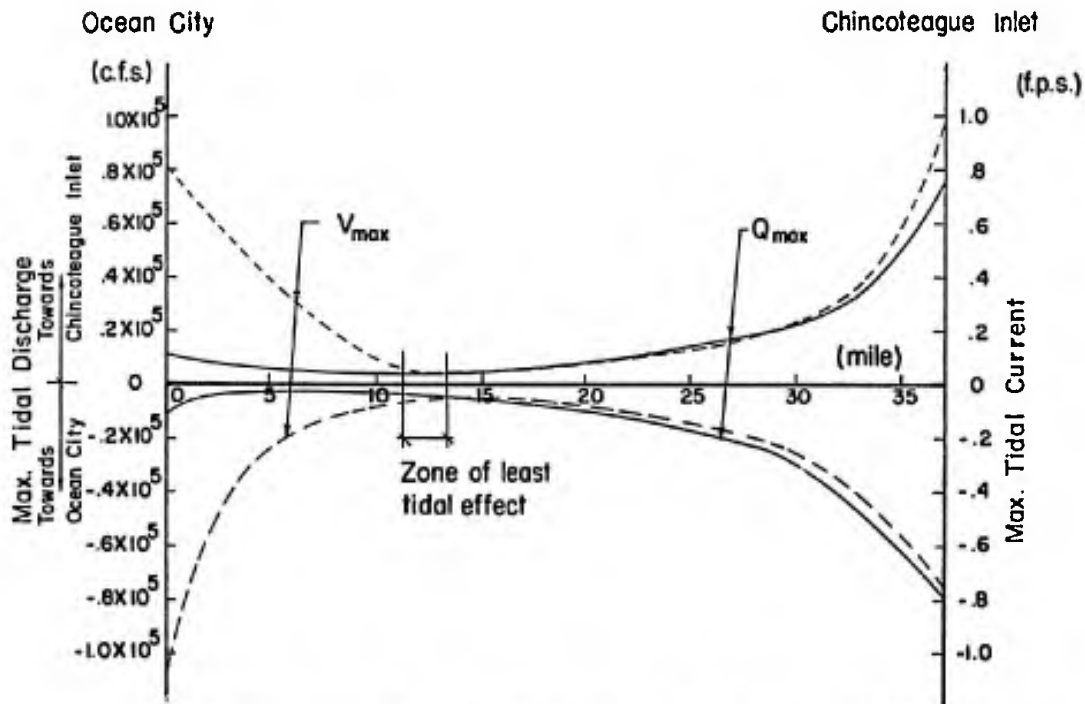


Fig. 73 Chincoteague Bay - Maximum Tidal Velocities and Discharges

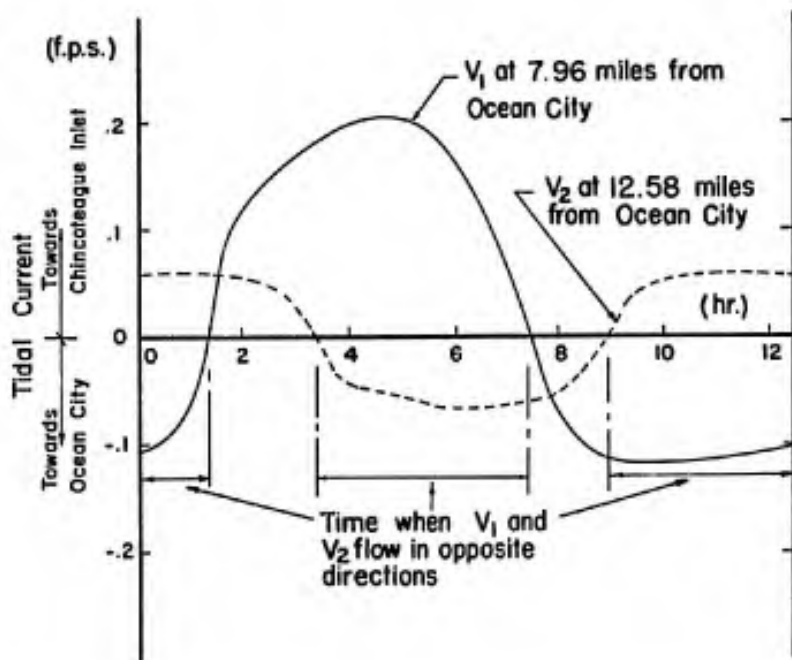


Fig. 74 Chincoteague Bay - Tidal Velocities at 7.96 and 12.58 Miles from Ocean City

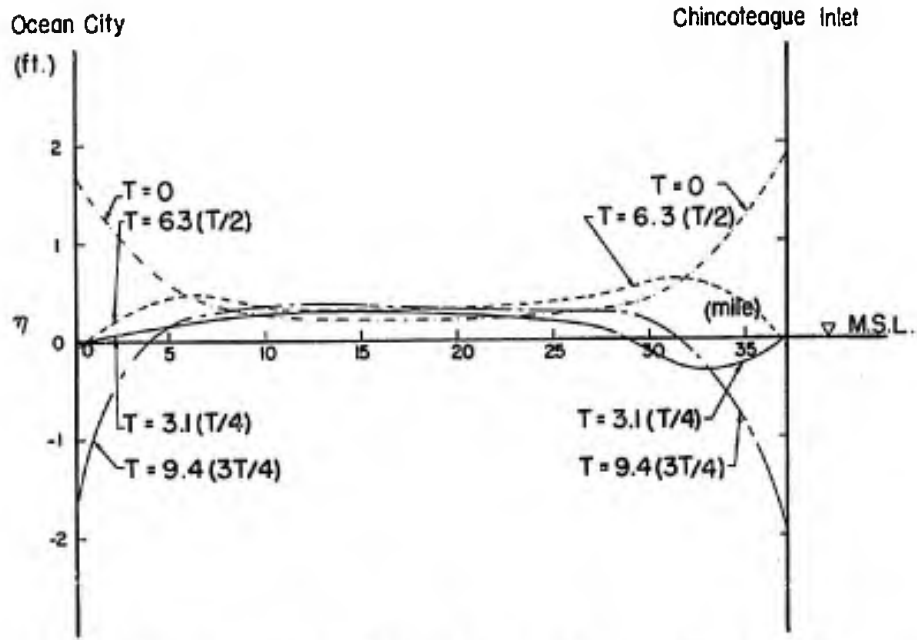


Fig. 75 Chincoteague Bay - Tidal Elevations Approximately at Time of 0, T/4, T/2, and T/4

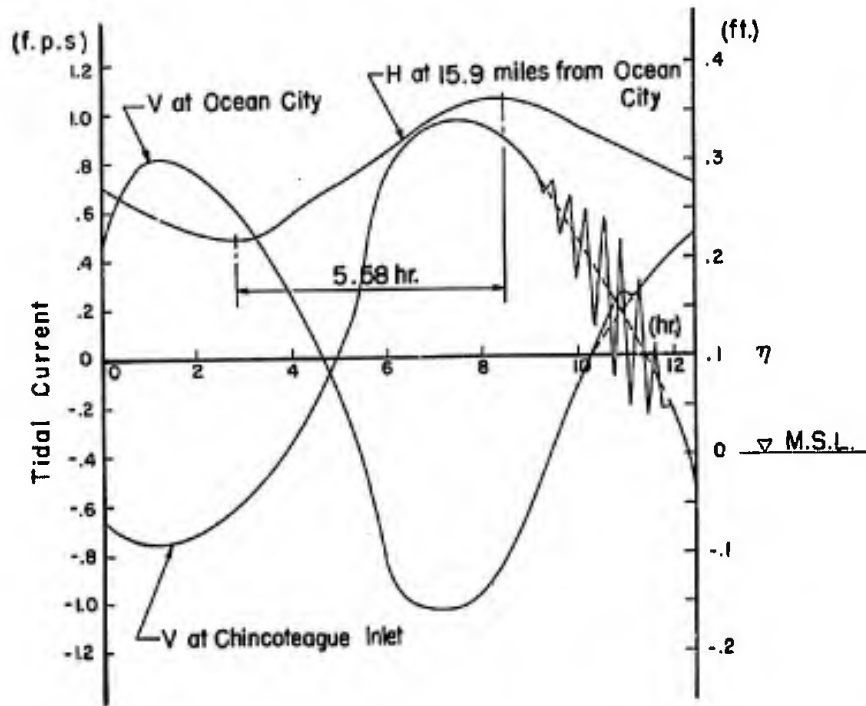


Fig. 76 Chincoteague Bay - Tidal Velocities at Ocean City and Chincoteague Inlet; and Tidal Variations in Elevation at 15.9 Miles from Ocean City

that there was some numerical instability near the time when the velocity reversed direction. The instability was reduced to an oscillation about the stable solution by reducing the time increment from  $\Delta t = 324$  sec., to  $\Delta t = 263$  sec., as shown in Fig. 76.

#### 6.6 W.E.S. Salinity Flume

Tidal motion and salinity intrusion experiments have been conducted in a uniform rectangular flume at the W.E.S., Vicksburg, Mississippi. The flume has been used to study salinity intrusion in estuaries (Ippen and Harleman 1961). One end of the flume is connected to a large tidal basin in which sinusoidal ocean tides of various amplitudes can be produced. The opposite end of the flume terminates in a vertical wall. Tidal elevations and velocities were measured at selected points on the flume. A summary of the test data and an analysis based on the linear method of damped cooscillating tides has been given by Harleman and Ippen (1961). An analysis of two of the tests reported (No. 1 and No. 4) has been included in this report in order to compare the linear analysis with the non-linear, finite difference computer solution for situations in which the tidal amplitude is not small compared to the depth.

##### 6.6.1 Schematization

The plastic flume has a length of 327 ft., measured from the tidal basin to the closed end. The width is 0.75 ft., and the depth to M.S.L. is 0.50 ft. The bottom of the flume is horizontal and the tidal period is 600 seconds for both tests. Other data are:

(a) Test No. 1:

Tidal range in the basin (sinusoidal) = 0.10 ft.

(20% of mean water depth)

Side wall roughness (1/4" plastic strips attached on 2" centers to the vertical side walls)

(b) Test No. 4:

Tidal range in the basin (sinusoidal) = 0.20 ft.

(40% of mean water depth)

No roughness strips.

Hydraulic tests were made with a steady state discharge in the flume for the purpose of determining the Manning n value. The results for Test No. 1 were  $n = 0.020$  and for the smooth flume (Test No. 4)  $n = 0.011$ .

Since the flume represents a closed-end estuary, an odd number of segments are required for the schematization. The following values of  $\Delta x$  and  $\Delta t$  were chosen:

<u>Test No. 1</u>	<u>Test No. 4</u>
$\Delta x = 25.2$ ft (13 segments)	$\Delta x = 25.2$ ft (13 segments)
$\Delta t = 6$ sec.	$\Delta t = 4$ sec.

In the computer solution trials were made using several values of Manning n; best agreement with the measured characteristics was found for  $n = 0.021$  for Test No. 1 and  $n = 0.012$  for Test No. 4. These are very close to the values determined independently by steady state flow tests.

#### 6.6.2 Tidal Characteristics of the W.E.S. flume

The comparisons between the laboratory measurements and the linear and non-linear solutions for surface elevations and tidal phase are given in Figs. 77, 78 and 79 (Test No. 1) and Figs. 84, 85 and 86 (Test No. 4). The agreement between the non-linear analysis and the measured values is much better than the linear analysis, especially for Test No. 4, which has a tidal range equal to 40% of the mean depth.

A comparison of the measured and calculated tidal velocities is shown in Fig. 80 (Test No. 1) and Fig. 87 (Test No. 4). The laboratory data shown by circles is the average centerline velocity. This is obviously higher than the average velocity for the entire cross section which is determined by the one-dimensional analysis. In Test No. 1 (Fig. 80) the experimental and calculated values agree well if the centerline velocities are reduced by a factor of 0.69. The corresponding factor is 0.85 for Test No. 4 (Fig. 87). These factors appear reasonable in view of the different roughnesses of the two tests.

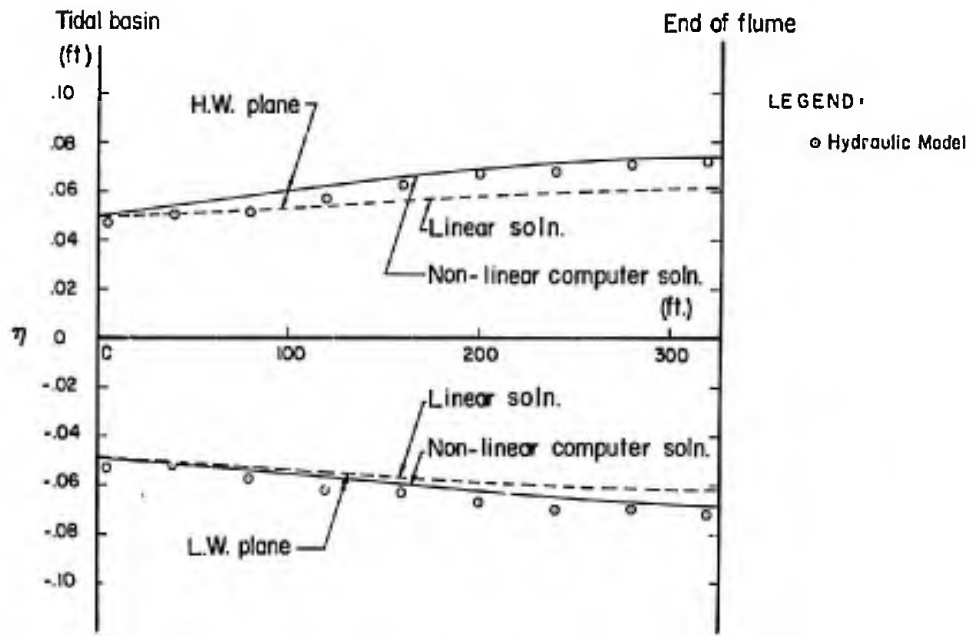


Fig. 77 Vicksburg Flume (Test No. 1) - High and Low Water Planes

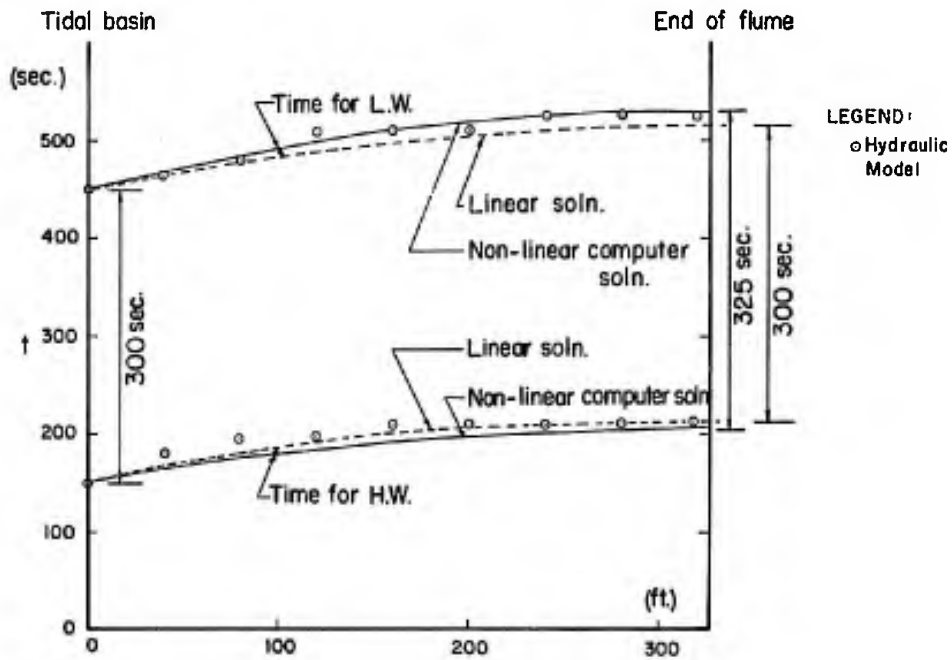


Fig. 78 Vicksburg Flume (Test No. 1) - Time for High and Low Waters

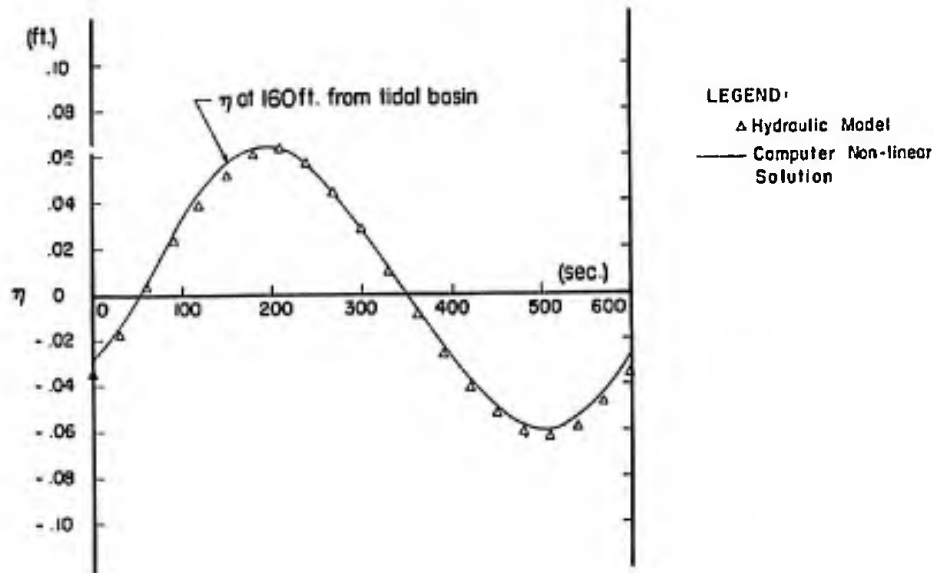


Fig. 79 Vicksburg Flume (Test No.1) - Tidal Variations In Elevation at 160 ft. from Tidal Basin

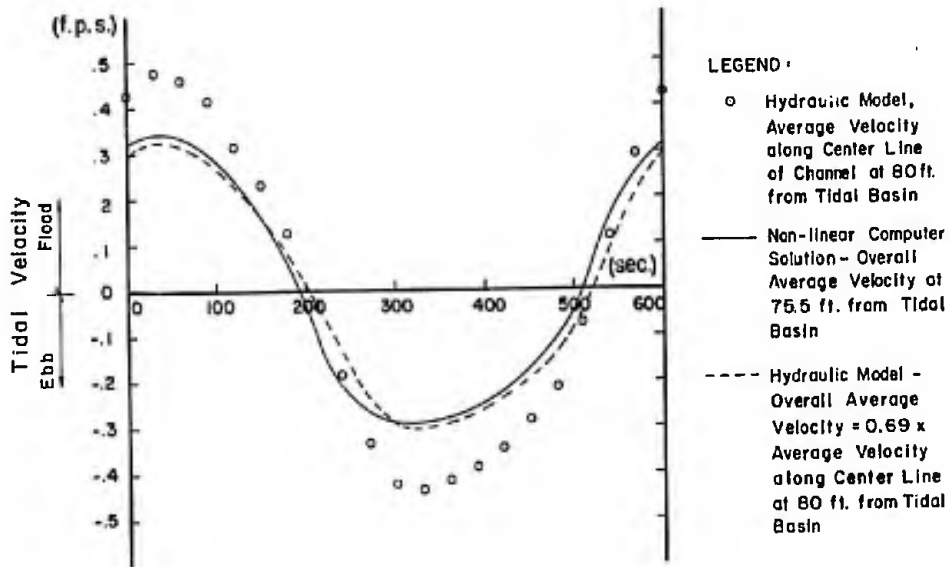


Fig. 80 Vicksburg Flume (Test No.1) - Tidal Curves for Tidal Velocities

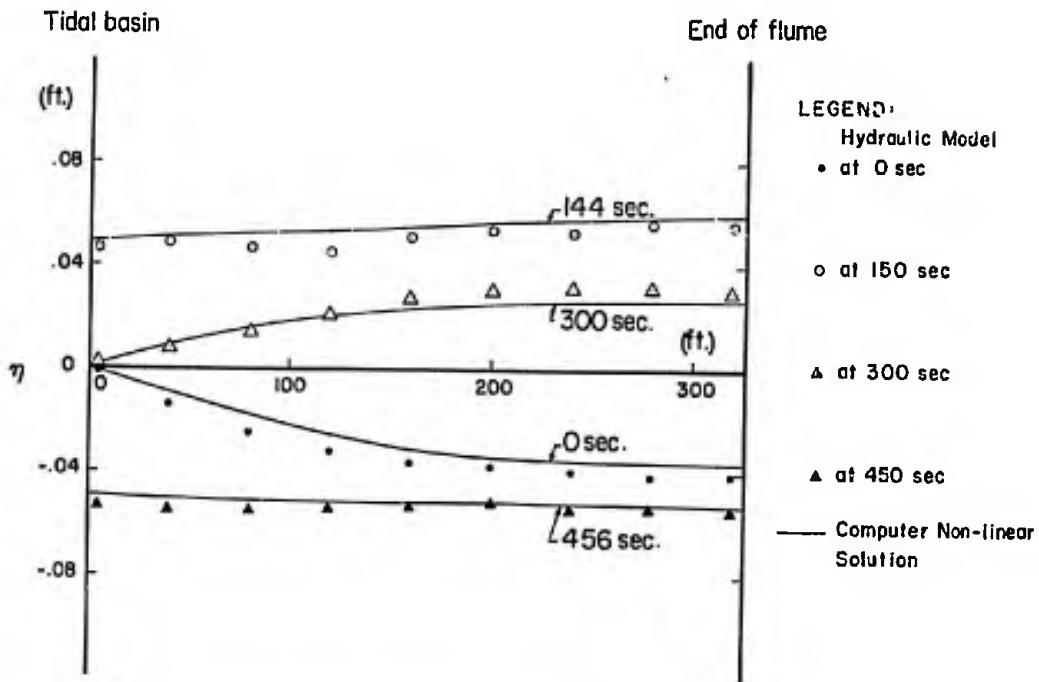


Fig. 81 Vicksburg Flume (Test No. 1) - Tidal Curves for Elevation at Time of 0, T/4, T/2, and 3T/4

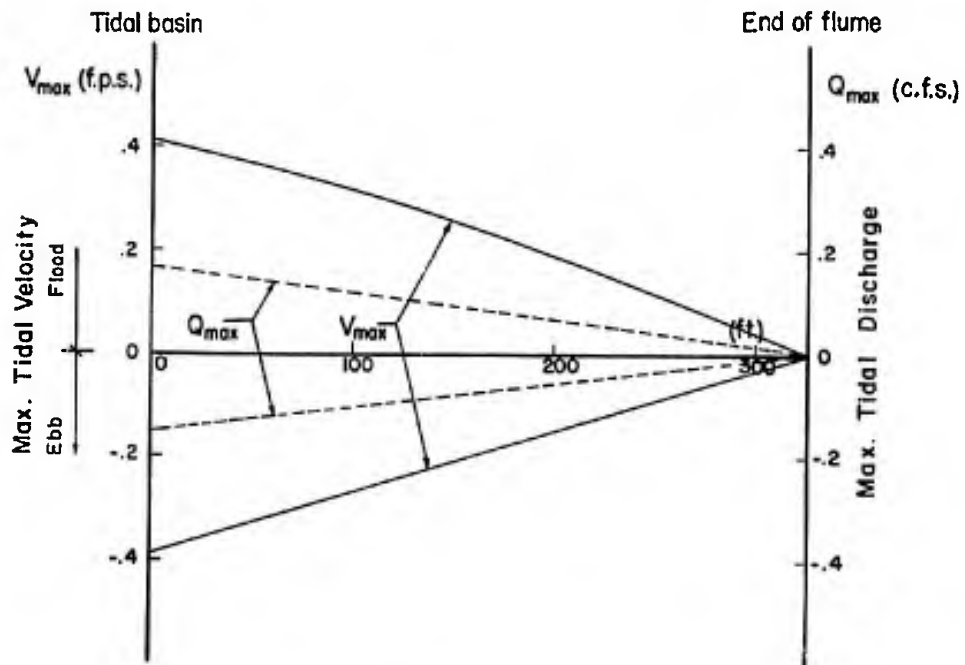


Fig. 82 Vicksburg Flume (Test No. 1) - Maximum Tidal Velocities and Discharges

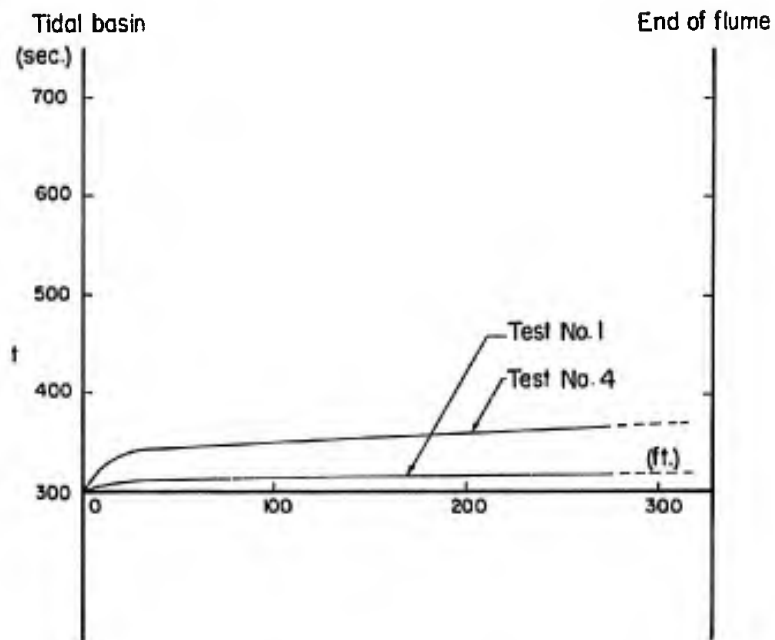


Fig. 83 Vicksburg Flume (Tests Nos 1 and 4) - Duration of Ebb Flow

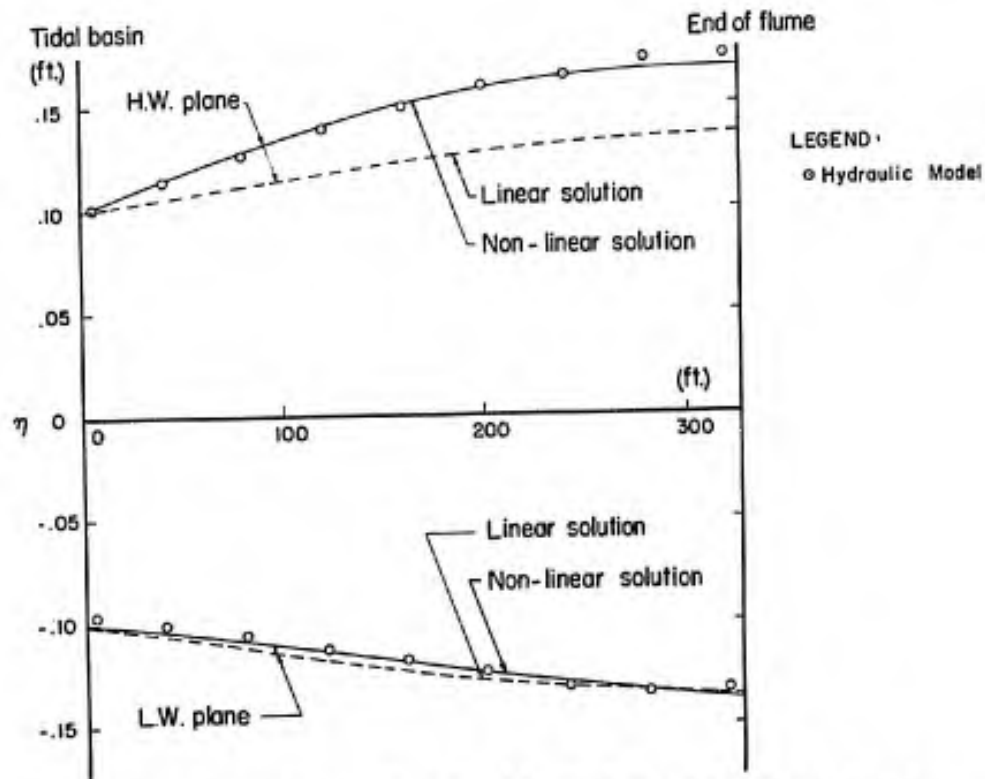


Fig. 84 Vicksburg Flume (Test No. 4) - High and Low Water Planes

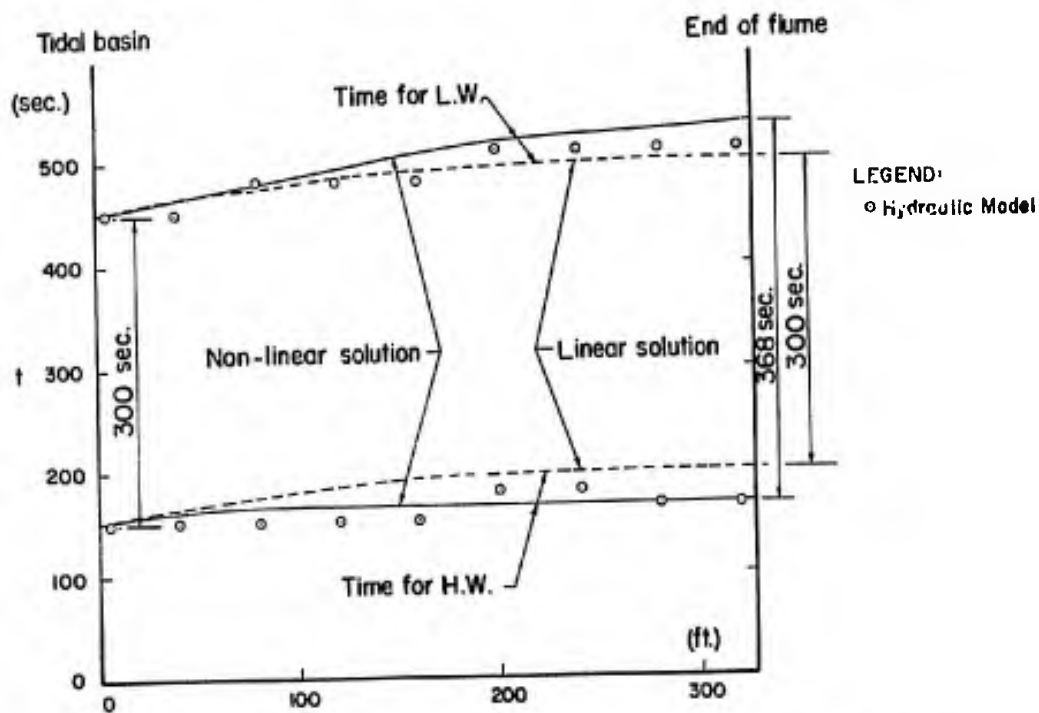


Fig. 85 Vicksburg Flume (Test No. 4) - Time for High and Low Waters

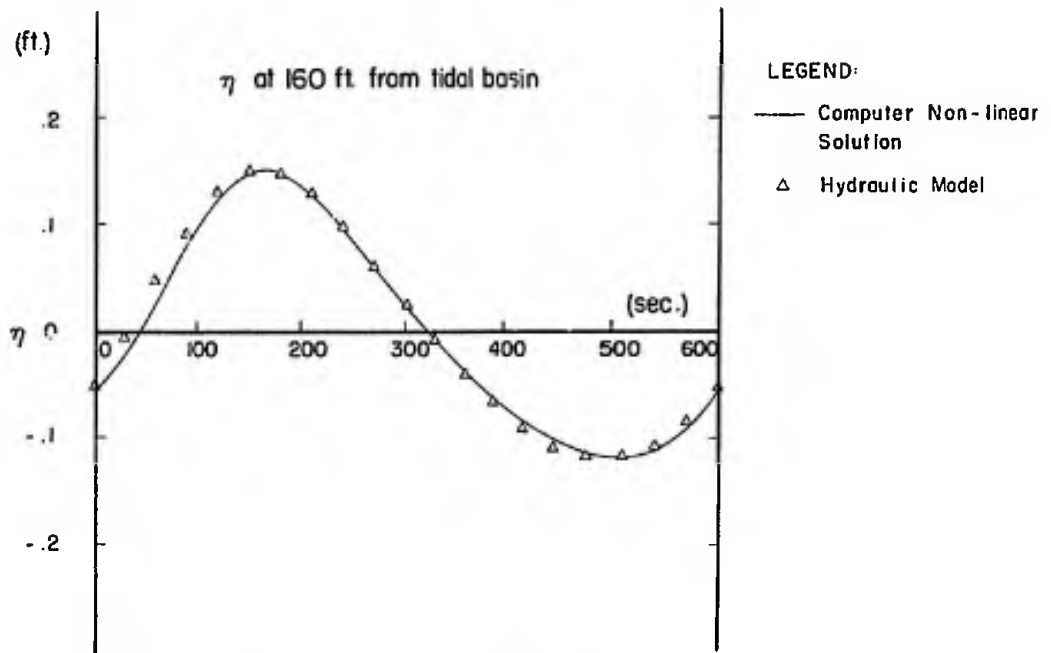


Fig. 86 Vicksburg Flume (Test No. 4) - Tidal Variations at 160 ft. from Tidal Basin

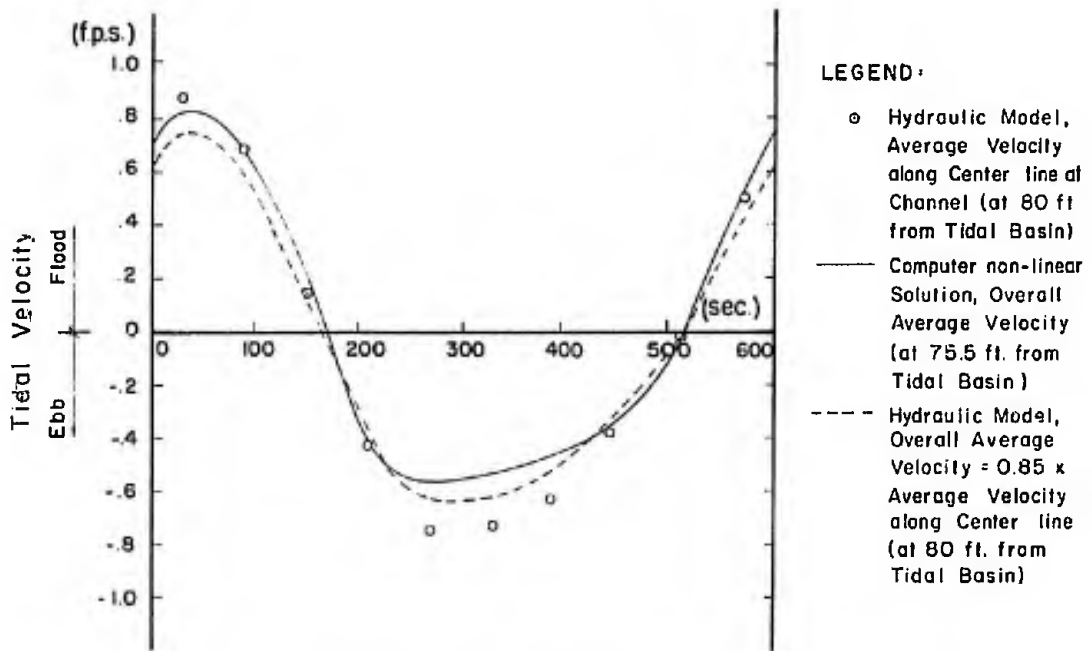


Fig. 87 Vicksburg Flume (Test No. 4) - Tidal Curves for Tidal Velocities

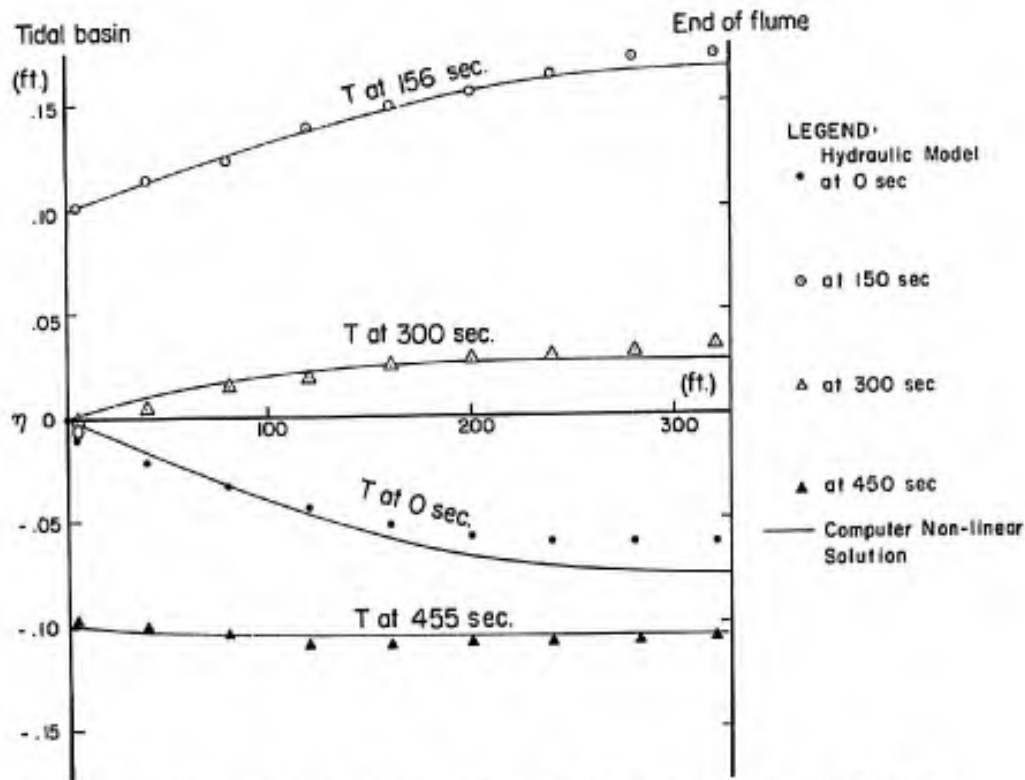


FIG. 88 Vicksburg Flume (Test No. 4) - Tidal Curves for Elevation at Time of 0, T/4, T/2 and 3T/4

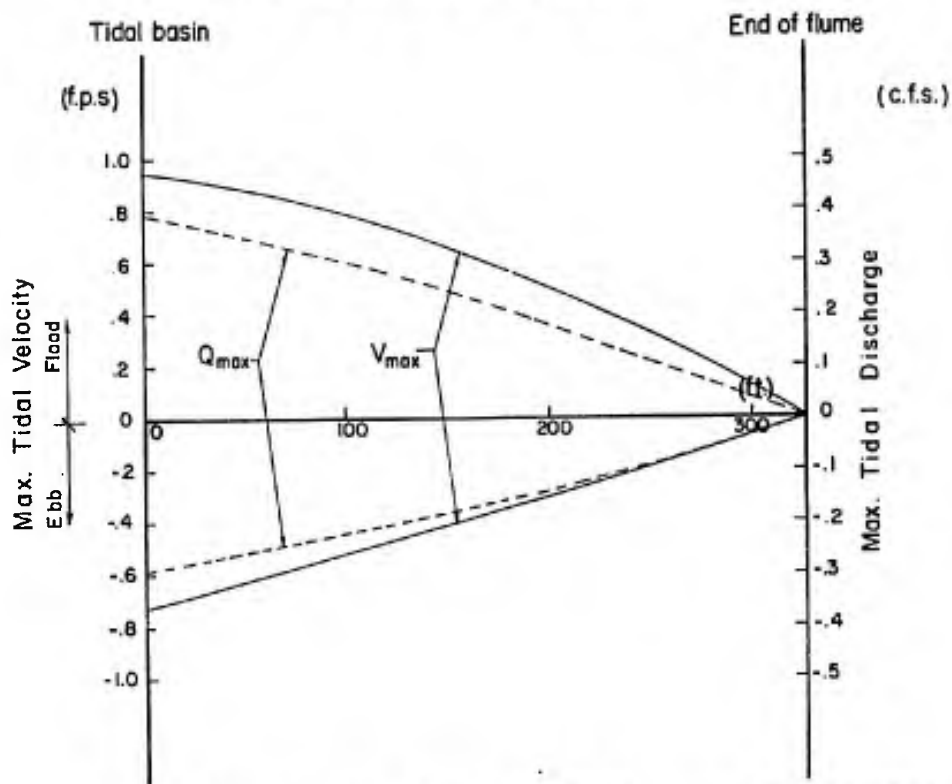


FIG. 89 Vicksburg Flume (Test No. 4) Maximum Tidal Velocities and Discharges

Additional comparisons between the measured and computer solutions for instantaneous tidal elevations are shown in Figs. 81 and 88. Calculated values of maximum tidal velocity and discharge along the flume are given in Figs. 82 and 89. The duration of ebb flow for both tests is also shown in Fig. 83.

The results clearly show that the effect of the non-linearity in the tidal motion is magnified as the ratio of tidal range to mean water depth increases.

#### 6.7 Dominquez Channel

The Dominquez Channel is a natural water course about 15 miles long. It carries surface runoff from an area southwest of Los Angeles, California, and discharges into the East Basin of the Los Angeles inner harbor. During heavy storms, the surface runoff exceeds the channel capacity and flooding occurs. In an effort to control flooding, it is proposed to improve the lower eight miles of the channel in order to increase its ability to carry storm water. Thus, a tidal channel with a closed end is created in the lower channel. Its geometry is as shown on Fig. 90 with other data as follows:

$\Delta x = 4844.4$  ft. (9 segments)

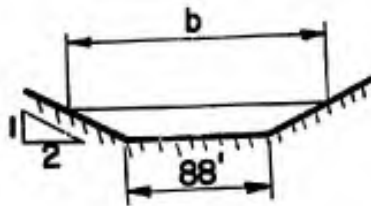
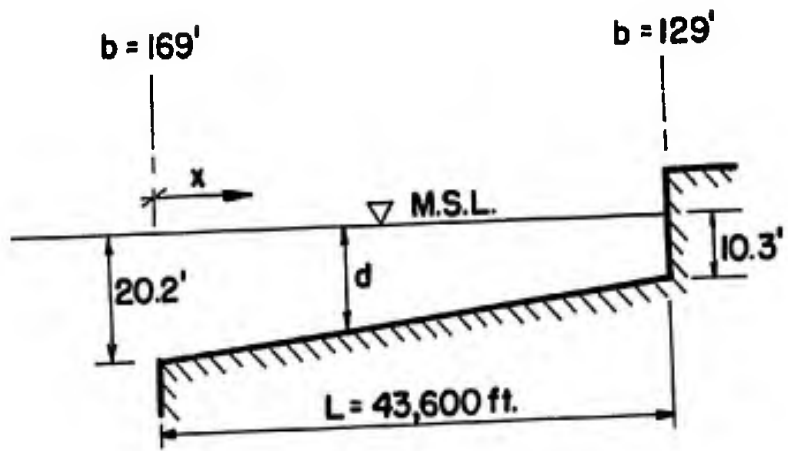
$\Delta t = 191.1$  sec.

Ocean tidal range = 3.8 ft. (sinusoidal)

Discharge at closed end = 0 cfs.

As the channel is at present under construction, field data are not yet available for comparisons. Figures 91 to 94 present the major results obtained from a computer solution. The following observations may be made for a short closed-end tidal channel such as the Dominquez Channel:

- (2) The water surface in the channel rises and falls almost simultaneously with that in the ocean. There is a negligible time lag between the time of high water at the entrance and the end of the channel (Figs. 91 and 92).



**Fig. 90 Dominquez Channel - Geometry of the Channel**

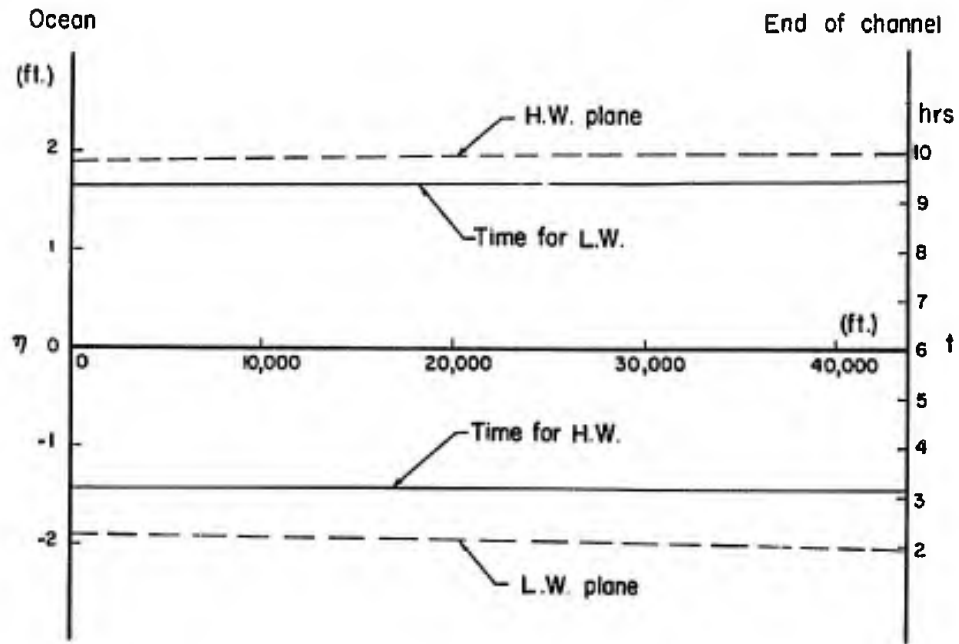


Fig. 91 Dominquez Channel - High and Low Water Planes; and Time for High and Low Waters

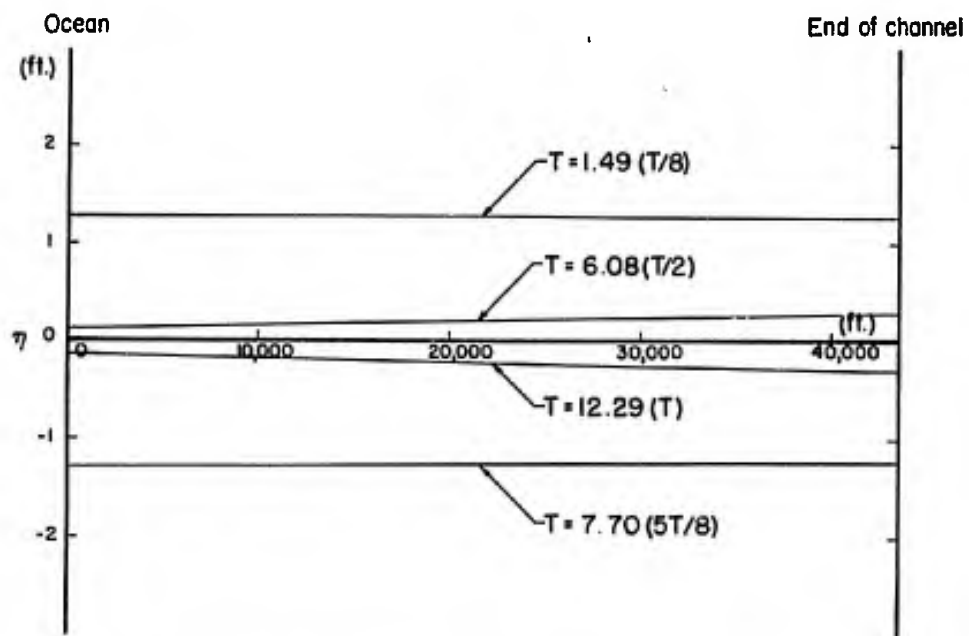


Fig. 92 Dominquez Channel - Tidal Elevations Approximately at Time of  $T/8$ ,  $T/2$ ,  $5T/8$  and  $T$

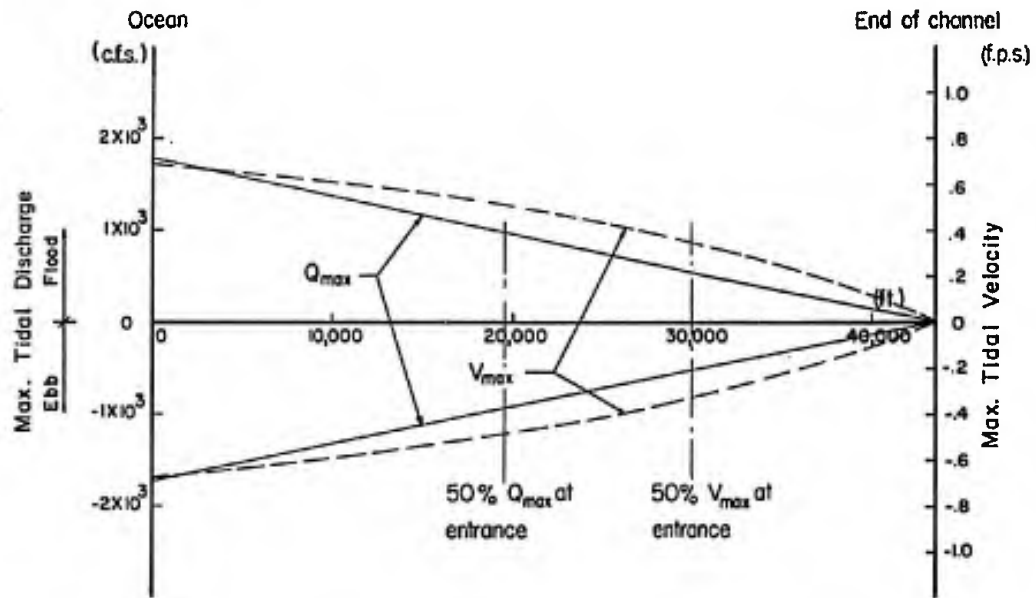


Fig. 93 Dominquez - Maximum Tidal Velocities and Discharges

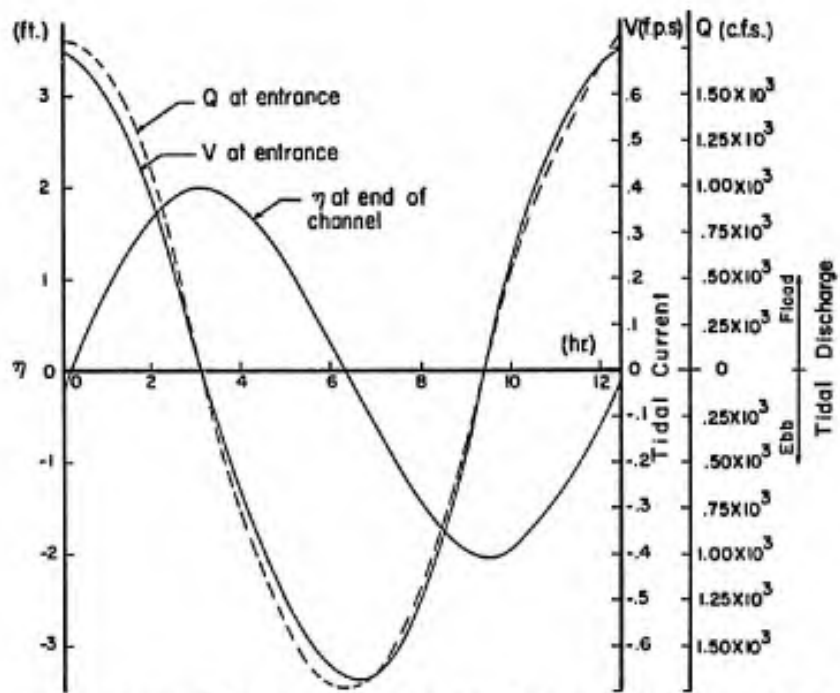


Fig. 94 Dominquez Channel - Tidal Velocity and Discharge at Entrance of the Channel; and Tidal Variations in Elevation at End of the Channel

- (b) The maximum tidal discharges are reduced to 50% of those of the entrance at about mid-length of the channel while the maximum tidal velocities are reduced by a similar percentage at about three-quarters of the length of the channel from the entrance (Fig. 93).
- (c) All curves showing variations of tidal elevation throughout the channel retain the shape of a sinusoidal curve (Fig. 94). Thus, no distortion in the tidal curve occurs along the channel.

## Chapter 7

### Discussion and Conclusions

It is concluded that the non-linear, finite difference method is the most satisfactory technique for solution of one-dimensional tidal hydraulic problems. The seven case studies in Chapter 6 have demonstrated the versatility of the method in both prismatic and irregular channels, in closed and open end estuaries and sea-level canals. The diagonal mesh computation method using an explicit scheme results in relatively simple computer programs and efficiency in computer time. Computer programs have been developed for closed-end estuaries, open end estuaries and sea-level canals.

The important features of the proposed method of solution are summarized in the following sections.

#### 7.1 Non-Linearity and Transient Characteristics

The ability of the proposed method to incorporate the non-linear features of tidal motion has been demonstrated. The important non-linear characteristics are summarized below:

1. There exists a gradual rise in the mean water surface of an estuary in the landward direction with respect to M.S.L. in the ocean.
2. There is a progressive distortion of the shape of the tidal wave in the landward direction.
3. The maximum flood tidal velocity is generally larger than the maximum ebb current except near the head of tide where the ebb velocity is dominant.
4. The duration of ebb flow is generally longer than the duration of flood flow.
5. There may be a time lag between the time of maximum tidal velocity and the time of maximum discharge at a section.
6. The non-linear effects increase as the ratio of tidal amplitude to mean depth increases.
7. Local wind effects may be incorporated into the solution.

The transient feature of the proposed method includes the ability to treat a continuous boundary tidal elevation record extending over many tidal cycles. The transient aspects have not been demonstrated in the case studies given in Chapter 6, owing to a lack of tidal data at the boundaries. The transient characteristics of the computer program have been illustrated by Harleman and Lee (1967) in recent studies on the inter-oceanic sea-level canal.

#### 7.2 Schematization, Initial and Boundary Conditions

Canals and estuaries of any geometry may be schematized for a finite difference solution following the procedures outlined in Chapter 5. The solution of a tidal problem requires the specification of initial and boundary conditions. It is shown that the final solution is independent of the assumed initial conditions. Hence, the tidal elevation and discharge may be assumed to have initial values of zero. A quasi-steady solution is obtained by repeating the calculation until the differences between successive tidal cycles are negligibly small. Two boundary conditions are required; these may be specified as either tidal elevation or tidal discharge. The choice depends on the physical characteristics as discussed in section 5.3. When a tidal elevation versus time is specified as a boundary condition the tide need not be sinusoidal.

#### 7.3 Frictional Resistance

In tidal estuaries, the Manning resistance coefficient is generally a function of  $x$ . Past records of tidal elevation may be used to determine the variation in the resistance coefficient in the case of existing estuaries. Prismatic channels and canals generally have constant resistance coefficients which are similar to those for steady state flow in a channel of similar roughness. In short sea-level canals, the resistance coefficient has little effect on the surface elevation; however, the effect on the magnitude of the tidal current is large.

#### 7.4 Stability Criteria and Round-off Errors

It is not possible to provide an exact stability criterion for an explicit, finite difference computational scheme which includes non-linear

effects and frictional resistance. The inequality given by eq., 77, which determines the relationship between  $\Delta x$  and  $\Delta t$ , is an approximation for the frictionless case. Perkins (1968) has investigated the stability of finite difference methods, including a linear friction term and concludes that stability is affected by friction. Attempts have been made in the present study to find the largest  $\Delta t$  possible for a stable solution. The results are summarized in Table V.

Thus, in view of the above facts, the stability criteria as recommended by (77) is by no means unique for a tidal channel of irregular shape with the friction effect being included in the solution. Table V clearly supports such a statement. Nevertheless, under any circumstances, a stable solution always exists. In the absence of a rigorous theory describing the stability of a numerical solution, it is necessary to begin by utilizing the inequality (77) as a rough guide, and thereafter, to find the largest  $\Delta t$  possible for a stable solution by trial and error. This is advantageous as, in association with the stability criteria, round-off errors always exist for any numerical methods. Violation of the stability criteria will lead to an unstable solution while, at the other extreme, too small a  $\Delta t$  may introduce undesirable round-off errors in the solution obtained. Also, too small a  $\Delta t$  will increase the computer time to obtain a solution. The increase is insignificant for one solution,

but its accumulation may become significant if many solutions of the same channel are to be obtained.

In the case of the Delaware, the largest possible  $\Delta t$  for a stable solution has been found to be 621 sec. for the 1951 survey, while  $\Delta t$  should be equal to or less than 646 sec. according to inequality (77). If  $\Delta t$  is reduced to 476 sec. (23% reduction), the solutions obtained for the two different  $\Delta t$  appear to have negligible differences in the tidal elevations (about  $\pm 0.2\%$ ) for practical purposes.

In the case of Chincoteague Bay, the computer indicates a stable solution with the largest possible  $\Delta t$  of 324 sec. (Table V). Subsequent examination of the velocity curve at the Chincoteague Inlet (Fig. 76)

Case	Length of Channel	$\Delta x$	Largest $\Delta t$ Possible for Stable Solutions (sec.)	$\Delta t$ According to Inequality (77) (sec.)	$\Delta t$ According to Inequality (76) (sec.)	Acceptable Error for Quasi-Steady State Solution (ft.)	No. of Cycles for Obtaining Quasi-Steady State Solution
Delaware (1951 Channel)	112.3 miles	3.4 miles	$\leq 621$	$\leq 646$	$\leq 613$	0.00001	6
Savannah (8,620 cfs)	25.0 miles	2.25 miles	$\leq 298$	$\leq 473$	$\leq 463$	0.00001	5
Proposed Sea-level Panama Canal (Case 1)	35.4 miles	2.95 miles	$\leq 344$	$\leq 305$	$\leq 267$	0.001	5
	38,035 ft.	4,754 ft.	$\leq 175$	$\leq 153$	$\leq 139$	0.00001	3
Cape Cod Canal		500' x 40'	6,339 ft.	$\leq 167$	$\leq 152$	0.00001	3
Chincoteague Bay	37.2 miles	2.65 miles	$\leq 324$	$\leq 809$	$\leq 782$	0.01	9
Dominguez Channel	43,600 ft.	4,844 ft.	$\leq 191$	$\leq 182$	$\leq 177$	0.0001	27
						0.01	3

Table V - Stability Criteria and Acceptable Errors for Quasi-Steady State Solution

reveals some instability. A reduction of  $\Delta t$  to 263 sec. (19% reduction) eliminates the zigzags on the curve, without introducing significant round-off errors. Therefore, it can be concluded that the round-off errors associating with the explicit scheme proposed in this report are insignificant. In any event, the magnitudes of round-off errors can always be detected empirically by using two different  $\Delta t$  while keeping all the other input data the same.

Finally, as shown on Table V, different acceptable errors for tidal elevations leading to the decision of whether a quasi-steady solution has been obtained are used for different tidal channels. For practical purposes, it is unnecessary to have the error magnitude greater than 0.001 ft. However, the prototype studies reveal the fact that tidal elevations converge faster to a quasi-steady state solution than tidal discharges. Also, as the acceptable error decreases, the time consumed in the computer for each solution obtained increases as shown on Table V for the case of the Chincoteague Bay. Nevertheless, it is necessary to have the acceptable error smaller than the tolerable error for practical purposes, in order to minimize the corresponding error for tidal discharges in the solution obtained.

#### 7.5 Evaluation

The outstanding advantage of the finite difference formulation, in the solution of one-dimensional tidal problems, is its applicability to a wide range of physical problems. The proposed method deals with the basic continuity and momentum equations and a high level of mathematical training in the solution of differential equations is not required. The boundary conditions are flexible and can be adapted to utilize the type of information which is available. In contrast to the multitude of analytical methods discussed in Chapter 4, the proposed explicit, finite difference method has the advantage of being able to treat both the simple and the complex tidal problem within the same general framework. There is little to be gained by developing computer programs for specialized and obsolete methods of analysis.

Some training in computer programming will obviously be required in order to utilize the proposed method. Fortunately competent advisors in this field are generally available and the engineer who lacks such ability can devote his primary attention to the important decisions regarding the input variables, and boundary conditions.

Several important areas for additional study have been suggested by the present investigation:

1. Extension of the one-dimensional, finite difference formulation to include tidal problems with multiple channel junctions as in the case of tidal delta networks.
2. An extension of the non-linear, finite difference formulation to two-dimensional tidal motion, including the Coriolis term, for application in wide estuaries and tidal embayments.

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## APPENDIX I: PROCEDURES USED FOR COMPUTATIONS AT END BOUNDARIES

One of the features of a diagonal mesh discussed in the main report is that only  $Q$  or  $\eta$  is required to be defined along any one of the end boundaries. However, the dependent variable not defined along the end boundaries may turn out to be of practical significance for the practicing engineer; for example, the discharges and velocities at both ends of a canal when the ocean tides are defined as the end boundary conditions or the stage at the head of tide for a closed end estuary or canal where only fresh water discharge is defined.

Procedures, which are in principle similar to the method of cubature, can be incorporated as supplements to the explicit solution as described in the following paragraphs.

- (A) End computation of discharge at both ends of a canal or the entrance to an estuary:

Fig. 95(a) shows part of the rectangular grid adjacent to an end boundary along which  $\eta$  is defined and  $Q$  is to be computed. By means of linear interpolation,  $\eta_{r,k+1}$  can be determined from  $\eta_{r-1,k+1}$  and  $\eta_{r+1,k+1}$ , and so thus  $\eta_{r,k-1}$  from  $\eta_{r-1,k-1}$  and  $\eta_{r+1,k-1}$ .

Over a duration of  $2\Delta t$ , the continuity equation must be satisfied for the last (or the first) reach of length  $\Delta x$ . Therefore, assuming that the average width for the reach is

$$b_{av} = \frac{1}{2} (b_{r,t} + b_{r+1,t}) \quad (78)$$

Then, for continuity:

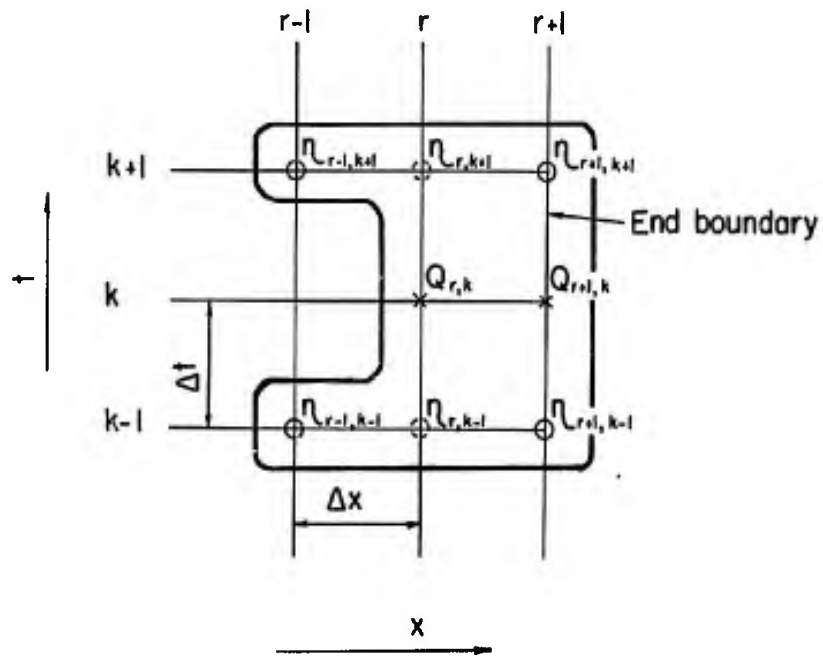


Fig. 95a Details of the Operator used for Computations of  $Q$  at the End Boundary

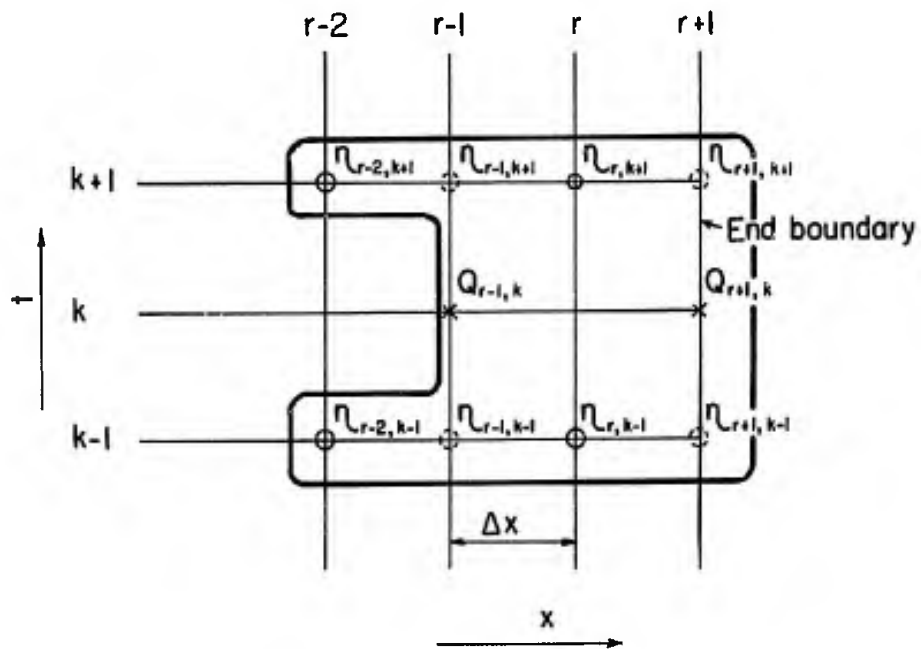


Fig. 95b Details of the Operator used for Computations of  $\eta$  at the End Boundary

$$\begin{aligned}
& (Q_{r+1,k} - Q_{r,k}) \cdot 2\Delta t \\
& = \frac{1}{2} (\eta_{r,k+1} - \eta_{r,k-1}) + (\eta_{r+1,k+1} - \eta_{r+1,k-1}) \cdot b_{av} \cdot \Delta x
\end{aligned}$$

$$Q_{r+1,k} = Q_{r,k} + \frac{\Delta t \cdot b_{av} \cdot t}{4\Delta x} (\eta_{r,k+1} - \eta_{r,k-1}) + (\eta_{r+1,k+1} - \eta_{r+1,k-1}) \quad (79)$$

Similarly, for the other end of the estuary or canal:

$$Q_{r+1,k} = Q_{r,k} - \frac{\Delta t \cdot b_{av} \cdot t}{4\Delta x} (\eta_{r,k+1} - \eta_{r,k-1}) + (\eta_{r+1,k+1} - \eta_{r+1,k-1}) \quad (80)$$

Eq. (80) is valid for the entrance to an estuary or a canal (i.e., the end boundary is at  $x = 0$ ), while Eq. (79) applies to the end boundary when  $x = l$ , the length of the estuary or canal.

(B) End computation of tidal elevation at head of tide for a closed end channel:

The closed end boundary condition of an estuary is defined by the upland discharge included as a lateral inflow to the last reach with  $Q_{r+1,k}$  equal to zero, while  $Q_{r-1,k}$  is always periodic (refer to Fig. 95b). Therefore, it is easy to realize that a very poor representation of  $Q_{r,k}$  would be obtained through a linear interpolation of  $Q_{r-1,k}$  and  $Q_{r+1,k}$ .

If the continuity equation is applied over a duration of  $2\Delta t$  to a reach of  $2\Delta x$  instead of  $\Delta x$  such that  $\eta_{r-1,k+1}$  and  $\eta_{r-1,k-1}$  can be obtained through linear interpolations, then

$$-Q_{r+1,k} + Q_{r-1,k} + q_r \cdot 2\Delta t = \frac{1}{2} (\eta_{r-1,k+1} - \eta_{r-1,k-1}) + \Delta\eta_k b_{r,t} \cdot 2\Delta x$$

with  $\Delta\eta_k = \eta_{r+1,k+1} - \eta_{r+1,k-1}$

$q_r$  = lateral inflow between (r-1) and (r+1).

Thus,

$$\Delta\eta_k = \frac{2 \Delta t}{b_{r,t} \cdot \Delta x} (-Q_{r+1,k} + Q_{r-1,k} + q_r - \eta_{r-1,k+1} - \eta_{r-1,k-1}) \quad (81)$$

Eq. (81) enables one to find only the correct shape of the stage curve for the tidal elevation at the head of tide, but without proper reference to the datum used in the solution. However, the tidal flow into the last reach is equal to

$-Q_{r+1,k} + Q_{r-1,k}$ . When it is equal to zero, the water surface at that particular time should be at a slope equal to the hydraulic gradient due to a steady flow of  $q_r$  in the last reach. Such a gradient,  $s_0$ , can be easily computed by using Manning's formula with  $u = C \sqrt{Rs_0}$ . Thus, it is possible to assume that, at that particular instance, the tidal elevation at the head of tide should be equal to the tidal elevation of the (r-1)<sup>th</sup> section, say  $(\eta_0)_{r-1}$ , plus  $2s_0 \Delta x$ . With one point on the stage curve defined, the tidal elevations at any other time of the tidal cycle can then be obtained accordingly by Eq. (81). But, it should be pointed out that it is virtually impossible to find the time when the net flow is exactly equal to zero for a discrete type solution obtained by the explicit scheme. So it is necessary to make an approximation by using the time when it is closest to zero.

The above procedures are meant to serve as first approximations only.

Owing to the application of the linear interpolation instead of an interpolation compatible with the non-linear solution, results obtained bear more of qualitative rather than quantitative significance. It is for this reason that these computations have been deleted from the main computer programs.

A. General Description of Computer Programs

The computer programs on tidal hydraulics, developed during the present research, consist of the following:

- (a) Program No. 1 -- for problems in connection with closed end estuaries and canals.
- (b) Program No. 2 -- for problems in connection with estuaries without a natural or artificial barrier at the river end.
- (c) Program No. 3 -- for problems in connection with natural channels or man-made canals connecting two bodies of water.

The basic differences among the three lie in the treatment of boundary conditions. Along any boundary, at either end of an estuary or a canal, either the total discharge across the boundary per unit time or the tidal elevation needs to be defined. Under normal circumstances, the requirements for defining the boundary conditions are as follows:

		Ocean End	River End (or the other end for Program No. 3)	Total Number of Reaches	"Nmax"
Program No. 1		H	FQ(fresh water discharge if any), $Q = 0$	odd	odd
" 2		H	Q (River Flow)	odd	odd
" 3		H	H	even	odd

In order to become general programs applicable to both natural tidal channels or man-made canals, the programs have been constructed to deal with channel geometry as follows:

- (a) Geometry of irregular shape for estuaries
- (b) Geometry of prismatic type

- (1) Rectangular channel of constant width for canals or long docks
- (2) Trapezoidal channel for canals
- (3) Rectangular channel of exponentially varying width for estuaries.

The feature of rectangular channel of exponentially varying width has been deleted for Program No. 2 and 3, as it rarely exists in reality for those cases.

The programming language used was Fortran IV - E-level subset and the computer programs were developed for the use of an IBM 360 Model 40 or 65 computer. But, they are equally applicable also if either F-level or G-level compiler is used instead.

Since the formulation concerns basically second order partial differential equations of hyperbolic type, which is similar to that for flood wave problems in rivers, it is expected that Program No. 2 can be extended with minor modifications to solve flood wave propagation problems in a river.

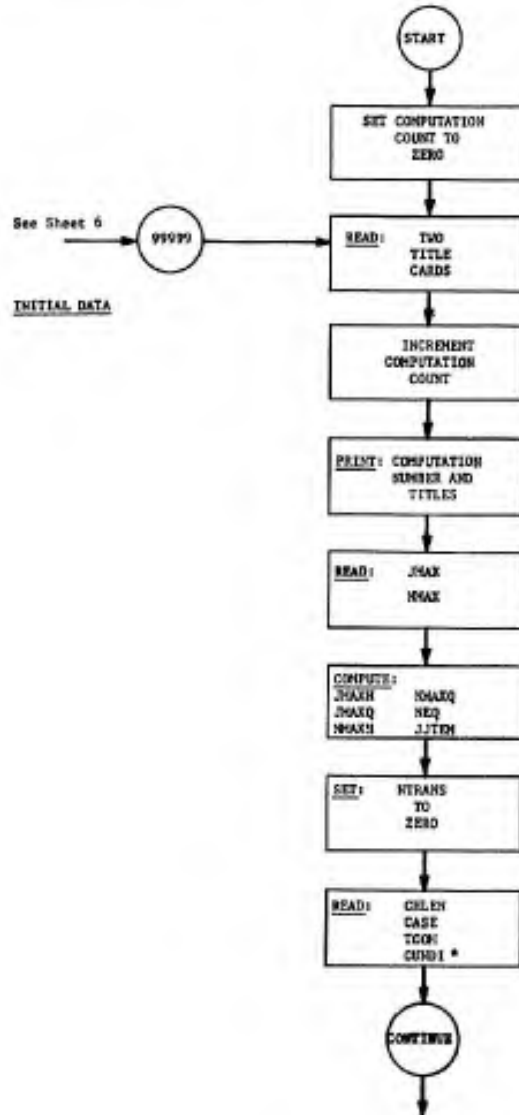
The computer programs were constructed with input data fully documented to avoid confusion among different runs. The programs were incorporated with capacity of producing both a quasi-steady state solution and transient solutions. In the case when transient solutions are to be obtained, a quasi-steady solution is first acquired to generate the initial conditions necessary for obtaining the subsequent solution. With proper instructions given to the computer, the programs can solve infinite numbers of different cases after a single compilation of the main program, subject only to the operating rules of the computer used.

In addition to the main programs, a separate plotting program written for use on an IBM 1130 computer with a Calcomp plotter has been included to provide graphical outputs, if so desired. The inputs to the plotting program are the card punch outputs obtainable from the main programs.

B. Flow Chart Showing the Logic of the Computer Programs

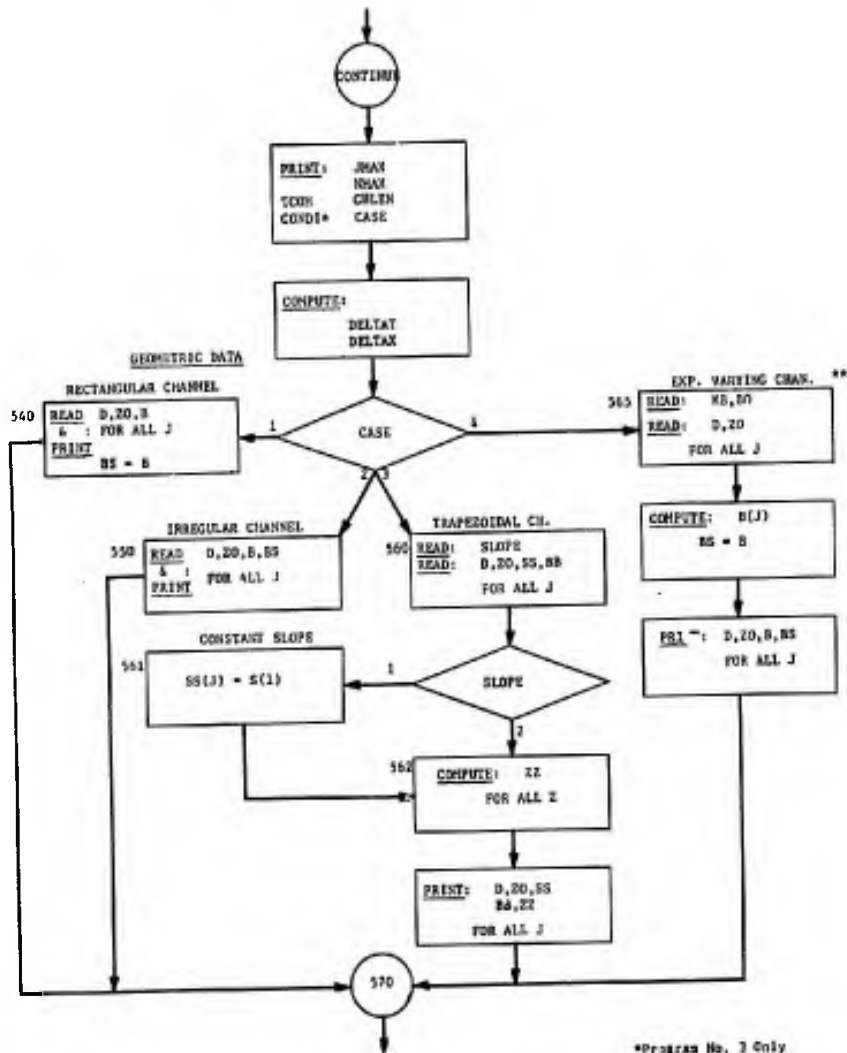
(The following flow charts show the logic of the main programs.)

(Note: Minor discrepancies exist between the flow charts and the listing of main programs due to latest changes made on the computer programs.)



\*Program No. 3 Only

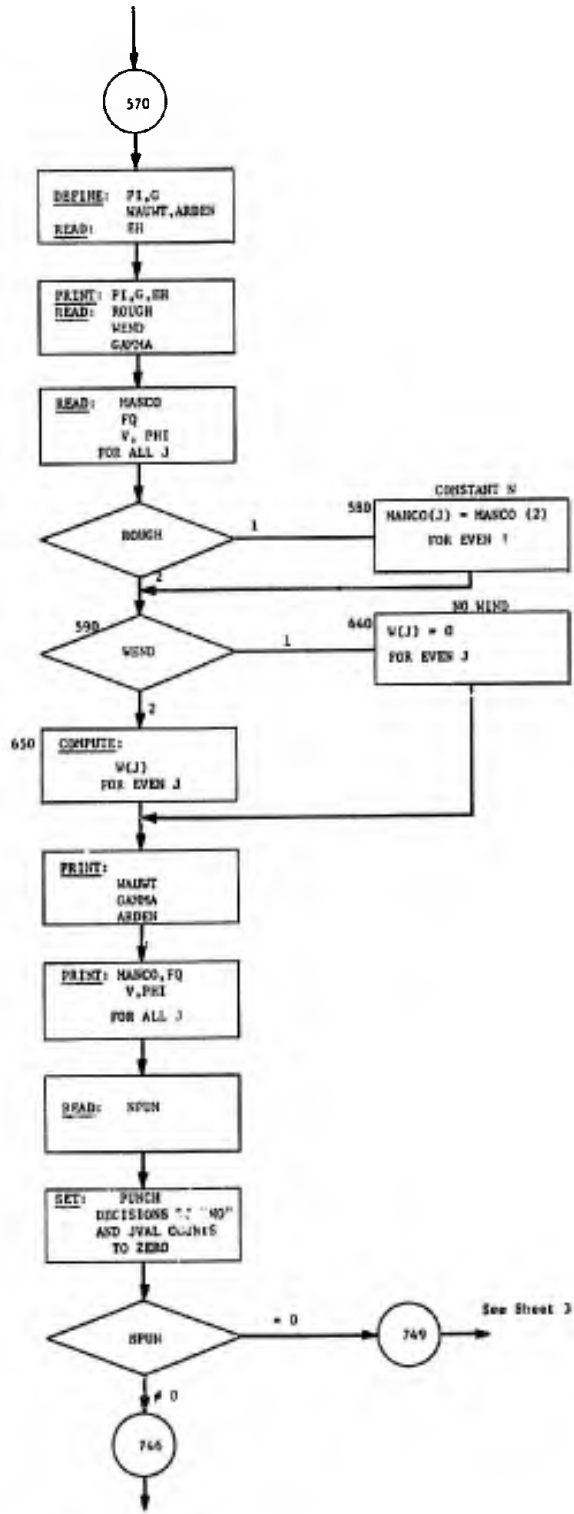
FLOW CHART FOR MAIN PROGRAM (SHEET 1)



\*Program No. 3 Only  
\*\*Program No. 1 Only

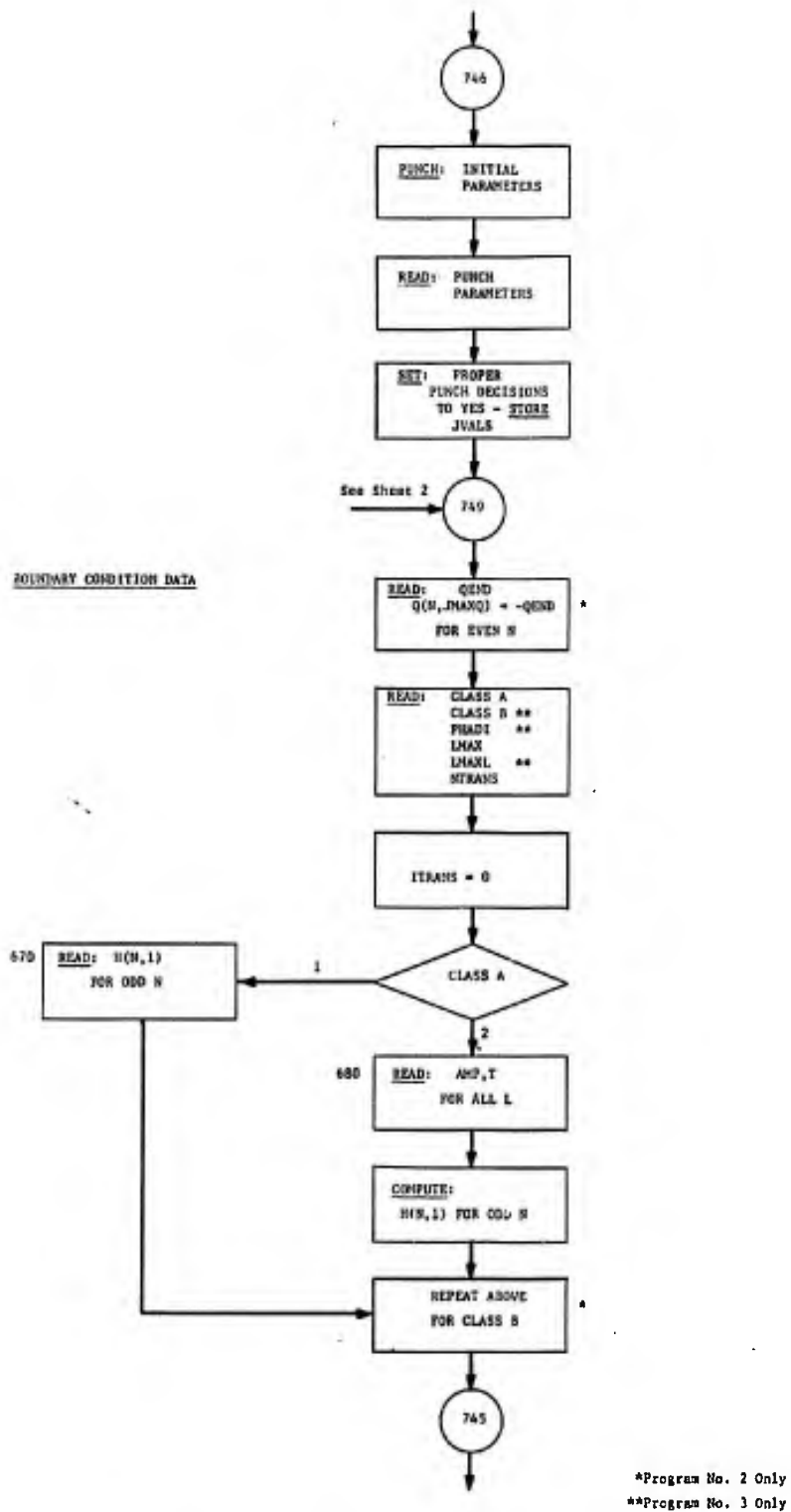
FLOW CHART FOR MAIN PROGRAM ( SHEET 2)

MISCELLANEOUS DATA

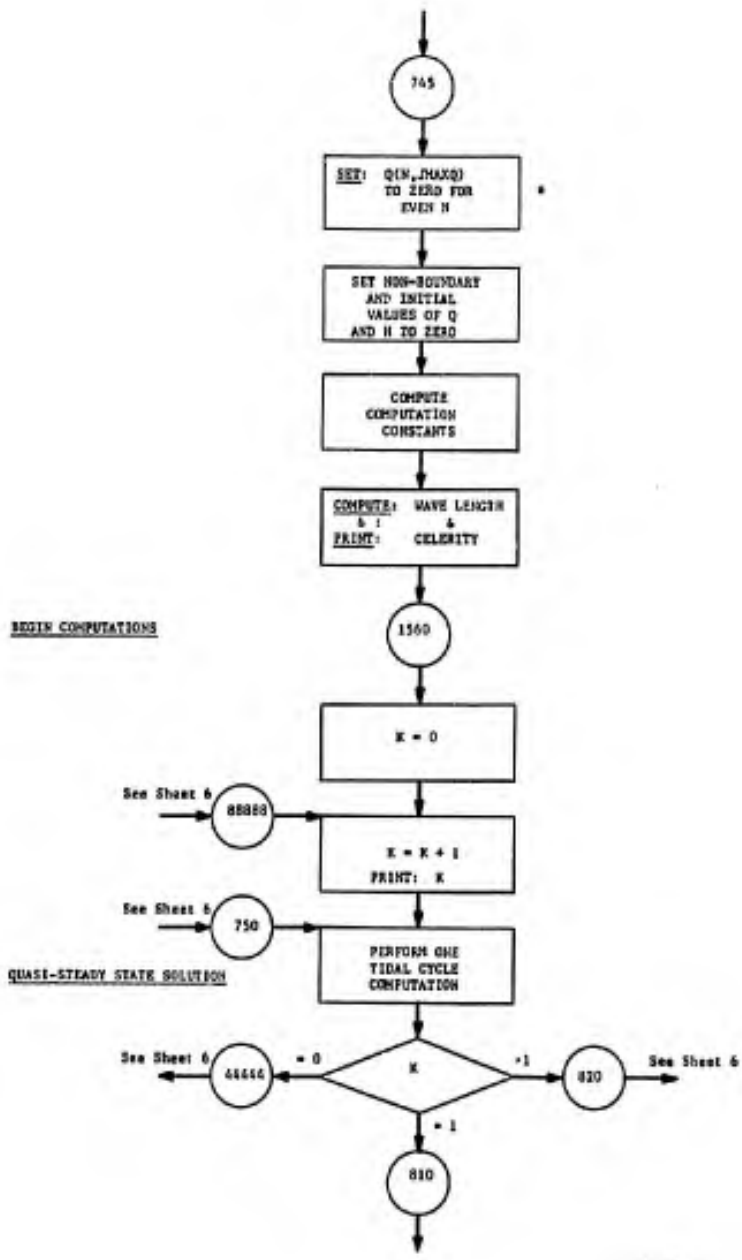


PLOTTING PROGRAM DATA

FLOW CHART FOR MAIN PROGRAM (SHEET 3)



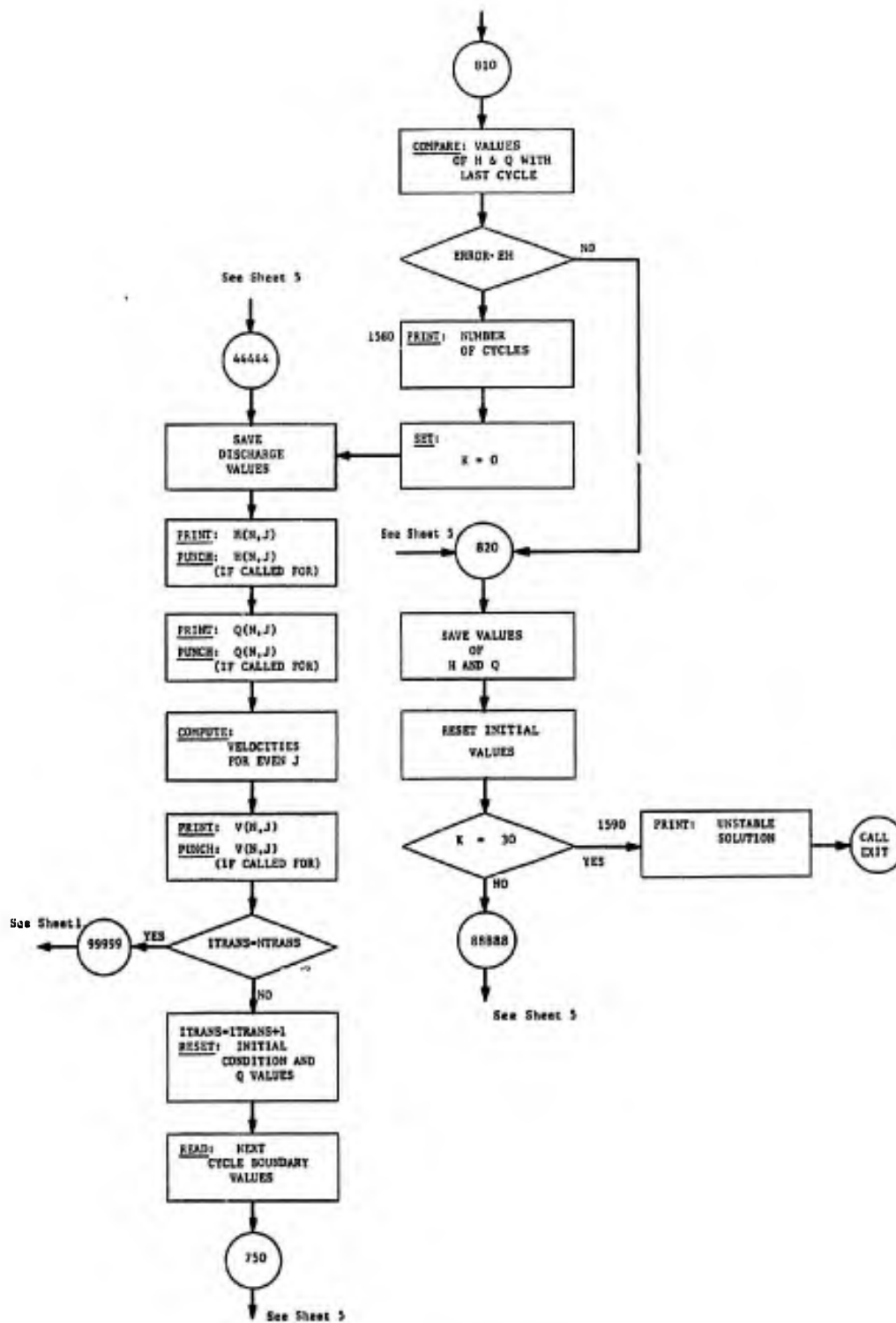
FLOW CHART FOR MAIN PROGRAM (SHEET 4)



\*Program No. 1 Only

FLOW CHART FOR MAIN PROGRAM (SHEET 5)

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FLOW CHART FOR MAIN PROGRAM (SHEET 6)

C. Listings of Main Programs



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CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C   DEFINE IMPORTANT INTEGER VARIABLES
C   JMAX IS AN EVEN NUMBER
C   READ (5,1000) JMAX,NMAX
C   JMAXH=JMAX-1
C   JMAXO=JMAX
C   NMAXH=NMAX
C   NMAXO=NMAX+1
C   NFO=NMAXO-2
C   JJYH = JMAXO-2
C   JJYO = JMAXO-2
C   ITPANS = 0
C   1000 FORMAT (I3,I6)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C   DEFINE GEOMETRIC AND GENERAL INPUT DATA
C   CASE1 DEFINES THE TYPE OF CHANNEL AFTER SCHEMATIZATION
C   CASE=1, FOR UNIFORM RECTANGULAR CHANNEL
C   CASE=2, FOR IRREGULARLY SHAPED CHANNEL
C   CASE=3, FOR TRAPEZOIDAL CHANNEL
C   CASE=4, FOR EXPONENTIALLY VARYING WIDTH RECTANGULAR CHANNEL
C   ALL TIDAL ELEVATIONS REFER TO AN ASSUMED INITIAL WATER SURFACE, NOT
C   NECESSARILY THE MEAN WATER PLANE
C   ALL WATER DEPTHS MEASURED FROM ASSUMED INITIAL WATER SURFACE TO BOTTOM
C   CHLEN = CHANNEL LENGTH IN MILES
C   CHANNEL LENGTH IS TAKEN UP TO HEAD OF TIDE AND DIVIDED INTO (JMAX-1)
C   SEGMENTS
C   TCOM = TIDAL PERIOD IN SECONDS
C   DIST = CHAINAGE OF THE CHANNEL
C   WP(J) = WETTED PERIMETER, R(J) = HYDRAULIC RADIUS, C(J) = CHEZY'S CIEFF.
C   FOR IRREGULAR CHANNEL
C   A(J) = AREA, D(J) = DEPTH OF CHANNEL, ZD(J) = HEIGHT BETWEEN CHANNEL
C   BOTTOM AND HORIZONTAL REFERENCE DATUM
C   R(J) = FULL WIDTH OF CHANNEL, RS(J) = WIDTH OF EFFECTIVE CHANNEL FOR TIDAL
C   FLOW EXPONENTIAL CHANNEL
C   FOR EXPONENTIAL CHANNEL
C   RD = WIDTH OF CHANNEL AT ENTRANCE, KR = EXPONENTIAL COEFFICIENT DEFINING
C   THE REDUCTION OF WIDTH IN CHANNEL, RC(J) = RS/J
C   SLOPE=1, REFERS TO SLOPE OF TRAPEZOIDAL CHANNEL ONLY
C   SLOPE=2, CONSTANT SIDE SLOPE
C   SLOPE=3, VARYING SIDE SLOPE
C   SS(J) = VERTICAL HEIGHT OF SIDE SLOPE OVER UNIT DISTANCE HORIZONTALLY
C   ZL(J) = LENGTH ALONG THE SLOPE OVER UNIT DISTANCE HORIZONTALLY
C   RB(L) = BOTTOM WIDTH OF TRAPEZOIDAL CHANNEL
C   READ (5,1050) CHLEN,CASE,TCOM
C   WRITE (6,1060)
C   WRITE (6,1100) JMAX,NMAX,CHLEN,TCOM
C   DELTAT=TCOM/(NMAX-1)
C   DELTAX=CHLEN*5280./(JMAX-1)

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1050 FORMAT (F10.5,2(2X,F10.5))
1060 FORMAT (5X,4HJMAX,5X,4HJMAX,5X,5HLEN,6X,4HTCDM)
1090 FORMAT (2(5X,14),2(1X,F10.3))
1100 FORMAT (F10.5,2(2X,F10.5),CASE)
1110 WRITE (6,1110)
1120 WRITE (6,1120)
1130 J=1,JMAX
1140 READ (5,1130) D(J),Z0(J),R(J)
1150 DIST=(J-1)*DELTA/5280.
1160 R(J)=R(I)
1170 RS(J)=R(I)
1180 WRITE (6,1140) DIST,D(J),Z0(J),R(J),RS(J)
1 CONTINUE
1190 FORMAT(30H CASE = 1 UNIFORM RECTANGULAR CHANNEL)
1200 FORMAT (3X,5HILES,8X,14D,11X,2470,14X,14H,10X,2HBS)
1210 FORMAT (10X,2F10.5,F10.1)
1220 FORMAT (F10.5,2(2X,F10.5),2(2X,F10.1))
1230 GO TO 570
550 WRITE (6,1150)
560 WRITE (6,1160)
570 J=1,JMAX
580 READ (5,170) D(J),Z0(J),R(J),RS(J)
590 DIST=(J-1)*DELTA/5280.
600 WRITE (6,1180) DIST,D(J),Z0(J),R(J),RS(J)
610 CONTINUE
620 FORMAT(34H CASE = 2 CHANNEL OF IRREGULAR SHAPE)
630 FORMAT (3X,5HILES,8X,14D,11X,2470,14X,14H,10X,2HBS)
640 FORMAT (10X,2F10.5,2F10.1)
650 FORMAT (F10.5,2(2X,F10.5),2(2X,F10.1))
660 GO TO 570
560 WRITE (6,1100)
570 WRITE (6,1200)
580 READ (5,1210) SLOPE
590 J=1,JMAX
600 READ (5,1220) D(J),Z0(J),RS(J),SS(I),RB(J)
610 GO TO (561,562), SLOPE
551 SS(J)=SS(I)
562 Z0(J)=Z0(I)+SS(I)*Z
630 DIST=(J-1)*DELTA/5280.
640 WRITE (6,1230) DIST,D(J),Z0(J),RS(J),SS(I),Z0(J)
650 CONTINUE
660 FORMAT(31H CASE = 3 TRAPEZOIDAL CHANNEL)
670 FORMAT (3X,5HILES,8X,14D,11X,2470,14X,24HBS,7X,2HSS,11X,24Z)
680 FORMAT (10X,2F10.5)
690 FORMAT (F10.5,2(2X,F10.5),2X,F10.1,2(2X,F10.5))

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0092      GO TO 570
0093      READ (5,1231) KR,RO
0094      WRITE (6,1232) KR
0095      WRITE (6,1140)
0096      DO 4 J=1,JMAX
0097      READ (5,1220) R(J),Z0(J)
0098      XI=KR*(J-1)*DELTA
0099      R(J)=RO*EXP(-XI)
0100      RCU(J)=R(J)
0101      DIST=(J-1)*DELTA/5280.
0102      WRITE (6,1140) DIST,D(J),Z0(J),R(J),RS(J)
0103      CONTINUE
0104      1231 FORMAT (F10.3/F10.5)
0105      1232 FORMAT (5H CASE = 4 EXPONENTIALLY VARYING RECTANGULAR CHANNEL, K
          1R = ,F10.2)
          C
          C END OF GEOMETRIC DATA INPUT
          C CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
          C DEFINE OTHER INPUT DATA
          C ROUGH = 1, FOR CONSTANT MANNING'S COEFFICIENT ALONG THE CHANNEL
          C ROUGH = 2, FOR MANNING'S COEFFICIENT VARIES ALONG THE CHANNEL
          C ALL LATERAL FRESH WATER INFLOWS POSITIVE
          C FLOW = FLOW AT HEAD OF TIDE PLUS OTHER INFLOWS FOR THE FIRST REACH
          C WEND=1, FOR NO WIND EFFECT
          C WEND=2, FOR WIND EFFECT INCLUDED
          C V(J) = MAGNITUDE OF VELOCITY OF WIND, POSITIVE WHEN BLOWING UPSTREAM
          C PHI(J) = ANGLE OF WIND WITH RESPECT TO LONGITUDINAL DIRECTION
          C WINDT = UNIT WEIGHT OF WATER
          C AFDEN = AIR DENSITY
          C GAMMA = SURFACE WIND COEFFICIENT
          C
          C 570 WRITE (6,1240)
          C 1240 FORMAT (11H OTHER DATA)
          C PI = 3.1415927
          C G = 32.2
          C WINDT = 64.0
          C AFDEN = .078
          C READ (5,1250) EH
          C WRITE (6,1260)
          C READ (5,1290) RCUH,WEND
          C DO 4 J=1,JMAX
          C READ (5,1300) WINDC(J),FO(J),V(J),PHI(J)
          C CONTINUE
          C 4
          C GO TO (580,590),RCUHQ
          C 580 WRITE (6,1310)

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DIM(M) = PROGRAM SWITCH INDICATING WHETHER GRAPH IMI IS TO BE PLOTTED.
DUM(M) = 1 SAYS NO, DUM(M) = 2 SAYS YES
READ (5,1496) NPUN
DO 201 M=1,0
DUM(M)=1
CONTINUE
201 JVAL(1,1)=0
JVAL(2,1)=0
JVAL(3,1)=0
IF (NPUN) 749,749,746
746 WRITE (7,1497) JMAX, NMAX, DELTAX, DELTAY
WRITE (7,1498) NPUN
DO 202 M=1, NPUN
READ (5,1496)(PTEM(M2), M2=1,26)
WRITE (7,1496)(PTEM(M2), M2=1,26)
M3=PTEM(1)
DUM(M3)=2
GO TO (202,202,747,202,202,747,202,202,747), M3
747 M4=M3/3
M5=JVAL(M4,1)
DO 203 M2=0,25
IF (PTEM(M2)) 203,203,749
749 M5=M5+1
JVAL(M6,M5+1)=PTEM(M2)
203 CONTINUE
JVAL(M6,1)=M5
202 CONTINUE
1495 FORMAT (2A13)
1497 FORMAT (13,14,2E10,3)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C CLASS1 DEFINES THE OCEAN BOUNDARY CONDITION
C CLASS=1, FOR OCEAN TIDE INPUT FROM TIDE TABLE OR FIELD DATA
C CLASS=2, FOR OCEAN TIDE INPUT OF HARMONIC TYPE
C NTRANS = TOTAL NUMBER OF TRANSIENT SOLUTIONS
C FOR HARMONIC TIDES
C LMAX = TOTAL NUMBER OF HARMONICS TO BE INCLUDED
C AMPL1 = AMPLITUDE OF HARMONIC TIDE
C T(1) = PERIOD OF HARMONIC TIDE
C OMEGA(1) = FREQUENCY OF TIDE
740 WRITE (6,1495)
READ (5,1410) CLASSA, LMAX, NTRANS
IF (NPUN) 744,744,743
743 WRITE (7,1496) NTRANS
744 GO TO (670,680), CLASSA
670 READ (5,1420) (M(1), N=1, NMAXH, 2)

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0197 WRITE (6,1430)
0198 FORMAT(34H CLASSA = 1 OCEAN TIDES FROM TABLE)
0199 GO TO 745
0200
0201 READ (5,1440) AMP(L),T(L)
0202 OMEGA(L)=2.*PI/T(L)
0203 DO CONTINUE
0204 DO 11 N=1,NMAXH,2
0205 H(N,1)=0.
0206 DO 11 L=1,LMAX
0207 THETA(L)=OMEGA(L)*(N-1)*DELTA
0208 H(N,1)=H(N,1)+AMP(L)*SIN(THETA(L))
0209 DO CONTINUE
0210
0211 WRITE (6,1450)
0212
0213 WRITE (6,1490) LMAX
0214 FORMAT (24H BOUNDARY CONDITION DATA)
0215
0216 READ (5,1460)
0217 OMEGA(L)=2.*PI/T(L)
0218 DO CONTINUE
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II-16





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0305 WRITE (6,1650)
0306 FORMAT (1X,5I4X,3HR.,9X,6HH(N,J),4X))
0307 DO 36 N=1,NMAXH,12
0308 CALL WRITE(H,N,J,TDH)
0309 CONTINUE
0310 CALL MAMH(H,N,J,NMAXH,TDH)
0311 CONTINUE
C PUNCH NECESSARY CARD OUTPUTS OF 'H' FOR PLOTTING ON I130 COMPUTER
0312 M2=JVAL(1,1)
0313 IF (M2) 353,353,351
0314 DO 352 M=1,M2
0315 M3=JVAL(1,M+1)
0316 WRITE (7,1655)(H(N,M3), N=1,NMAXH,2)
0317 CONTINUE
0318 1655 FORMAT (9F10.3)
0319 353 PTEST1=PUN(4)
0320 PTEST2=PUN(5)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
0321 WRITE (6,1660)
0322 1660 FORMAT(31H VARIATIONS OF Q ARE AS FOLLOWS)
0323 DO 39 J=2,JMAXQ,2
0324 DIST=(J-1)*DELTAQ/5280.
0325 WRITE (6,1640) DIST,J
0326 WRITE (6,1670)
0327 1670 FORMAT (1X,5I4X,3HR.,9X,6HQ(N,J),4X))
0328 DO 40 N=2,NMAXQ,10
0329 CALL WRITE(Q,N,J,TDH)
0330 CONTINUE
0331 CALL MAMQ(Q,N,J,NMAXQ,TDH)
0332 CONTINUE
C PUNCH NECESSARY CARD OUTPUTS OF 'Q' FOR PLOTTING ON I130 COMPUTER
0333 M2=JVAL(2,1)
0334 IF (M2) 393,393,391
0335 DO 392 M=1,M2
0336 M3=JVAL(2,M+1)
0337 WRITE (7,1655)(Q(N,M3), N=2,NEQ,2)
0338 CONTINUE
0339 PTEST1=PUN(7)
0340 PTEST2=PUN(8)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C COMPUTATION OF AVERAGE VELOCITY ALONG THE 'ANNE'
0341 DO 41 N=2,NEQ,2
0342 DO 41 J=2,JMAXQ,2
0343 IF (JMAXQ-J) 447,447,448
0344 HAV=.5*(H(N+1,JMAXH)+H(N-1,JMAXH))
0345 GO TO 449
0346 448 HAV=.25*(H(N+1,J+1)+H(N+1,J-1)+H(N-1,J+1)+H(N-1,J-1))
0347 GO TO (260,960,950,960),CASE

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C QUASI-STeady SOLUTION NOT OBTAINED AFTER 30 TIDAL CYCLES, READJUST  
DT VALUES FOR NEW COMPUTATION  
33333 CALL EXIT  
CC  
END

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C THIS SUBROUTINE COMPUTES 'H' AND 'Q' BY ALTERNATE USES OF CONTINUITY
C AND MOMENTUM EQUATIONS
REAL MANCO,KB,KNOTS
INTEGER CLASSA,CASE,ROUGH,SLOPE,PUN,PTEM,MEND
INTEGER PTEST1,PTEST2
COMMON N,J,JMAX,NMAX,JMAXH,JMAXQ,NMAXH,NMAXQ,NEQ,JJTEM
COMMON NODS,CLASSA,CASE,ROUGH
COMMON DELTAT,DELTA,DIS,TDH,TCOM,CHLEN
COMMON P,G,DI,D2,D3,DTEM
COMMON M,M2,M3,M4,M5
COMMON PTEM(26),PUN(9),JVAL(3,26),NPUN
COMMON A(60),R(60),RS(60),D(60),DZ(60),WP(60),R(60),C(60)
COMMON BB(60),SS(60),ZZ(60)
COMMON MANCO(60),FQ(60),Y(60),PHI(60),H(60),D4(60)
COMMON H(1282,ZD),Q(1282,ZD)
DO 23 NN=3,NMAXH,2
N=NN
DO 24 J=3,NMAXH,2
FRDIS = FQ(J)+FQ(J+1)
GO TO (770,770,760,770),CASE
760 B(J)= BB(J)+ 2.*D(J)+H(N-2,J)*SS(J)
770 H(N,J)=H(N-2,J)-(Q(N-1,J+1)-Q(N-1,J-1))-FRDIS)*DI/B(J)
24 CONTINUE
N=NN+1
DO 25 J=2,JJTEM,2
GO TO (790,790,780,790),CASE
780 RTEM=D(J)+5*(H(N-1,J-1)+H(N-1,J+1))
R(J)= BB(J)+2.*RTEM*SS(J)
R(J)= BB(J)+RTEM*SS(J)
R(J)=BS(J)+RTEM
WR(J)= BB(J)+2.*RTEM*ZZ(J)
GO TO 800
A(J)=BS(J)*D(J)+5*(H(N-1,J+1)+H(N-1,J-1))
WR(J)=2.*D(J)+BS(J)+H(N-1,J+1)+H(N-1,J-1)
800 R(J)=A(J)/WP(J)
C(J)=1-486*(R(J)*WP)/MANCO(J)
EI=D2/A(J)
E2=5/((C(J)+2)*(A(J)+2)*R(J))
E3=6(1+BS(J))/IG*(A(J)+2)
E4=25*(H(N-1,J+1)+H(N-1,J-1)-H(N-3,J+1)-H(N-3,J-1))/DELTAT
FRDIS=IFQ(J)+FQ(J+1))/I2*DELTAT
E5=FRDIS/IG*(A(J)+2)
Q(N,J)=(Q(N-2,J)+EI-ABS(Q(N-2,J))+E2+E3+E4-E5)*D3*(H(N-1,J-1)-
H(N-1,J+1))+H(J)/R(J)+D4(J))/EI+E2*ABS(Q(N-2,J)))
25 CONTINUE
23 CONTINUE
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
END

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C
SUBROUTINE HAMI(H,N,J,NMAX,TDH)
SEARCH FOR MAXIMUM AND MINIMUM VALUES OF H
REAL MAX, MIN, P, L, M
REAL MEAN
INTEGER PTEST1, PTEST2
COMMON PTEST1, PTEST2
DIMENSION H(1:28,1)
DIMENSION STOI(9)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
MEAN DENOTES THE AMPLITUDE OF VARIATION
MAX = H(1,J)
HM=0.
DO 1 N=3,NMAX,2
DO 1 N=3,NMAX,2
IF (MAX - H(N,J)) 510,510,1
510 MAX = H(N,J)
HM=IN-1)*TDH
1 CONTINUE
LM=0.
DO 2 N=3,NMAX,2
IF (MIN - H(N,J)) 2,2,220
520 MIN = H(N,J)
LM=IN-1)*TDH
2 CONTINUE
1010 WRITE (6,1010) HM,MAX,LM,MIN
1010 FORMAT(4H HM=F6.3,2X,4HMAX=F10.5,5X,3HLM=F6.3,2X,4HMIN(F10.5)
MEAN=.5*(MAX+ABS(MIN))
WRITE (6,1020) MEAN
1020 FORMAT(7H MEAN =F12.5)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
TEST IF PUNCHING TO BE DONE AND DO IT IF SO
GO TO 1521, PTEST1
C
PUNCH VALUES OF HMAX AND TIME OF HMAX
WRITE (7,1005) J,MAX,HM,MIN,LM
1005 FORMAT (I3,F10.3)
521 GO TO 1528, PTEST2
C
PUNCH 'A' VS. DISTANCE AT 1.5 HOUR INTERVALS
DO 3 N=1,5
EPS=(N-1)*.5/TDH)+1.0001
IEPS=EPS/2.
IF ((IEPS/2.) - IEPS) - .5) 525+525,526
525 N1=2*IEPS-1
GO TO 527
526 N1=2*IEPS+1
527 N2=N1+2
STQ(N)=((IEPS-N1)/2.0)*H(N2,J)-H(N1,J))+H(N1,J)

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3 CONTINUE  
WRITE (7,1006) (STO(N), N=1,9),J  
1006 FORMAT (B10.3/E10.3,13)  
CC  
528 RETURN  
END

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0001 CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
0002 SUBROUTINE HANIQ(I,N,J,NMAX,TDH)
0003 SEARCH FOR MAXIMUM AND MINIMUM VALUES OF Q OR U
0004 REAL MAX*MIN,H*,LW
0005 INTEGER PTEST1,PTEST2
0006 COMMON PTEST1,PTEST2
0007 DIMENSION Q(1282,1)
0008 DIMENSION ST(9)
0009 CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
0010 C MEAN DENOTES THE AMPLITUDE OF VARIATION
0011 MAX = Q(2,J)
0012 HM=TDH
0013 DO 1 N=4,MAXQ,2
0014 IF (MAX - Q(N,J)) 510,510,1
0015 510 MAX = Q(N,J)
0016 H*=(N-1)*TDH
0017 1 CONTINUE
0018 MIN = Q(2,J)
0019 LW=TDH
0020 DO 2 N=6,MAXQ,2
0021 IF (MIN - Q(N,J)) 2,2,520
0022 520 MIN = Q(N,J)
0023 LW=(N-1)*TDH
0024 2 CONTINUE
0025 WRITE (6,1010) H*,MAX,LW,MIN
0026 1010 FORMAT(4H H*,F6.3,2X,4H MAX=-E12.5,5X,3HLW=,F6.3,2X,4H MIN=-E12.5)
0027 MEAN=-5*(MAX+ABS(MIN))
0028 WRITE (6,1020) MEAN
0029 1020 FORMAT(7H MEAN =,E12.5)
0030 CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
0031 C TEST IF PUNCHING TO BE DONE AND DC IT IF SO
0032 GO TO (521),PTEST1
0033 C PUNCH VALUES OF VMAX AND TIME OF VMAX
0034 WRITE (7,1005) J,MAX,H*,MIN,LW
0035 1005 FORMAT (13,4E10,3)
0036 521 GO TO (520),PTEST2
0037 C PUNCH Q OR V VS. DISTANCE AT 1.5 HOUR INTERVALS
0038 ST(1)=Q(MAX,J)+Q(NMAX-2,J)/2.0
0039 DO 3 N=2,9
0040 EPS=(N-1)*1.5/TDH)+1.0
0041 IEPS=EPS/2.
0042 NI=2*IEPS
0043 ST(N)=(IEPS-NI)/2.0*(Q(N2,J)-Q(N1,J))+Q(N1,J)
0044 3 CONTINUE
0045 WRITE (7,1006) (ST(I), N=1,9),J

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1006 FORMAT (8E10.3/E10.3,I3)  
CC  
528 RETURN  
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CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
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C   SUBROUTINE WRITE(E,N,J,TDH)
C   THIS SUBROUTINE PRINTS OUTPUTS
C   DIMENSION E(1:22*1)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
T0=(N-1)*TDH
T1=(N+1)*TDH
T2=(N+3)*TDH
T3=(N+5)*TDH
T4=(N+7)*TDH
WRITE (6,1616) T0,E(N+J),T1,E(N+J),T2,E(N+J),T3,E(N+J),T4,E
IN*8,J)
1610 FORMAT (1X,5(F6.3,1X,F15.5,4X))
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
RETURN
END

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0046 1090 FORMAT (5X,4HJMAX,5X,4HMAX,5X,5HCHLEN,6X,4HTCOH)
0047 1100 FORMAT (2I5X,14),2(1X,F10.31)
0048 GO TO (540,550,560),CASE
0049 540 WRITE (6,11101)
0050 WRITE (6,1120)
0051 DO 1 J=1,JMAX
0052 READ (5,1130) D(J),Z0(J),B(J)
0053 DIST=(J-1)*DELTA/5280.
0054 B(J)=B(1)
0055 BSI(J)=B(1)
0056 WRITE (6,1140) DIST,D(J),Z0(J),B(J),BS(J)
0057 1 CONTINUE
0058 1110 FORMAT(39H CASE = 1 UNIFORM RECTANGULAR CHANNEL)
0059 1120 FORMAT (3X,5HMILES,8X,1HD,11X,2HZO,14X,1HB,10X,2HBS)
0060 1130 FORMAT (10X,2F10.5,F10.1)
0061 1140 FORMAT (F10.5,2I2X,F10.5),2(2X,F10.1)
0062 GO TO 570
0063 550 WRITE (6,1150)
0064 WRITE (6,1160)
0065 DO 2 J=1,JMAX
0066 READ (5,1170) D(J),Z0(J),B(J),BS(J)
0067 DIST=(J-1)*DELTA/5280.
0068 WRITE (6,1180) DIST,D(J),Z0(J),B(J),BS(J)
0069 2 CONTINUE
0070 1150 FORMAT(38H CASE = 2 CHANNEL OF IRREGULAR SHAPE)
0071 1160 FORMAT (3X,5HMILES,8X,1HD,11X,2HZO,14X,1HB,10X,2HBS)
0072 1170 FORMAT (10X,2F10.5,2F10.1)
0073 1180 FORMAT (F10.5,2I2X,F10.5),2(2X,F10.1)
0074 GO TO 570
0075 560 WRITE (6,1190)
0076 WRITE (6,1200)
0077 READ (5,1210) SLOPE
0078 DO 3 J=1,JMAX
0079 READ (5,1220) D(J),Z0(J),SS(J),BB(J)
0080 GO TO (561,562), SLOPE
0081 561 SS(J)=SS(1)
0082 ZZ(J)=1.+SS(J)**2
0083 ZZ(J)=SQRT(ZZ(J))
0084 DIST=(J-1)*DELTA/5280.
0085 WRITE (6,1230) DIST,D(J),Z0(J),BB(J),SS(J),ZZ(J)
0086 3 CONTINUE
0087 1190 FORMAT(31H CASE = 3 TRAPEZOIDAL CHANNEL)
0088 1200 FORMAT (3X,5HMILES,8X,1HD,11X,2HZO,13X,2HBB,7X,2HSS,11X,2HZZ)
0089 1210 FORMAT (13)
0090 1220 FORMAT (10X,4F10.5)
0091 1230 FORMAT (F10.5,2(2X,F10.5),2X,F10.1,2I2X,F10.5)
C END OF GEOMETRIC DATA INPUT
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

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0092 C DEFINE OTHER INPUT DATA
0093 C *ROUGH DEFINES THE VARIATION OF MANNING'S COEFFICIENT ALONG THE CHANNEL
0094 C ROUGH = 1, FOR CONSTANT MANNING'S COEFFICIENT ALONG THE CHANNEL
0095 C ROUGH = 2, FOR MANNING'S COEFFICIENT VARIES ALONG THE CHANNEL
0096 C ALL LATERAL FRESH WATER INFLOWS POSITIVE
0097 C FQ(J) DENOTES ADD. FR. WATER DISCH. WITHIN REACH BTW. J & J-1
0098 C *MEND, DESCRIBES WIND EFFECT ON THE CHANNEL
0099 C MEND=1, FOR NO WIND EFFECT
0100 C MEND=2, FOR WIND EFFECT INCLUDED
0101 C V(J) = MAGNITUDE OF VELOCITY OF WIND, POSITIVE WHEN BLOWING UPSTREAM
0102 C PHI(J) = ANGLE OF WIND WITH RESPECT TO LONGITUDINAL DIRECTION
0103 C WAUNT = AIR WEIGHT OF WATER
0104 C ARDEN = AIR DENSITY
0105 C GAMMA = SURFACE WIND COEFFICIENT
0106 C 570 WRITE (6,1240)
0107 C 1240 FORMAT (11H OTHER DATA)
0108 C G = 32.2
0109 C WAUNT = 64.0
0110 C ARDEN = .078
0111 C READ (5,1250) FH
0112 C WRITE (6,1260)
0113 C READ (5,1270) PI,G,EH
0114 C READ (5,1280) ROUGH,MEND
0115 C DO 4 J=1,JMAX
0116 C READ (5,1290) GAMMA
0117 C 4 CONTINUE
0118 C READ (5,1300) MANCO(I),FQ(I),V(I),PHI(I)
0119 C GO TO (580,590),ROUGH
0120 C 580 WRITE (6,1310)
0121 C DO 5 J=2,JMAX,2
0122 C MANCO(J)=MANCO(I)
0123 C 5 CONTINUE
0124 C GO TO 630
0125 C 590 WRITE (6,1320)
0126 C 630 DO 6 J=1,JMAX,2
0127 C MANCO(J) = 0.
0128 C 61 CONTINUE
0129 C GO TO (640,650),MEND
0130 C 640 WRITE (6,1330)
0131 C DO 6 J=2,JMAX,2
0132 C VI(J)=0.
0133 C 6 CONTINUE
0134 C GO TO 660
0135 C 650 WRITE (6,1360)
0136 C DO 7 J=2,JMAX,2
0137 C VCOS = VI(J)*COS(PHI(J))
0138 C VCS = VCS+ABS(VCOS)
0139 C 7 CONTINUE
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0126 V(I,J)=(GAMMA**2)*ARDEN*VCOS/VAUHT
0127 7 CONTINUE
0128 660 WRITE (6,1370)
0129 WRITE (6,1380) VAUHT,GAMMA,ARDEN
0130 WRITE (6,1390)
0131 DO 8 J=1,NPUN
0132 DIST=(J-1)*DELTA/5280.
0133 WRITE (6,1400) DIST,MANCO(J),FOI(J),V(I,J),PHI(J)
0134 8 CONTINUE
0135 1250 FORMAT (F10.7)
0136 1260 FORMAT (3X,2HP1,11X,1MG,11X,2HFH)
0137 1270 FORMAT (312X,F10.7)
0138 1280 FORMAT (13)
0139 1290 FORMAT (F10.5)
0140 1300 FORMAT (10X,F10.7,F10.3,2F10.7)
0141 1310 FORMAT(55H ROUGH = 1 MANNING COEFFICIENT CONSTANT ALONG CHANNEL)
0142 1320 FORMAT(54H ROUGH = 2 MANNING COEFFICIENT DEFINED ALONG CHANNEL)
0143 1330 FORMAT(26H WEND = 1 NO WIND EFFECT)
0144 1340 FORMAT(32H WEND = 2 WIND EFFECT INCLUDED)
0145 1350 FORMAT (3X,5HVAUHT,6X,5HMANCO,11X,2HF0,7X,1HV,10X,3HPHT)
0146 1360 FORMAT (3X,F10.7,2(F10.6))
0147 1370 FORMAT (3X,5HVAUHT,6X,5HMANCO,11X,2HF0,7X,1HV,10X,3HPHT)
0148 1400 FORMAT (F10.5,2X,F10.7,2(F10.7))
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C READ PUNCH PARAMETERS FOR PLOTTING ON I130 COMPUTER
C PTEM(J) = GRAPH NUMBER TO BE PLOTTED AND IN SOME CASES STATION NUMBER, IF
C J = 1 IT DENOTES GRAPH NUMBER, IF J=2 TO 76 IT DENOTES STATION NUMBERS FOR
C GRAPHS TYPE 3+6 AND 9
C JVAL(I,J) = STORAGE FOR STATION NUMBERS (J) TO BE PLOTTED FOR GRAPHS TYPE
C 3+6 AND 9
C PUN(I) = PROGRAM SWITCH INDICATING WHETHER GRAPH (I) IS TO BE PLOTTED,
C PUN(I) = 1 SAYS NO,PUN(I) = 2 SAYS YES
C RF(1) = 1496) NPUN
DD.201 M=1,9
PUN(I)=
201 CONTINUE
JVAL(1,1)=0
JVAL(2,1)=0
JVAL(3,1)=0
IF (NPUN) 745,749,749,745
745 WRITE (7,1030)
WRITE (7,1497) JMAX,NMAX,DELTA,DELTAT
90 202 M=1,NPUN
READ (5,1496)(PTEM(M2), M2=1,76)
WRITE (7,1496)(PTEM(M2), M2=1,26)
M3=PTEM(1)

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0164 PUN(M3)=2
0165 GO TO (202,202,747,202,202,747,202,747),M3
0166 747 M3=M3/3
0167 M5=JVAL(M4,1)
0168 DO 203 M2=2,26
0169 IF (PTEM(M2)) 203,203,748
0170 748 M5=M5+1
0171 JVAL(M4,M5+1)=PTEM(M2)
0172 203 CONTINUE
0173 JVAL(M4,1)=M5
0174 202 CONTINUE
0175 1496 FORMAT (28I3)
0176 1497 FORMAT (13I4,2F10.3)
0177 CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
0178 C SET UP BOUNDARY CONDITIONS AT RIVER END
0179 C 749 WRITE (6,1405)
0180 READ (5,1440) QEND
0181 DO 19 N=2,NMAX,2
0182 Q(N,JMAX)=QEND
0183 19 CONTINUE
0184 WRITE (6,2100) QEND
0185 1405 FORMAT (24H BOUNDARY CONDITION DATA)
0186 2100 FORMAT (12PH CONSTANT RIVER FLOW =,F12.4, 7H C.-F.-S.)
0187 CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
0188 C SET UP OCEAN BOUNDARY CONDITION
0189 *CLASSA1 DEFINES THE OCEAN BOUNDARY CONDITION
0190 CLASSA=1, FOR OCEAN TIDE INPUT FROM TIDE TABLE OR FIELD DATA
0191 CLASSA=2, FOR OCEAN TIDE INPUT OF HARMONIC TYPE
0192 NTRANS = TOTAL NUMBER OF TRANSIENT SOLUTIONS
0193 FOR HARMONIC TIDES
0194 LMAX = TOTAL NUMBER OF HARMONICS TO BE INCLUDED
0195 AMP(1) = AMPLITUDE OF HARMONIC TIDE
0196 T(1) = PERIOD OF HARMONIC TIDE
0197 OMEGA(1) = FREQUENCY OF TIDE
0198 READ (5,1410) CLASSA,LMAX,NTRANS
0199 IF (NTRANS) 744,744,743
0200 743 WRITE (7,1496) NTRANS
0201 744 GO TO (670,680), CLASSA
0202 670 READ (5,1420) (H(N),N=1,NMAX),N=1,NMAX,2)
0203 WRITE (6,1430)
0204 GO TO 745
0205 680 DO 10 L=1,LMAX
0206 READ (5,1440) AMP(L),T(L)
0207 OMEGA(L)=2.*PI/T(L)
0208 10 CONTINUE
0209 DO 11 N=1,NMAX,2
0210 H(N,1)=0.
0211 DO 11 L=1,LMAX

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0199 THETA(I)=OMEGA(I)*(N-I)*DELTA
0200 H(N,I)=H(N,I)*AMPL(I)*SIN(THETA(I,I))
0201 CONTINUE
0202 I1 WRITE (6,1450)
0203 741 WRITE (6,1460) LMAX
0204 741 WRITE (6,1490) LMAX
0205 1410 FORMAT (F10.5)
0206 1420 FORMAT (3H)
0207 1430 FORMAT (3H)
0208 1440-1450-1460-1470-1480-1490-1500-1510-1520-1530-1540-1550-1560-1570-1580-1590-1600-1610-1620-1630-1640-1650-1660-1670-1680-1690-1700-1710-1720-1730-1740-1750-1760-1770-1780-1790-1800-1810-1820-1830-1840-1850-1860-1870-1880-1890-1900-1910-1920-1930-1940-1950-1960-1970-1980-1990-2000-2010-2020-2030-2040-2050-2060-2070-2080-2090-2100-2110-2120-2130-2140-2150-2160-2170-2180-2190-2200-2210-2220-2230-2240-2250-2260-2270-2280-2290-2300-2310-2320-2330-2340-2350-2360
0212 C
0213 C
0214 C
0215 C
0216 C
0217 C
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0230 C
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0232 C
0233 C
0234 C
0235 C
0236 C

THETA(I)=OMEGA(I)*(N-I)*DELTA
H(N,I)=H(N,I)*AMPL(I)*SIN(THETA(I,I))
CONTINUE
WRITE (6,1450)
WRITE (6,1460) LMAX
WRITE (6,1490) LMAX
FORMAT (F10.5)
FORMAT (3H)
FORMAT (3H)
1440-1450-1460-1470-1480-1490-1500-1510-1520-1530-1540-1550-1560-1570-1580-1590-1600-1610-1620-1630-1640-1650-1660-1670-1680-1690-1700-1710-1720-1730-1740-1750-1760-1770-1780-1790-1800-1810-1820-1830-1840-1850-1860-1870-1880-1890-1900-1910-1920-1930-1940-1950-1960-1970-1980-1990-2000-2010-2020-2030-2040-2050-2060-2070-2080-2090-2100-2110-2120-2130-2140-2150-2160-2170-2180-2190-2200-2210-2220-2230-2240-2250-2260-2270-2280-2290-2300-2310-2320-2330-2340-2350-2360
BOUNDARY CONDITION AT OCEAN A DEFINED
DEFINE INITIAL CONDITIONS
745 DO 20 J=3,JMAXH*2
H(I,J)=0.
Q(I,J)=0.
20 CONTINUE
INITIAL CONDITIONS DEFINED
PERFORM OTHER PRELIMINARY COMPUTATIONS
P=1./6.
KNOTS=3600./6080.
D1=DELTA/DELTA
D2= 57(DELTA*G)
D3= 5/DELTA
DTEM=1./D1
TOD=DELTA/1600.
DO 21 J=2,JMAXH*2
IF H(S,L) IN BOTH BODIES OF WATERS TO BE THE SAME, THEN D4(J)=0.
D4(J)=D3*(D1-J)-D1*(J+1)+20*(J-1)-ZD(J+1)
21 CONTINUE
WRITE (6,1500) DELTA,DELTA
COMPUTATION OF CELERITY WITH RESPECT TO MEAN DEPTH
SCEL DENOTES THE CELERITY WITH RESPECT TO THE DEPTH ONLY
WALEN REFERS TO TIDAL WAVE LENGTH
WRITE (6,1520)
WRITE (6,1530)
DO 22 J=1,JMAX
DIST=(J-1)*DELTA/5280.
SCEL(J)=(G*D1(J))**.5
WALEN(J)=SCEL(J)*TCOM/5280.
WRITE (6,1540) DIST,SCEL(J),WALEN(J)
22 CONTINUE
1500 FORMAT (8H DELTA=,2X,F10.5,6HSEC., 7HDELTA=,2X,F10.3,4HFEET)

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0237
0238
0239
0240
1510 FORMAT(15H DELTAX/DELTAT=F10,S.9H FT./SEC.)
1520 FORMAT(13H CELERITY WITH RESPECT TO DEPTH ONLY)
1530 FORMAT(3X,5HILES,8X,4HSCAL,6X,5HMALEN)
1540 FORMAT(F10,12X,F10,3,2X,F10,5)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C TIDAL PROPAGATION COMPUTATION BEGINS
C H DENOTES HEIGHT OF TIDAL ELEVATION ABOVE MEAN WATER SURFAC (FT.)
C U DENOTES TOTAL DISCHARGE ACROSS THE COMPLETE CROSS-SECTION(CFS)
C PHIN(J) = HIN(J) OF TIDAL FLOW ACROSS THE SECTION (FT./SEC.)
C N REFERS TO TIME
C J REFERS TO POSITION ALONG THE CHANNEL
WRITE (6,1560)
1560 FORMAT (77719H COMPUTATION BEGINS)
K=K+1
88888 K=K+1
WRITE (6,1570) K
1570 FORMAT (4H K =,I3)
750 CALL COMP
IF (K-1) 44444,820,810
C COMPARE 'H' VALUES OVER COMPLETE TIDAL CYCLE TO CHECK IF QUASI-STEADY
C SOLUTION HAS BEEN OBTAINED
810 DO 26 N=1,NMAXH,2
DO 26 J=1,JMAXH,2
IF (ABS(HIN(J)-PHIN(J))-.EH) 26,26,820
26 CONTINUE
C QUASI-STEADY SOLUTION HAS BEEN OBTAINED
WRITE (6,1580) K
1580 FORMAT(13H STABLE AFTER,16,2X,6HCYCLES)
WRITE (6,1491) NTRANS
1491 FORMAT (* NUMBER OF TRANSIENT SOLUTIONS REQUIRED = ,I3)
K=0
GO TO 44444
C DEFINE PHIN(J) FOR NEXT COMPARISON
820 DO 27 N=1,NMAXH,2
DO 27 J=1,JMAXH,2
PHIN(J)=HIN(J)
27 CONTINUE
C REDEFINE THE INITIAL CONDITIONS FOR NEXT TIDAL CYCLE COMPUTATION
DO 28 J=1,JMAXH,2
H(1,J)=H(NMAXH,J)
28 CONTINUE
DO 29 J=2,JMAXQ,2
Q(2,J)=Q(NMAXQ,J)
29 CONTINUE
C INITIAL CONDITION REDEFINED FOR QUASI-STEADY STATE SOLUTION ONLY
IF (K-30) 88888,840,840

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0308 WRITE (6,1660)
0309 FORMAT(/31H VARIATIONS OF Q ARE AS FOLLOWS)
0310 DO 39 J=2,JMAXQ,2
0311 DIST=(J-1)*DELTAQ/5280.
0312 WRITE (6,1640) DIST,J
0313 WRITE (6,1670)
0314 FORMAT (1X,5I4,3HR.,9X,6H0(N,J),4X)
0315 DO 40 N=2,NMAXQ,10
0316 CALL WRITE(Q,N,J,TDH)
0317
0318 CALL HAMIQU(Q,N,J,NMAXQ,TDH)
0319
C
0320
0321 PUNCH NECESSARY CARD OUTFUTS OF 'Q' FOR PLOTTING ON 1130 COMPUTER
0322 DO 392 M=1,M2
0323 M3=JVAL(2,M+1)
0324 WRITE (7,1655)(Q(N,M3), N=2,NEQ,2)
0325
0326
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C THIS SUBROUTINE COMPUTES 'H' AND 'Q' BY ALTERNATE USES OF CONTINUITY
SUBROUTINE COMP
AND MOMENTUM EQUATIONS
REAL MANDQ,KB,KNOTS
INTEGER CLASSA,CASE,ROUGH,SLOPF,PUM,PTER,MEMD
INTEGER PTEST1,PTEST2
COMMON PTEST1,PTEST2
COMMON N1,J,JMAX,NMAX,JMAXH,JMAXQ,NMAXH,NMAXQ,NEG,JJTEM
COMMON KNOTS,CLASSA,CASE,ROUGH
COMMON DELTAT,DELTA X,DI ST,TDH,TCOM,CHLEN
COMMON P,G,DI,DZ,DB,DTEN
COMMON M,M2,M3,M,M5
COMMON PTEM(26),PUNI(9),JVAL(3,26),NPUW
COMMON AF(60),B(60),BS(60),D(60),ZD(60),WP(60),R(60),C(60)
COMMON BB(60),SS(60),Z(60)
COMMON MAYCO(60),FQ(60),VF(60),PHI(60),M(60),D(60)
COMMON HI1282,201,DI1282,201
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
DO 23 NN=3,NMAXH,2
N=NN
DO 24 J=3,JMAXH,2
FRDIS = FQ(J)+FQ(J+1)
GO TO (770,770,760),CASE
760 R(J)= RB(J)+ 2*(DI(J)+H(N-2,J))*SS(J)
770 H(N,J)=H(N-2,J)-I*(N-1,J)*1-Q(N-1,J-1)-FRDIS I*DI/8(J)
24 CONTINUE
N=NN+1
DO 25 I=2,JJTEM,2
GO TO (790,790,780),CASE
780 WFER=DI(J)+5*(H(N-1,J-1)+H(N-1,J+1))
R(J)= RB(J)+2*(HTEM*SS(J)
R(J)= RB(J)+HTEM*SS(J)
M(J)= BS(J)+HTEM
MP(J)= RB(J)+2*(HTEM*ZZI(J)
GO TO 800
790 A(J)=BS(J)+DI(J)+5*(H(N-1,J+1)+H(N-1,J-1))
800 R(J)=2*(DI(J)+BS(J)+H(N-1,J+1)+H(N-1,J-1))
C(J)=1.486*(R(J)**P)/MANCO(J)
E1=DZ/A(J)
E2= 5/(C(J)**2)*(A(J)**2)*R(J)
E3=(B(J)+BS(J))/(C*(A(J)**2))
E4=25*(H(N-1,J+1)+H(N-1,J-1)-H(N-3,J+1)-H(N-3,J-1))/DELTAT
E5=FRDIS/(G*(A(J)**2))
Q(N,J)=(O(N-2,J)+E1-E5)*ABS(Q(N-2,J))+E2+E3+E4-E5+D3*(H(N-1,J-1)-

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I(N=1-J))W(J)/R(J)+D4(J)/E1+E2\*ABS(Q(N-2,J))  
25 CONTINUE  
23 CONTINUE  
CC  
RETURN  
END

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0045  
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II-40

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0044

3 CONTINUE  
WRITE (7,106) (STC(I), N=1,9),J  
106 FORMAT (BE10.3/E10.3,I3)  
CC  
528 RETURN  
END

II-12



41

1006 FORMAT (SEIO, 2/EIO, 3, 13)  
CC  
528 RETURN  
END

0040  
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II-44

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CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C   SUBROUTINE WRITE(E,N,J,TDH)
C   THIS SUBROUTINE PRINTS OUTPUTS
C   DIMENSION E(1282,1)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
TDH=IN-11*TDH
T1=IN+11*TDH
T2=IN+31*TDH
T3=IN+51*TDH
T4=IN+71*TDH
WRITE (6,1010) T0,E(IN,J),T1,E(N+2,J),T2,E(IN+4,J),T3,E(IN+6,J),T4,EI
IN*8,J)
1610 FORMAT (1X,5I6.3,1X,F15.5,4X)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
RETURN
END

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0029      1030 FORMAT (80H
0030      1040 FORMAT(16H COMPUTATION NO.,I3)
C          CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C          DEFINE IMPORTANT INTEGER VARIABLES
C          READ (5,1009) JMAX,NMAX
0031      JMAXH = JMAX
0032      JMAXQ = JMAX - 1
0033      NMAXH = NMAX
0034      NMAXQ = NMAX + 1
0035      NEQ = NMAXQ - 2
0036      JJTEM = JMAXH - 2
0037      ITRANS = 0
0038      ITRANS = 0
0039      1009 FORMAT (13/I4)
C          CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C          DEFINE GEOMETRIC AND GENERAL INPUT DATA
C          *CASE* DEFINES THE TYPE OF CHANNEL AFTER SCHEMATIZATION
C          CASE=1, FOR UNIFORM RECTANGULAR CHANNEL
C          CASE=2, FOR IRREGULARLY SHAPED CHANNEL
C          CASE=3, FOR TRAPEZOIDAL CHANNEL
C          ALL TIDAL ELEVATIONS REFER TO AN ASSUMED INITIAL WATER SURFACE, NOT
C          NECESSARILY THE MEAN WATER PLANE
C          ALL WATER DEPTHS MEASURED FROM ASSURED INITIAL WATER SURFACE TO BOTTOM
C          CHLEN = CHANNEL LENGTH IN HILES
C          CHANNEL LENGTH IS TAKEN UP TO HEAD OF TIDE AND DIVIDED INTO (JMAX-1)
C          SEGMENTS
C          TCOM = TIDAL PERIOD IN SECONDS
C          DIST = CHAINAGE OF THE CHANNEL
C          WP(I,J) = WETTED PERIMETER, R(I,J) = HYDRAULIC RADIUS, C(I,J) = CHEZY'S COEFF.
C          FOR IRREGULAR CHANNEL
C          AL(J) = AREA, DL(J) = DEPTH OF CHANNEL, ZD(J) = HEIGHT BETWEEN CHANNEL
C          BOTTOM AND HORIZONTAL REFERENCE DATUM
C          BL(J) = FULL WIDTH OF CHANNEL, BS(J) = WIDTH OF EFFECTIVE CHANNEL FOR TIDAL
C          FLOW
C          FOR EXPONENTIAL CHANNEL
C          BD = WIDTH OF CHANNEL AT ENTRANCE, KE = EXPONENTIAL COEFFICIENT DEFINING
C          THE REDUCTION OF WIDTH IN CHANNEL, B(I) = BS(J)
C          *SLOPE* REFERS TO SLOPE OF TRAPEZOIDAL CHANNEL ONLY
C          SLOPE=1, CONSTANT SIDE SLOPE
C          SLOPE=2, VARYING SIDE SLOPE
C          SS(I,J) = VERTICAL HEIGHT OF SIDE SLOPE OVER UNIT DISTANCE HORIZONTALLY
C          ZZ(I,J) = LENGTH ALONG THE SLOPE OVER UNIT DISTANCE HORIZONTALLY
C          BS(I,J) = BOTTOM WIDTH OF TRAPEZOIDAL CHANNEL
C          READ (5,1050) CHLEN,CASE,TCOM
0040      WRITE (6,1060)
0041      WRITE (6,1090)
0042      WRITE (6,1090)
0043      WRITE (6,1100) JMAX,NMAX,CHLEN,TCOM

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0044 DELTAT=ICOM/(NMAX-1)
0045 DELTAX=CLEN*5280./JMAX-1)
0046 FORMAT (F12.3,F10.3)
0047 FORMAT (13M GEOMETRIC DATA)
0048 FORMAT (5X,4HJMAX,5X,4HAPAX,5X,5HCLEN,6X,4HICOM)
0049 FORMAT (2F5.1,F10.2,F10.3)
0050 GO TO (540,550,560),CASE
0051 WRITE (6,1110)
0052 WRITE (6,1120)
0053 CO 1 J=1,JMAX
0054 HEAD (5,1130) D(I),Z(I),B(I)
0055 DIST=(J-1)*DELTAX/5280.
0056 B(I)=B(1)
0057 B(I)=B(1)
0058 WRITE (6,1140) DIST,D(I),Z(I),B(I),B(I)
0059 1 CONTINUE
0060 1110 FORMAT(39H CASE = 1 UNIFORM RECTANGULAR CHANNEL)
0061 1120 FORMAT (3X,5HFILES,8X,1HD,11X,2HZC,14X,1HD,10X,2HRS)
0062 1130 FORMAT (10X,2F10.5,F10.1)
0063 1140 FORMAT (F10.5,2I2X,F10.5),2(F10.1)
0064 GO TO 570
0065 550 WRITE (6,1150)
0066 WRITE (6,1160)
0067 CO 2 J=1,JMAX
0068 READ (5,1170) D(I),Z(I),B(I),B(I)
0069 DIST=(J-1)*DELTAX/5280.
0070 WRITE (6,1180) DIST,D(I),Z(I),B(I),B(I)
0071 2 CONTINUE
0072 1150 FORMAT(39H CASE = 2 CHANNEL OF IRREGULAR SHAPE)
0073 1160 FORMAT (3X,5HFILES,8X,1HD,11X,2HZC,14X,1HD,10X,2HRS)
0074 1170 FORMAT (10X,2F10.5,F10.1)
0075 1180 FORMAT (F10.5,2I2X,F10.5),2I2X,F10.1)
0076 GO TO 570
0077 560 WRITE (6,1190)
0078 WRITE (6,1200)
0079 READ (5,1210) SLOPE
0080 CO 3 J=1,JMAX
0081 READ (5,1220) D(I),Z(I),SS(I),B(I)
0082 GO TO (561,562), SLOPE
0083 561 SS(I)=SS(1)
0084 Z(I)=1.+SS(I)**2
0085 Z(I)=SQRT(Z(I))
0086 DIST=(J-1)*DELTAX/5280.
0087 WRITE (6,1230) DIST,D(I),Z(I),B(I),SS(I),Z(I)
0088 3 CONTINUE
0089 1190 FORMAT(31H CASE = 3 TRAPEZOIDAL CHANNEL)
0090 1210 FORMAT (3X,5HFILES,8X,1HD,11X,2HZC,13X,2HHD,7X,2HSS,11X,2HFI)
0091 1230 FORMAT (13)

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0093
1220 FORMAT (10X,4F10.5)
1230 FORMAT (F10.5,2I2X,F10.5),2X,F10.1,2(I2X,F10.5))
C
C END OF GEOMETRIC DATA INPUT
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C DEFINE OTHER INPUT DATA
C
C *ROUGH* DEFINES THE VARIATION OF MANNING'S COEFFICIENT ALONG THE CHANNEL
C *ROUGH = 1, FOR CONSTANT MANNING'S COEFFICIENT ALONG THE CHANNEL
C *ROUGH = 2, FOR MANNING'S COEFFICIENT VARIES ALONG THE CHANNEL
C ALL LATERAL FRESH WATER INFLOWS POSITIVE
C *FQ(J) DENOTES ADD. FR. WATER DISCH. WITHIN REACH BETWEEN J & J-1
C *WEND* DESCRIBES WIND EFFECT ON THE CHANNEL
C *WEND=1, FOR NO WIND EFFECT
C *WEND=2, FOR WIND EFFECT INCLUDED
C *V(I,J) = MAGNITUDE OF VELOCITY OF WIND, POSITIVE WHEN BLOWING UPSTREAM
C *PHI(I,J) = ANGLE OF WIND WITH RESPECT TO LONGITUDINAL DIRECTION
C *WAUMT = UNIT WEIGHT OF WATER
C *ARDEN = AIR DENSITY
C *GAMMA = SURFACE WIND COEFFICIENT
C
570 WRITE (6,1240)
1240 FORMAT (11P,10F10.2)
G = 32.2
WAUMT = 64.0
ARDEN = .078
READ (5,1250) EH
WRITE (6,1260)
WRITE (6,1270) PI,G,EH
READ (5,1280) ROUGH,WEND
READ (5,1290) GAMMA
GO 4 J=1,JMAX
READ (5,1300) MANCC(I),FQ(J),V(I),PHI(I)
4 CONTINUE
GO TO (580,590),ROUGH
580 WRITE (6,1310)
GO 5 J=2,JMAX,2
MANCC(J)=MANCC(I)
5 CONTINUE
GO TO 630
590 WRITE (6,1320)
630 DC 61 J=1,JMAX,2
MANCC(J) = 0.
61 CONTINUE
GO TO (640,650),WEND
640 WRITE (6,1350)
DC 6 J=2,JMAX,2
PHI(J)=0.
6 CONTINUE
GO TO 660

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0124 650 WRITE (6,1360)
0125 DO 7 J=2,JMAXQ,2
0126 VCS = V(J)*COS(PHI(J))
0127 VCS = VCS*ABS(VCS)
0128 W(J)=(GAMMA**2)*ARDEN*VCS/WAUMT
0129 7 CONTINUE
0130 660 WRITE (6,1370)
0131 WRITE (6,1380) WAUMT,GAMMA,ARDEN
0132 WRITE (6,1390)
0133 DO 8 J=1,JMAX
0134 DIST=(J-1)*DELTAX/5280.
0135 WRITE (6,1400) DIST,MANCO(J),FQ(J),V(J),PHI(J)
0136 8 CONTINUE
0137 1250 FORMAT (F10.7)
0138 1260 FORMAT (3X,2HP1,1X,1HG,1X,2HEH)
0139 1270 FORMAT (3(2X,F10.7))
0140 1280 FORMAT (13)
0141 1290 FORMAT (E10.5)
0142 1300 FORMAT (10X,F10.7,F10.3,2F10.7)
0143 1310 FORMAT(55H ROUGH = 1 MANNING COEFFICIENT CONSTANT ALONG CHANNEL)
0144 1320 FORMAT(54H ROUGH = 2 MANNING COEFFICIENT DEFINED ALONG CHANNEL)
0145 1330 FORMAT(26H WEND = 1 NO WIND EFFECT)
0146 1340 FORMAT(32H WEND = 2 WIND EFFECT INCLUDED)
0147 1350 FORMAT (3X,5HWAUMT,6X,5HMANCO,11X,2HFC,7X,1HV,10X,3HPH1)
0148 1360 FORMAT (3X,F10.7,2(1X,E10.4))
0149 1370 FORMAT (3X,5HMILES,5X,5HMANCO,11X,2HFC,7X,1HV,10X,3HPH1)
0150 1400 FORMAT (F10.5,2X,F10.7,2X,F10.3,2(2X,F10.7))
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C READ PUNCH PARAMETERS FOR PLOTTING ON 1130 COMPUTER
C NPUN = TOTAL NUMBER OF GRAPHS TO BE PLOTTED
C PTEM(J) = GRAPH NUMBER TO BE PLOTTED AND IN SOME CASES STATION NUMBER, IF
C J = 1 IT DENOTES GRAPH NUMBER, IF J=2 TO 26 IT DENOTES STATION NUMBERS FOR
C GRAPHS TYPE 3,6 AND 9
C JVAL(I,J) = STORAGE FOR STATION NUMBERS (JI TO BE PLOTTED FOR GRAPHS TYPE
C 3,6,AND 9
C PUN(M) = PROGRAM SWITCH INDICATING WHETHER GRAPH IMI IS TO BE PLOTTED,
C PUN(M) = 1 SAYS NO,PUN(M) = 2 SAYS YES
C READ (5,1496) NPUN
C DO 201 M=1,9
C PUN(M)=1
201 CONTINUE
C JVAL(1,1)=0
C JVAL(2,1)=0
C JVAL(3,1)=0
C IF (NPUN) 745,749,746
745 WRITE (7,1030)
746 WRITE (7,1497) JMAX,NMAX,DELTAX,DELTAT
WRITE (7,1496) NPUN
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0162 DO 202 M=1,NPUN
0163 READ (5,1496)(PTEM(M2), M2=1,26)
0164 WRITE (7,1496)(PTEM(M2), M2=1,26)
0165 M3=PTEM(1)
0166 PUN(M3)=2
0167 GO TO (202,202,747,202,747,202,747,202,747),M3
0168 747 M3=M3/3
0169 M5=JVAL(M4,1)
0170 DO 203 M2=2,26
0171 IF (PTEM(M2)) 203,203,748
0172 748 M5=M5+1
0173 JVAL(M4,M5+1)=PTEM(M2)
0174 203 CONTINUE
0175 JVAL(M4,1)=M5
0176 202 CONTINUE
0177 1496 FORMAT (I3,I4,2F10.3)
0178 1497 FORMAT (I3,I4,2F10.3)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C *CLASSA* DEFINES OCEAN BOUNDARY CONDITION FOR OCEAN A
C OCEAN A AT X = 0
C CLASSA=1, FOR OCEAN TIDE INPUT FROM TIDE TABLE OR FIELD DATA
C CLASSA=2, FOR OCEAN TIDE INPUT OF HARMONIC TYPE
C *CLASSB* DEFINES OCEAN BOUNDARY CONDITION FOR OCEAN B
C OCEAN B AT X = CHLEN
C CLASSB=1, FOR OCEAN TIDE INPUT FROM TIDE TABLE OR FIELD DATA
C CLASSB=2, FOR OCEAN TIDE INPUT OF HARMONIC TYPE
C NTRANS = TOTAL NUMBER OF TRANSIENT SOLUTIONS
C CONDI = 1, FOR CHANNEL CONNECTING AN OCEAN AND A LAKE OF CONSTANT WATER
C LEVEL
C CONDI = 2, FOR CHANNEL CONNECTING TWO OCEANS
C FOR CONDI = 2, THE LAKE WATER LEVEL IS ASSUMED TO BE ZERO TIDAL STAGE
C FOR HARMONIC TIDES AT OCEAN A
C LMAX = TOTAL NUMBER OF HARMONICS TO BE INCLUDED
C AMP(L) = AMPLITUDE OF HARMONIC TIDE
C T(L) = PERIOD OF HARMONIC TIDE
C OMEGA(L) = FREQUENCY OF TIDE
C FOR HARMONIC TIDES AT OCEAN B
C LMAXL = TOTAL NUMBER OF HARMONICS TO BE INCLUDED
C AMPL(L) = AMPLITUDE OF HARMONIC TIDE
C TL(L) = PERIOD OF HARMONIC TIDE
C OMEGL(L) = FREQUENCY OF TIDE
C PHADI = INTEGER NUMBER DENOTING THE PHASE LAG BETWEEN TWO OCEANS IN TERMS
C OF DELTA T, FOR HARMONIC TIDES ONLY
C 749 WRITE (6,1405)
C READ (5,1410) CLASSA,CLASSB,PHADI,LMAX,LMAXL,NTRANS,CONDI
C IF (NPUN) 744,744,743
C 743 WRITE (7,1496) NTRANS

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0183 744 GO TO (670,680), CLASSA
0184 670 READ (5,1420) (H(N,1), N=1,NMAXH,2)
0185 WRITE (6,1430)
0186 GO TO 690
0187 DO 10 L=1,LMAX
0188 READ (5,1440) AMP(L),T(L)
0189 OMEGA(L)=2.*PI/T(L)
0190 CONTINUE
0191 DO 11 N=1,NMAXH,2
0192 HH(N)=0.
0193 DO 11 L=1,LMAX
0194 THETA(L)=OMEGA(L)*(N-1)*DELTAT
0195 H(N,1)=H(N,1)+AMP(L)*SIN(THETA(L))
0196 CONTINUE
0197 WRITE (6,1450)
C BOUNDARY CONDITION AT OCEAN A DEFINED
0198 690 GO TO (700,710),COND1
0199 700 DO 12 N=1,NMAXH,2
0200 H(N,JMAXH)=0.
0201 CONTINUE
0202 WRITE (6,1498)
0203 GO TO 745
0204 710 GO TO (720,730),CLASSB
0205 720 READ (5,1420) (H(N,JMAXH), N=1,NMAXH,2)
0206 WRITE (6,1460)
0207 GO TO 745
0208 DO 14 L=1,LMAXL
0209 READ (5,1440) AMPL(L),TL(L)
0210 OMEGL(L)=2.*PI/TL(L)
0211 CONTINUE
0212 DO 15 N=1,NMAXH,2
0213 HH(N,JMAXH)=0.
0214 DO 15 L=1,LMAXL
0215 THETA(L)=OMEGL(L)*(N-1)*DELTAT
0216 H(N,JMAXH)=H(N,JMAXH)+AMPL(L)*SIN(THETA(L))
0217 CONTINUE
0218 DO 16 N=1,NMAXH,2
0219 HH(N)=HH(N,JMAXH)
0220 CONTINUE
0221 NP=NMAXH-PHADI
0222 DO 17 N=1,NP,2
0223 NPH=N+PHADI
0224 HH(N,JMAXH)=HH(N)
0225 CONTINUE
0226 DO 18 N=NP,NMAXH,2
0227 NPN=N+1-NP
0228 H(NPN,JMAXH)=HH(N)
0229 CONTINUE

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0267 SCEL(J)=(GSD(J))**.5
0268 MALEN(J)=SCEL(J)*TCOM/5280.
0269 WRITE (6,1540) DIST,SCEL(J),MALEN(J)
0270
0271 22 CONTINUE
0272 1500 FORMAT(8H DELTAT=,2X,F10.5,6HSEC.,7HDELTA=,2X,F10.3,4HFEEET)
0273 1510 FORMAT(15H DELTAX/DELTAT=,F10.5,9H FT./SEC.)
0274 1520 FORMAT (36H CELERITY WITH RESPECT TO DEPTH ONLY)
0275 1530. FORMAT (3X,5HILES,8X,4HSECEL,6X,5HMALEN)
      1540. FORMAT (F10.5,2X,F10.3,2X,F10.5)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
TIDAL PROPAGATION COMPUTATION BEGINS
C H DENOTES HEIGHT OF TIDAL ELEVATION ABOVE MEAN WATER SURFAC (FT.)
C Q DENOTES TOTAL DISCHARGE ACROSS THE COMPLETE CROSS-SECTION(CFS)
C U DENOTES AV. VELOCITY OF TIDAL FLOW ACROSS THE SECTION (FT./SEC.)
C PH(N,J) = H(N,J) OF THE PREVIOUS TIDAL CYCLE
C N REFERS TO TIME
C J REFERS TO POSITION ALONG THE CHANNEL
      1560 FORMAT (//19H COMPUTATION BEGINS)
      K=0
80888 K=K+1
      WRITE (6,1570) K
1570 FORMAT (5H K =,I3)
750 CALL COMP
      IF (K-1) 4444,820,810
      COMPARE 'H' VALUES OVER COMPLETE TIDAL CYCLE TO CHECK IF QUASI-STEADY
      SOLUTION HAS BEEN OBTAINED
      DO 26 N=1,NMAXH,2
      IF (ABS(H(N,J)-PH(N,J))-EH) 26,26,820
26 CONTINUE
      QUASI-STEADY SOLUTION HAS BEEN OBTAINED
      WRITE (6,1580) K
1580 FORMAT(13H STABLE AFTER,16,2X,6HCYCLES)
1491 FORMAT (' NUMBER OF TRANSIENT SOLUTIONS REQUIRED = ',I3)
      K=0
      GO TO 4444
      DEFINE PH(N,J) FOR NEXT COMPARISON
      DO 27 N=1,NMAXH,2
      DO 27 J=1,JMAXH,2
      PH(N,J)=H(N,J)
27 CONTINUE
      REDEFINE THE INITIAL CONDITIONS FOR NEXT TIDAL CYCLE COMPUTATION
      DO 28 J=1,JMAXH,2
      H(1,J)=H(NMAXH,J)
28 CONTINUE
0300

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0301      DO 29 J=2,JMAXC,2
0302      Q(2,J)=Q(NMAXC,J)
0303      29 CONTINUE
0304      C      INITIAL CONDITION REDEFINED FOR QUASI-STEADY STATE SOLUTION ONLY
0305      IF (K-30) 88888,840,840
0306      840 WRITE (6,1590)
0307      1590 FORMAT(54H QUASI-STEADY STATE SOLUTION NOT OBTAINED BY 30 CYCLES)
           GO TO 33333
0308      C      END OF QUASI-STEADY COMPUTATION
0309      CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
0310      C      TRANSIENT SOLUTION BEGINS
           Q(I,J) = DISCHARGE VALUES RETAINED FOR NEXT TIDAL CYCLE COMPUTATION
           44444 DO 62 J=2,JMAXC,2
           62 CONTINUE
           CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
           C      WRITE OUTPUT AND PUNCH OUTPUT CARDS FOR PLOTTING
           WRITE (6,1600)
           1600 FORMAT(//21H OUTPUT IS AS FOLLOWS)
           IF (ITRANS) 860,860,870
           860 WRITE (6,2030)
           2030 FORMAT (//33H QUASI-STEADY SOLUTION AS FOLLOWS)
           GO TO 880
           870 WRITE (6,2040) ITRANS
           2040 FORMAT (//25H TRANSIENT SOLUTION CYCLE,18)
           CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
           880 WRITE (6,1630)
           1630 FORMAT (//31H VARIATIONS OF H ARE AS FOLLOWS)
           1640 FORMAT(26H DISTANCE FROM OCEAN END A,F10.5,2X,4HILE,5X,2HJ=,13)
           PTEST1=PUN(1)
           PTEST2=PUN(2)
           DO 35 J=1,JMAXH,2
           DIST=(J-1)*DELTA X/5280.
           WRITE (6,1640) DIST,J
           WRITE (6,1650)
           1650 FORMAT (1X,514X,3HHR.,9X,6HH(N,J),4X1)
           DO 36 N=1,NMAXH,12
           CALL WRITE(H,N,J,TDH)
           36 CONTINUE
           CALL MAH(H,N,J,NMAXH,TDH)
           35 CONTINUE
           C      PUNCH NECESSARY CARD OUTPUTS OF 'H' FOR PLOTTING ON I130 COMPUTER
           M2=JVAL(1,1)
           IF (M2) 353,353,351
           351 DO 352 M=1,M2
           M3=JVAL(1,M+1)
           WRITE (7,1655) (H(N,M3), N=1,NMAXH,2)
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0381 DIST = (J-1)*DELTA X/5280.
0382 WRITE (6,1640) DIST,J
0383 WRITE (6,1690)
0384 FORMAT (1X,5(4X,3HHR.,9X,6HU(N,J),4X))
0385 DO 46 N=2,NEQ,12
0386 CALL WRITE(Q,N,J,TDH)
0387 CONTINUE
0388 CALL MAMQUIC(N,J,NEQ,TDH)
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DIST = (J-1)*DELTA X/5280.
WRITE (6,1640) DIST,J
WRITE (6,1690)
FORMAT (1X,5(4X,3HHR.,9X,6HU(N,J),4X))
DO 46 N=2,NEQ,12
CALL WRITE(Q,N,J,TDH)
CONTINUE
CALL MAMQUIC(N,J,NEQ,TDH)
C PUNCH NECESSARY CARD OUTPUTS OF 'U' FOR PLOTTING ON 1130 COMPUTER
11111 M2=JVAL(3,1)
IF (M2) 850,850,451
451 DO 452 M=1,M2
M3=JVAL(3,M+1)
WRITE (7,1655)(Q(N,M3), N=2,NEQ,2)
452 CONTINUE
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
PREPARE FOR TRANSIENT SOLUTION
850 IF (NTRANS - ITRANS) 453,453,851
851 ITRANS=ITRANS+1
C REDEFINE INITIAL CONDITIONS
DO 291 J=1,JMAXH,2
H(1,J)=MINMAXH,J
291 CONTINUE
DO 292 JT=2,JMAXQ,2
Q(2,J)=Q(1,J)
292 CONTINUE
C
DEFINE NEW BOUNDARY CONDITIONS AT OCEAN END
READ (5,1420) DUMH, IH(N,1), N=3,NMAXH,2)
READ (5,1420) DUMH, IH(N,JMAXH), N=3,NMAXH,2)
GO TO 750
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
GO TO NEXT CASE
453 GO TO 99955
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
QUASI-STEADY SOLUTION NOT OBTAINED AFTER 30 TIDAL CYCLES. READJUST
C DT VALUES FOR NEW COMPUTATION
33333 CALL EXIT
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
END

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CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C THIS SUBROUTINE COMPUTES 'H' AND 'Q' BY ALTERNATE USES OF CONTINUITY
SUBROUTINE COMP
REAL MANG,KB,KNOTS
INTEGER CLASSA,CASE,ROUGH,SLOPE,PUN,PTEN,WEND
INTEGER PTEST1,PTEST2
COMMON N,J,JMAX,NMAX,JMAXH,JMAXQ,NMAXH,NMAXQ,REQ,JJTEM
COMMON KNOTS,CLASSA,CASE,ROUGH
COMMON DELTAT,DELTA,DIS,TDH,TCOM,CHLEN
COMMON P,G,D1,D2,D3,DTM
COMMON M,M2,M3,M4,M5
COMMON PTEI(26),PUN(9),JVAL(3,26),NPUN
COMMON A(60),R(60),BS(60),D(60),ZD(60),HP(60),R(60),C(60)
COMMON QB(60),SS(60),Z(60)
COMMON MANG(60),FQ(60),V(60),PHI(60),M(60),D4(60)
COMMON H(128,20),F(128,20)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
DD 23 NN=3,NMAX,72
N=NN
DD 24 J=3,JJTEM,2
PROIS = FQ(J)*FQ(J+1)
GO TO (770,770,760),CASE
760 B(J)= BB(J)+ 2.*ID(J)*H(N-2,J))*SS(J)
770 H(N,J)=H(N-2,J)-IQ(N-1,J+1)-Q(N-1,J-1)-PROIS)*D1/B(J)
24 CONTINUE
N=NN+1
DD 25 J=2,JMAXQ,2
GO TO (790,790,780),CASE
780 HTEM=D(J)+.5*(H(N-1,J-1)+H(N-1,J+1))
B(J)= BB(J)+2.*HTEM*SS(J)
BS(J)= BB(J)+HTEM*SS(J)
A(J)=BS(J)*HTEM
HP(J)= BB(J)+2.*HTEM*ZZ(J)
GO TO 800
790 A(J)=BS(J)*ID(J)+.5*(H(N-1,J+1)+H(N-1,J-1))
HP(J)=2.*D(J)+BS(J)+H(N-1,J+1)+H(N-1,J-1)
800 R(J)=A(J)/HP(J)
C(J)=1+.66*(R(J)*HP(J)/MANG(J))
E1=D2/A(J)
E2=.5/(C(J)+2)*A(J)*2)*R(J)
E3=18(J)+BS(J)/(G*(A(J)+2))
E4=.25*(H(N-1,J-1)+H(N-1,J+1)-H(N-3,J+1)-H(N-3,J-1))/DELTAT
PROIS=(FQ(J)*FQ(J+1))/I2*DELTA
E5=PROIS/(G*(A(J)+2))
Q(N,J)=IQ(N-2,J)+E1)*E2+E3+E4+E5)+D3*(H(N-1,J-1)-

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1MCH-1 \*J\*J1) \*W\* J1) \*R1) \*O\* J1) / (E1 \*E\*H\*BS (Q1M-2, J1))  
25 CONTINUE  
23 CONTINUE  
CC  
RETURN  
END

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3 CONTINUE  
WRITE (7, IUB6) (SIGIN), N=1,91,J  
1006 FORMAT (BEID,3/EID,3,I3)  
CC  
528 RETURN  
END

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0044



1006 FORMAT 1#E10,2/E10,3,131  
CC  
520 RETURN  
END

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C      THIS SUBROUTINE PRINTS OUTPUTS
C      DIMENSION E(12E2,1)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
T0=(N-1)*TDH
T1=(N+1)*TDH
T2=(N+3)*TDH
T3=(N+5)*TDH
T4=(N+7)*TDH
WRITE (6,1610) T0,E(N,J),T1,E(N+2,J),T2,E(N+4,J),T3,E(N+6,J),T4,E
(N+8,J)
1610 FORMAT (1X,5(F6-3,1X,F15.5,4X))
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
RETURN
END

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#### D. Brief Discussions on Preparation of Input Data

##### Choice of $\Delta x$ and $\Delta t$ :

The choice of  $\Delta x$  and  $\Delta t$  are governed by the following three criteria:

- (1) The nature of the tidal problem to be solved.
- (2) The size of computer storage available for the particular computer used.
- (3) The stability criteria necessary to guarantee a stable solution  
(Equations 76 and 77).

Since the objective is to obtain a meaningful solution, the first criterion is no doubt the most important one. However, the nature of an explicit scheme is such that  $\Delta x$  is more critical than  $\Delta t$  for practical problems. Under normal circumstances, the computer programs will provide solutions at an interval of  $2\Delta t$  which is smaller than that required for practical problems.

After the approximate magnitude of  $\Delta x$  has been chosen according to the nature of the problem, the second and third criteria will assist the engineer to decide whether the particular computer chosen by the engineer is capable of handling the problem or not.

It is necessary to limit the present discussion to a fairly general manner as the nature of each tidal problem varies considerably from one to another. An example showing how the magnitudes of  $\Delta x$  and  $\Delta t$  have been determined in the case of the proposed sea-level Panama Canal is given in Appendix VII of Reference No. 18.

##### Preparation of Geometric Data

For natural tidal channels, the geometry of irregular shape should normally be adopted. However, in case of an estuary such as the Delaware Estuary, it is possible to simplify the preparation of the geometric data by assuming that the tidal channel possesses the geometry of a rectangular channel of exponentially varying width. For the geometry of irregular shape, the method of schematization has

been discussed in detail in Chapter 5. For the geometry of prismatic type, all geometric data are fully defined by construction drawings or assumptions made in the simulation of channel geometry.

#### Initial Condition Data for Quasi-Steady Solution

The initial condition data along the tidal channel for transient solutions are generated from a quasi-steady state solution, while those for the quasi-steady state solution are assigned in the computer programs as follows:

$$Q_o = 0$$

$$\eta_o = 0$$

These imply that the plane of water surface as defined by the geometric data of  $(d + z_o)$  is assumed to be the initial water surface along the tidal channel and the outputs of  $\eta$  obtained for the solution should always be referred to this initial water surface as the reference datum.

#### Boundary Condition Data

Three possible sources are available for defining the tidal elevation at the ocean end as the boundary condition data:

- (1) Harmonic analysis of ocean tide
- (2) Actual field data
- (3) Measurements made in a hydraulic model or readings from tide table.

All three computer programs have provisions allowed to incorporate the boundary condition data obtained from the sources stated above.

Discharges per unit time at the river end can be determined either by measurements made at the overflow weirs upstream or the hydrograph obtained through other appropriate means.

For a quasi-steady solution, the boundary condition data need to cover the duration of one tidal cycle only. For a transient solution, it is necessary to have continuous boundary condition data up to the time where the transient solution is expected to end. The data covering the first tidal cycle of the continuous records are used for generating the quasi-steady solution prior to the execution of the subsequent transient solution.

#### Other Physical Data

The most important physical data are the Manning's resistance coefficient. The space-dependency of the Manning's resistance coefficient along a long estuary has been demonstrated in the prototype studies described in Chapter 6. Due to the reversing-flow characteristics which are typical of tidal flows, the Manning resistance coefficients for tidal channels appear to be higher in magnitudes than those under a uni-directional flow condition, such as the flow in a river. Past experience seems to indicate that they range from 0.02 to 0.05 for a tidal channel of average depth varying from 20 to 50 feet.

If sufficient field measurements of tidal elevations at various points along a tidal channel are available, it is possible to determine the Manning's resistance coefficients by trial and error through fittings of computer outputs with the field measurements. However, it must be pointed out that it would be infeasible to do so if the frictional effect is found to be insignificant in a tidal channel whose channel length is comparatively smaller than the tidal wave length.

Wind velocities and directions can be obtained through the use of wind gauges. Unfortunately, not much research has been made in the past on the determination of wind resistance coefficients under prototype conditions. Intelligent use of laboratory data is needed. However, except for the study of extreme

conditions such as those under hurricanes or gust conditions, the wind effect on tidal propagation in an estuary or canal is expected to be insignificant.

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E. Input Data Format

(The following tables are included to show the order of input data cards as well as their formats used for all three main programs.)

Input Format for General Program #1

<u>Type of Data</u>	<u>Content of Card</u>	<u>Format</u>	<u>No. of Cards</u>	
<u>Title Cards</u>	Title #1	80H	1	
	Title #2	80H	1	
<u>Initial Data</u>	JMAX	I3	1	
	NMAX	I4	1	
	CHLEN	F12.3	1	
	CASE	I3	1	
	TGOM	F10.3	1	
<u>Geometric Data</u>	Case=1	J,D(J),ZO(J),B(J)	JMAX	
	Case=2	J,D(J),ZO(J),B(J),BS(J)	JMAX	
	Case=3	SLOPE	I3	1
		J,D(J),ZO(J),SS(J),BB(J)	10X,4F10.5	JMAX
	Case=4	KB	E10.3	1
		BO	F10.5	1
		J,D(J),ZO(J)	10X,2F10.5	JMAX
<u>Miscellaneous Data</u>	EH	F10.7	1	
	ROUGH	I3	1	
	WEND	I3	1	
	GAMMA	E10.4	1	
	J,MANCO(J),FQ(J),V(J),PHI(J)	10X,F10.7,F10.3,2F10.7	JMAX	
	NPUN	I3	1	
	PTEM(J)	26I3	NPUN	
<u>Boundary Data</u>	CLASSA	I3	1	
	LMAX	I3	1	
	NTRANS	I3	1	
	CLASSA=1	H(N,L)-	5F,10.5	NMAXH/10
	CLASSA=2	AMP(L)/T(L)	F12.3/F12.3	2LMAX
	NTRANS>0	H(N,1)	5F10.5	NMAXH/10
		FQ(JMAX)	F12.4	1

(Note: Repeat last two sets of data cards for each transient cycle.)

Input Format for General Program #2

<u>Type of Data</u>	<u>Content of Card</u>	<u>Format</u>	<u>No. of Cards</u>
<u>Title Cards</u>	Title #1	80H	1
	Title #2	80H	1
<u>Initial Data</u>	JMAX	I3	1
	NMAX	I4	1
	CHLEN	F12.3	1
	CASE	I3	1
	TCOM	F10.3	1
<u>Geometric Data</u>			
Case=1	J,D(J),ZO(J),B(J)	10X,2F10.5,F10.1	JMAX
Case=2	J,D(J),ZO(J),B(J),BS(J)	10X,2F10.5,2F10.1	JMAX
Case=3	SLOPE	I3	1
	J,D(J),ZO(J),SS(J),BB(J)	10X,4F10.5	JMAX
<u>Miscellaneous Data</u>			
	EH	F10.7	1
	ROUGH	I3	1
	WEND	I3	1
	GAMMA	E10.4	1
	J,MANCO(J),FQ(J),V(J),PHI(J)	10X,F10.7,F10.3,2F10.7	JMAX
<u>Punch Parameters</u>			
	NPUN	I3	1
	PTEM(J)	26I3	NPUN
	QEND	F12.4	1
<u>Boundary Data</u>			
	CLASSA	I3	1
	LMAX	I3	1
	NTRANS	I3	1
CLASSA=1	H(N,1)-initial data	5F10.5	NMAXH/10
CLASSA=2	AMP(L)/T(L)	F12.3/F12.3	2LMAX
TRANS>0	H(N,1)-	5F10.5	NMAXH/10
	QEND	F12.4	1

(Note: Repeat last two sets of data cards for each transient cycle.)

Input Format for General Program #3

<u>Type of Data</u>	<u>Content of Card</u>	<u>Format</u>	<u>No. of Cards</u>
<u>Title Cards</u>	Title #1	80H	1
	Title #2	80H	1
<u>Initial Data</u>	JMAX	I3	1
	NMAX	I4	1
	CHLEN	F12.3	1
	CASE	I3	1
	TCOM	F10.3	1
<u>Geometric Data</u>			
Case=1	J,D(J),ZO(J),B(J)	10Y,2F10.5,F10.1	JMAX
Case=2	J,D(J),Z(J),B(J),BS(J)	10X,2F10.5,2F10.1	JMAX
Case=3	SLOPE	I3	1
	J,D(J),ZO(J),SS(J),BB(J)	10X,4F10.5	JMAX
<u>Miscellaneous Data</u>			
	EH	F10.7	1
	ROUGH	I3	1
	WEND	I3	1
	GAMMA	E10.4	1
	J,MANCO(J),FQ(J),V(J),PHI(J)	10X,F10.7,F10.3,F10.7	JMAX
<u>Punch Parameters</u>			
	NPUN	I3	1
	PTEM(J)	26I3	NPUN
<u>Boundary Data</u>			
	CLASSA	I3	1
	CLASSB	I3	1
	PHAD1	I3	1
	LMAX	I3	1
	LMAXL	I3	1
	NTRANS	I3	1
	COND1	I3	1
ClassA=1	H(N,1)	5F10.5	NMAXH/10
CLASSA=2	AMP(I)/T(L)	F12.3/F12.3	2LMAX
CLASSB=1	H(N,JMAX)	5F10.5	NMAXH/10
CLASSB=2	AMPL(L)/TL(L)	F12.3/F12.3	2LMAXL
NTRANS>0	H(N,1)	5F10.5	NMAXH/10
	H(N,JMAXH)	5F10.5	NMAXH/10

(Note: Repeat last two sets of data cards for each transient cycle.)

F. Sample Input Data

(For main program No. 3 only)

TIDAL COMPUTATIONS IN PROPOSED SEA LEVEL CANAL -- EXTREME TIDE  
CASE 79, GEOMETRY VII-C, 45 MILES, CONV. CHANNEL, 20-MILE PASSING ZONE, N=.025

```

017
161
45.0
002
45180.0
1      55.50000  4.50000  711.00000  655.50000
2      55.78125  4.21875  711.56250  655.78125
3      56.06250  3.93750  712.12500  656.06250
4      56.34375  3.65625  712.68750  656.34375
5      56.62500  3.37500  713.25000  656.62500
6      56.90625  3.09375  713.81250  656.90625
7      57.18750  2.81250  714.37500  657.18750
8      57.46875  2.53125  714.93750  657.46875
9      57.75000  2.25000  715.50000  657.75000
10     58.03125  1.96875  716.06250  658.03125
11     58.31250  1.68750  716.62500  658.31250
12     58.59375  1.40625  717.18750  658.59375
13     58.87500  1.12500  717.75000  658.87500
14     59.15625  0.84375  718.31250  659.15625
15     59.43750  0.56250  718.87500  659.43750
16     59.71875  0.28125  719.43750  659.71875
17     60.00000  0.00000  720.00000  660.00000

```

```

.001
001
001
0.260E-02
1      .025      0.0      0.0      0.0
2      .025      0.0      0.0      0.0
3      .025      0.0      0.0      0.0
4      .025      0.0      0.0      0.0
5      .025      0.0      0.0      0.0
6      .025      0.0      0.0      0.0
7      .025      0.0      0.0      0.0
8      .025      0.0      0.0      0.0
9      .025      0.0      0.0      0.0
10     .025      0.0      0.0      0.0
11     .025      0.0      0.0      0.0
12     .025      0.0      0.0      0.0
13     .025      0.0      0.0      0.0
14     .025      0.0      0.0      0.0
15     .025      0.0      0.0      0.0
16     .025      0.0      0.0      0.0
17     .025      0.0      0.0      0.0

```

```

006
001
002
005
007
008
009 02 08 16
001
001
000
000
000

```

002				
002				
-1.80	-1.00	-0.20	0.55	1.30
2.05	2.80	3.55	4.30	4.85
5.40	6.05	6.70	7.25	7.80
8.30	8.80	9.10	9.40	9.70
10.00	10.20	10.40	10.60	10.80
10.85	10.90	10.75	10.60	10.25
9.90	9.50	9.10	8.65	8.30
7.70	7.10	6.65	6.20	5.60
5.00	4.35	3.70	3.00	2.30
1.55	0.80	0.25	-0.30	-1.00
-1.70	-2.45	-3.20	-3.90	-4.60
-5.20	-5.80	-6.45	-6.90	-7.50
-8.10	-8.45	-8.80	-8.95	-9.10
-9.15	-9.20	-9.15	-9.10	-8.95
-8.80	-8.50	-8.20	-7.50	-6.80
-5.95	-5.10	-4.35	-3.60	-2.70
-1.80				
.70	.69	.68	.67	.65
.63	.60	.57	.55	.47
.40	.37	.35	.30	.25
.19	.18	.14	.10	.07
.05	.03	.01	.01	.0
-.03	-.05	-.07	-.10	-.15
-.20	-.21	-.21	-.22	-.22
-.23	-.25	-.25	-.26	-.24
-.22	-.21	-.20	-.19	-.18
-.17	-.16	-.16	-.15	-.11
-.06	-.03	0.0	.01	.03
.09	.15	.17	.20	.23
.25	.30	.35	.37	.40
.43	.45	.47	.50	.53
.55	.57	.60	.63	.64
.65	.65	.67	.68	.69
.70				
-1.80	-1.05	-0.20	0.42	1.16
1.90	2.80	3.55	4.30	4.95
5.60	6.25	6.90	7.45	8.00
8.50	9.00	9.35	9.70	9.90
10.10	10.30	10.50	10.60	10.80
10.90	10.80	10.65	10.50	10.10
9.70	9.25	8.80	8.35	7.90
7.35	6.80	6.25	5.70	5.10
4.50	3.80	3.10	2.30	1.50
.70	-.10	-.85	-1.60	-2.65
-3.30	-4.05	-4.60	-5.20	-5.80
-6.25	-6.70	-7.10	-7.50	-7.90
-8.30	-8.50	-8.70	-8.90	-9.10
-9.00	-8.90	-8.60	-8.30	-7.95
-7.40	-6.90	-6.40	-5.70	-5.00
-4.20	-3.40	-2.65	-1.90	-.95
0.0				
.70	.70	.70	.70	.70
.68	.65	.65	.65	.63
.62	.61	.60	.59	.58
.57	.57	.56	.56	.55

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.55	.53	.50	.45	.40
.39	.38	.34	.30	.25
.20	.19	.18	.12	.05
.02	-.02	-.04	-.07	-.11
-.15	-.17	-.20	-.20	-.20
-.21	-.22	-.22	-.22	-.21
-.20	-.19	-.18	-.18	-.18
-.17	-.15	-.13	-.10	-.06
-.02	-.01	0.0	.03	.05
.08	.10	.11	.12	.13
.15	.16	.17	.17	.18
.18	.19	.19	.20	.21
.22				
0.00	1.00	2.00	2.65	3.30
4.15	4.90	5.55	6.20	6.80
7.40	7.90	8.40	8.90	9.40
9.80	10.20	10.45	10.70	10.90
11.10	11.25	11.40	11.50	11.40
11.30	11.20	10.90	10.60	10.00
9.60	9.10	8.60	8.10	7.60
7.05	6.50	5.85	5.20	4.55
3.90	3.15	2.40	1.55	0.70
-.15	-1.00	-1.75	-2.50	-3.20
-3.90	-4.55	-5.20	-5.75	-6.30
-6.80	-7.30	-7.75	-8.20	-8.70
-9.20	-9.40	-9.60	-9.50	-9.40
-9.20	-9.00	-8.60	-8.20	-7.85
-7.50	-7.00	-6.50	-5.85	-5.20
-4.60	-3.60	-2.60	-1.60	-0.80
.0				
.22	.23	.24	.24	.24
.25	.26	.28	.30	.30
.30	.28	.25	.24	.22
.20	.18	.17	.16	.13
.10	.07	.05	.02	0.0
-.01	-.02	-.06	-.10	-.14
-.18	-.19	-.20	-.21	-.20
-.19	-.18	-.17	-.16	-.15
-.15	-.13	-.10	-.07	-.05
-.03	0.0	.01	.01	.03
.04	.07	.10	.13	.15
.17	.18	.19	.20	.23
.25	.28	.30	.35	.40
.42	.43	.46	.50	.53
.55	.58	.60	.63	.65
.65	.66	.67	.68	.69
.70				

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## G. Brief Discussions on Output Data

### Implications Due to One-Dimensional Formulation

It is important for the engineer to perceive that all outputs obtained from the computer programs represent AVERAGE values for the complete cross section extending over the reach concerned. It implies that the effects due to local variations in the geometry of the tidal channel within any particular reach cannot be reflected in the solution, while, actually, the velocity may vary from point to point within that particular reach of tidal channel. Also, the solution does not give the bottom velocity which is critical for the sediment transport processes. Therefore, any attempt in correlating the average tidal velocity with the sediment movements at the bottom of the tidal channel should not be made. In other words, the density current effect in the case of a stratified estuary has not been correctly reproduced.

### Compatible Field Instrumentation for Determination of Manning

#### Resistance Coefficient

The format of output calls for a field instrumentation scheme which is necessarily different from the current practices adopted by hydraulic engineers. At present, tidal gauges are installed along a tidal channel only at points of interest to the hydraulic engineers. However, in order to provide with better field measurements for the determination of Manning resistance coefficients in an existing tidal channel by computer solutions, it is necessary to install tidal gauges at regular intervals as specified by the magnitude of  $2\Delta x$ . Until such compatible field instrumentation has been implemented, the full potential of the computer programs could not be exploited. Similarly, this is also true of instrumentation in a hydraulic model study.

H. Sample Output (For main program No. 3 only)

COMPUTATION NO. 1  
 TIDAL COMPUTATIONS IN PROPOSED SEA LEVEL CANAL -- EXTREME TIDE  
 CASE 79. GEOMETRY VII-C. 45 MILES, CONV. CHANNEL, 20-MILE PASSING ZONE, N=025  
 GEOMETRIC DATA

CASE #	Z	JMAX	NMAX	161	CHLEN	ICGM	BS
			161	451000	45100000		
			CHANNEL OF IRREGULAR SHAPE				
MILES	D	ZD	B	B	BS		
0.0	55.50000	4.50000	711.0	711.0	655.5		
2.81250	55.78125	4.21875	711.6	711.6	655.8		
5.62500	56.06250	3.93750	712.1	712.1	656.1		
8.43750	56.34375	3.65625	712.7	712.7	656.3		
11.25000	56.62500	3.37500	713.3	713.3	656.6		
14.06250	56.90625	3.09375	713.9	713.9	656.9		
16.87500	57.18750	2.81250	714.4	714.4	657.2		
19.68750	57.46875	2.53125	714.9	714.9	657.5		
22.50000	57.75000	2.25000	715.4	715.4	657.8		
25.31250	58.03125	1.96875	715.9	715.9	658.1		
28.12500	58.31250	1.68750	716.4	716.4	658.4		
30.93750	58.59375	1.40625	716.9	716.9	658.7		
33.75000	58.87500	1.12500	717.4	717.4	659.0		
36.56250	59.15625	0.84375	717.9	717.9	659.3		
39.37500	59.43750	0.56250	718.4	718.4	659.6		
42.18750	59.71875	0.28125	718.9	718.9	659.9		
45.00000	60.00000	0.0	719.4	719.4	660.2		
			720.0	720.0	660.0		

OTHER DATA  
 PI 3.1415926  
 G 32.1999965  
 EH 0.0010000  
 ROUGH = 1 MANNING COEFFICIENT CONSTANT ALONG CHANNEL  
 WEND = 1 NO WIND EFFECT

HAULT	GAMMA	ARDBN	V	PHI
MILES	MARKO	FR	V	PHI
0.0	0.0	0.0	0.0	0.0
2.81250	0.0250000	0.0	0.0	0.0
5.62500	0.0	0.0	0.0	0.0
8.43750	0.0250000	0.0	0.0	0.0
11.25000	0.0	0.0	0.0	0.0
14.06250	0.0250000	0.0	0.0	0.0
16.87500	0.0	0.0	0.0	0.0
19.68750	0.0250000	0.0	0.0	0.0
22.50000	0.0	0.0	0.0	0.0
25.31250	0.0250000	0.0	0.0	0.0
28.12500	0.0	0.0	0.0	0.0
30.93750	0.0250000	0.0	0.0	0.0
33.75000	0.0	0.0	0.0	0.0
36.56250	0.0250000	0.0	0.0	0.0
39.37500	0.0	0.0	0.0	0.0
42.18750	0.0250000	0.0	0.0	0.0
45.00000	0.0	0.0	0.0	0.0

BOUNDARY CONDITION DATA  
 CLASS = 1 OCEAN A TIDES FROM TABLE  
 CLASS = 1 OCEAN B TIDES FROM TABLE  
 DELTA = 282.3760000 SEC DELTA  
 DELTA/DELTA = 52.58905 FT./SEC.  
 Celerity WITH RESPECT TO DEPTH ONLY  
 MILES MALEN

0.0	42.274	301.73120
2.81250	42.381	302.64657
5.62500	42.488	303.55981
8.43750	42.594	304.47070
11.25000	42.700	305.37939

14.06250	42.806	366.28540
16.87500	42.912	367.18570
19.68750	43.017	368.09131
22.50000	43.122	368.99121
25.31250	43.227	369.88843
28.12500	43.332	370.78369
30.93750	43.436	371.67651
33.75000	43.540	372.56763
36.56250	43.644	373.45679
39.37500	43.748	374.34326
42.18750	43.851	375.22728
45.00000	43.955	376.11060

COMPUTATION BEGINS

K = 1

K = 2

K = 3

STABLE AFTER 3 CYCLES

NUMBER OF TRANSIENT SOLUTIONS REQUIRED = 2

OUTPUT IS AS FOLLOWS

QUASI-STEADY SOLUTION AS FOLLOWS

VARIATIONS OF H ARE AS FOLLOWS

DISTANCE FROM OCEAN END A 0.0

HR.

H(N,J)

HR.

MILE

H(N,J)

HR.

MILE

H(N,J)

HR.

MILE

H(N,J)

HR.

MILE

H(N,J)

HR.

MILE

H(N,J)

HR.

MILE

H(N,J)

HR.

MILE

H(N,J)

HR.

MILE

H(N,J)

HR.

MILE

H(N,J)

HR.

MILE

H(N,J)

HR.

MILE

H(N,J)

HR.

MILE

H(N,J)

HR.

MILE

H(N,J)

HR.

MILE

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225

0.0	0.941	1.882	2.824	3.765	4.706	5.647	6.589	7.530	8.471	9.412	10.354	11.295	12.236	13.177	14.118	15.059	16.000	16.941	17.882	18.824	19.765	20.706	21.647	22.589	23.530	24.471	25.412	26.354	27.295	28.236	29.177	30.118	31.059	32.000	32.941	33.882	34.824	35.765	36.706	37.647	38.589	39.530	40.471	41.412	42.354	43.295	44.236	45.177	46.118	47.059	48.000	48.941	49.882	50.824	51.765	52.706	53.647	54.589	55.530	56.471	57.412	58.354	59.295	60.236	61.177	62.118	63.059	64.000	64.941	65.882	66.824	67.765	68.706	69.647	70.589	71.530	72.471	73.412	74.354	75.295	76.236	77.177	78.118	79.059	80.000	80.941	81.882	82.824	83.765	84.706	85.647	86.589	87.530	88.471	89.412	90.354	91.295	92.236	93.177	94.118	95.059	96.000	96.941	97.882	98.824	99.765	100.706	101.647	102.589	103.530	104.471	105.412	106.354	107.295	108.236	109.177	110.118	111.059	112.000	112.941	113.882	114.824	115.765	116.706	117.647	118.589	119.530	120.471	121.412	122.354	123.295	124.236	125.177	126.118	127.059	128.000	128.941	129.882	130.824	131.765	132.706	133.647	134.589	135.530	136.471	137.412	138.354	139.295	140.236	141.177	142.118	143.059	144.000	144.941	145.882	146.824	147.765	148.706	149.647	150.589	151.530	152.471	153.412	154.354	155.295	156.236	157.177	158.118	159.059	160.000	160.941	161.882	162.824	163.765	164.706	165.647	166.589	167.530	168.471	169.412	170.354	171.295	172.236	173.177	174.118	175.059	176.000	176.941	177.882	178.824	179.765	180.706	181.647	182.589	183.530	184.471	185.412	186.354	187.295	188.236	189.177	190.118	191.059	192.000	192.941	193.882	194.824	195.765	196.706	197.647	198.589	199.530	200.471	201.412	202.354	203.295	204.236	205.177	206.118	207.059	208.000	208.941	209.882	210.824	211.765	212.706	213.647	214.589	215.530	216.471	217.412	218.354	219.295	220.236	221.177	222.118	223.059	224.000	224.941	225.882	226.824	227.765	228.706	229.647	230.589	231.530	232.471	233.412	234.354	235.295	236.236	237.177	238.118	239.059	240.000	240.941	241.882	242.824	243.765	244.706	245.647	246.589	247.530	248.471	249.412	250.354	251.295	252.236	253.177	254.118	255.059	256.000	256.941	257.882	258.824	259.765	260.706	261.647	262.589	263.530	264.471	265.412	266.354	267.295	268.236	269.177	270.118	271.059	272.000	272.941	273.882	274.824	275.765	276.706	277.647	278.589	279.530	280.471	281.412	282.354	283.295	284.236	285.177	286.118	287.059	288.000	288.941	289.882	290.824	291.765	292.706	293.647	294.589	295.530	296.471	297.412	298.354	299.295	300.236	301.177	302.118	303.059	304.000	304.941	305.882	306.824	307.765	308.706	309.647	310.589	311.530	312.471	313.412	314.354	315.295	316.236	317.177	318.118	319.059	320.000	320.941	321.882	322.824	323.765	324.706	325.647	326.589	327.530	328.471	329.412	330.354	331.295	332.236	333.177	334.118	335.059	336.000	336.941	337.882	338.824	339.765	340.706	341.647	342.589	343.530	344.471	345.412	346.354	347.295	348.236	349.177	350.118	351.059	352.000	352.941	353.882	354.824	355.765	356.706	357.647	358.589	359.530	360.471	361.412	362.354	363.295	364.236	365.177	366.118	367.059	368.000	368.941	369.882	370.824	371.765	372.706	373.647	374.589	375.530	376.471	377.412	378.354	379.295	380.236	381.177	382.118	383.059	384.000	384.941	385.882	386.824	387.765	388.706	389.647	390.589	391.530	392.471	393.412	394.354	395.295	396.236	397.177	398.118	399.059	400.000	400.941	401.882	402.824	403.765	404.706	405.647	406.589	407.530	408.471	409.412	410.354	411.295	412.236	413.177	414.118	415.059	416.000	416.941	417.882	418.824	419.765	420.706	421.647	422.589	423.530	424.471	425.412	426.354	427.295	428.236	429.177	430.118	431.059	432.000	432.941	433.882	434.824	435.765	436.706	437.647	438.589	439.530	440.471	441.412	442.354	443.295	444.236	445.177	446.118	447.059	448.000	448.941	449.882	450.824	451.765	452.706	453.647	454.589	455.530	456.471	457.412	458.354	459.295	460.236	461.177	462.118	463.059	464.000	464.941	465.882	466.824	467.765	468.706	469.647	470.589	471.530	472.471	473.412	474.354	475.295	476.236	477.177	478.118	479.059	480.000	480.941	481.882	482.824	483.765	484.706	485.647	486.589	487.530	488.471	489.412	490.354	491.295	492.236	493.177	494.118	495.059	496.000	496.941	497.882	498.824	499.765	500.706	501.647	502.589	503.530	504.471	505.412	506.354	507.295	508.236	509.177	510.118	511.059	512.000	512.941	513.882	514.824	515.765	516.706	517.647	518.589	519.530	520.471	521.412	522.354	523.295	524.236	525.177	526.118	527.059	528.000	528.941	529.882	530.824	531.765	532.706	533.647	534.589	535.530	536.471	537.412	538.354	539.295	540.236	541.177	542.118	543.059	544.000	544.941	545.882	546.824	547.765	548.706	549.647	550.589	551.530	552.471	553.412	554.354	555.295	556.236	557.177	558.118	559.059	560.000	560.941	561.882	562.824	563.765	564.706	565.647	566.589	567.530	568.471	569.412	570.354	571.295	572.236	573.177	574.118	575.059	576.000	576.941	577.882	578.824	579.765	580.706	581.647	582.589	583.530	584.471	585.412	586.354	587.295	588.236	589.177	590.118	591.059	592.000	592.941	593.882	594.824	595.765	596.706	597.647	598.589	599.530	600.471	601.412	602.354	603.295	604.236	605.177	606.118	607.059	608.000	608.941	609.882	610.824	611.765	612.706	613.647	614.589	615.530	616.471	617.412	618.354	619.295	620.236	621.177	622.118	623.059	624.000	624.941	625.882	626.824	627.765	628.706	629.647	630.589	631.530	632.471	633.412	634.354	635.295	636.236	637.177	638.118	639.059	640.000	640.941	641.882	642.824	643.765	644.706	645.647	646.589	647.530	648.471	649.412	650.354	651.295	652.236	653.177	654.118	655.059	656.000	656.941	657.882	658.824	659.765	660.706	661.647	662.589	663.530	664.471	665.412	666.354	667.295	668.236	669.177	670.118	671.059	672.000	672.941	673.882	674.824	675.765	676.706	677.647	678.589	679.530	680.471	681.412	682.354	683.295	684.236	685.177	686.118	687.059	688.000	688.941	689.882	690.824	691.765	692.706	693.647	694.589	695.530	696.471	697.412	698.354	699.295	700.236	701.177	702.118	703.059	704.000	704.941	705.882	706.824	707.765	708.706	709.647	710.589	711.530	712.471	713.412	714.354	715.295	716.236	717.177	718.118	719.059	720.000	720.941	721.882	722.824	723.765	724.706	725.647	726.589	727.530	728.471	729.412	730.354	731.295	732.236	733.177	734.118	735.059	736.000	736.941	737.882	738.824	739.765	740.706	741.647	742.589	743.530	744.471	745.412	746.354	747.295	748.236	749.177	750.118	751.059	752.000	752.941	753.882	754.824	755.765	756.706	757.647	758.589	759.530	760.471	761.412	762.354	7
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12.236	-3.36103	12.353	-2.83324	12.550	0.0	12.864	0.0	H(N,J)	HR.
HR. 4.236	MAX= 8.07899	LW=10.197	MIN= -7.24373	12.550				H(N,J)	HR.
MEAN =									
DISTANCE FROM OCEAN END A	11.25000	MILE	J= 5						
HR.	H(N,J)	HR.	H(N,J)	HR.	H(N,J)	HR.	H(N,J)	HR.	H(N,J)
0.0	-2.18835	0.157	-1.79572	0.314	-1.32286	0.471	-0.83012	0.627	-0.31329
0.941	0.83393	1.098	1.47526	1.255	2.17847	1.412	2.90281	1.569	3.53388
1.882	4.53822	2.039	5.06740	2.196	5.61646	2.353	6.08289	2.510	6.44845
2.824	7.04178	2.981	7.16700	3.137	7.13794	3.294	7.04503	3.451	6.91162
3.765	6.65879	3.922	6.66526	4.079	6.75078	4.236	6.76934	4.392	6.74265
4.706	6.48839	4.863	6.31559	5.020	6.11770	5.177	5.94984	5.334	5.78350
5.647	5.41530	5.804	5.08461	5.961	6.11770	6.118	4.44886	6.275	4.12580
6.589	3.32850	6.746	2.89772	6.902	4.70534	7.059	2.03300	7.216	1.57318
7.530	0.52321	7.687	0.09335	7.844	-0.33972	8.001	-0.83012	8.157	-1.34992
8.471	-2.55642	8.628	-3.08572	8.785	-3.23162	8.942	-3.95930	9.099	-4.32251
9.412	-4.51390	9.569	-5.15056	9.726	-5.24162	9.883	-5.47200	10.040	-5.83151
10.354	-5.42286	10.511	-5.22379	10.667	-4.78258	10.824	-4.76803	10.981	-4.63857
11.295	-4.47215	11.452	-4.34165	11.609	-4.78258	11.766	-3.98258	11.922	-3.51418
12.236	-2.54103	12.393	-2.55423	12.550	-2.18835	12.707	0.0	12.864	0.0
MEAN = 2.981	MAX= 7.16700	LW=10.040	MIN= -5.54315						
DISTANCE FROM OCEAN END A	16.87500	MILE	J= 7						
HR.	H(N,J)	HR.	H(N,J)	HR.	H(N,J)	HR.	H(N,J)	HR.	H(N,J)
0.0	-2.30814	0.157	-1.98426	0.314	-1.63462	0.471	-1.20420	0.627	-0.69428
0.941	0.39342	1.098	0.97682	1.255	1.60059	1.412	2.27368	1.569	2.98504
1.882	4.18347	2.039	4.64165	2.196	5.12806	2.353	5.62768	2.510	6.04804
2.824	6.56362	2.981	6.65752	3.137	6.59066	3.294	6.42526	3.451	6.21742
3.765	6.06871	3.922	6.05126	4.079	6.10514	4.236	6.15957	4.392	6.14742
4.706	6.05696	4.863	5.95443	5.020	5.81302	5.177	5.66294	5.334	5.53195
5.647	5.16967	5.804	4.97057	5.961	4.68053	6.118	4.29136	6.275	3.98350
6.589	3.35087	6.746	2.96624	6.902	2.57575	7.059	2.14956	7.216	1.72719
7.530	0.30372	7.687	0.33032	7.844	-0.11658	8.001	-0.51627	8.157	-0.95436
8.471	-2.00380	8.628	-2.57465	8.785	-3.08271	8.942	-3.83266	9.099	-4.58249
9.412	-4.43465	9.569	-4.64921	9.726	-4.61193	9.883	-4.35869	10.040	-5.01044
10.354	-4.86590	10.511	-4.66634	10.667	-4.46684	10.824	-4.32684	10.981	-4.23466
11.295	-4.03084	11.452	-3.92159	11.609	-3.80325	11.766	-3.51418	11.922	-3.25418
12.236	-2.96642	12.393	-2.63702	12.550	-2.30828	12.707	0.0	12.864	0.0
MEAN = 2.981	MAX= 6.65752	LW=10.040	MIN= -5.01044						
DISTANCE FROM OCEAN END A	22.50000	MILE	J= 9						
HR.	H(N,J)	HR.	H(N,J)	HR.	H(N,J)	HR.	H(N,J)	HR.	H(N,J)
0.0	-2.37367	0.157	-2.04864	0.314	-1.74121	0.471	-1.38184	0.627	-0.96271
0.941	0.05239	1.098	0.57939	1.255	1.12400	1.412	1.71763	1.569	2.37148
1.882	3.75541	2.039	4.30118	2.196	4.70827	2.353	5.11259	2.510	5.54835
2.824	5.94015	2.981	5.91117	3.137	5.91117	3.294	5.83273	3.451	5.69704
3.765	5.62049	3.922	5.37546	4.079	5.49675	4.236	5.49641	4.392	5.58302
4.706	5.60091	4.863	5.55555	5.020	5.50827	5.177	5.40819	5.334	5.24768
5.647	4.92176	5.804	4.70291	5.961	4.46721	6.118	4.19885	6.275	3.85729
6.589	3.28896	6.746	2.57529	6.902	2.59016	7.059	2.20222	7.216	1.81894
7.530	1.02063	7.687	0.58504	7.844	0.12696	8.001	-0.31574	8.157	-0.71928
8.471	-1.54505	8.628	-2.01930	8.785	-2.51623	8.942	-2.98778	9.099	-3.47507
9.412	-3.92872	9.569	-4.13794	9.726	-4.29958	9.883	-4.38613	10.040	-4.38617
10.354	-4.19981	10.511	-4.10462	10.667	-4.04673	10.824	-3.97237	10.981	-3.85084
11.295	-3.61414	11.452	-3.51412	11.609	-3.41210	11.766	-3.30684	11.922	-3.16084
12.236	-2.87880	12.393	-2.64975	12.550	-2.37367	12.707	0.0	12.864	0.0
MEAN = 2.924	MAX= 5.96015	LW=10.040	MIN= -4.38617						
DISTANCE FROM OCEAN END A	28.12500	MILE	J= 11						
HR.	H(N,J)	HR.	H(N,J)	HR.	H(N,J)	HR.	H(N,J)	HR.	H(N,J)
0.0	-2.32326	0.157	-2.05408	0.314	-1.73542	0.471	-1.39240	0.627	-0.94406
0.941	-0.22902	1.098	0.25430	1.255	0.75860	1.412	1.27948	1.569	1.82927
1.882	3.11214	2.039	3.76296	2.196	4.30195	2.353	4.66506	2.510	4.89569
2.824	5.18572	2.981	5.20112	3.137	5.14658	3.294	5.14869	3.451	5.19950
3.765	5.11102	3.922	5.03420	4.079	4.98170	4.236	4.95956	4.392	4.97530
4.706	5.12541	4.863	5.16059	5.020	5.12665	5.177	5.04910	5.334	4.92915
5.647	4.55656	5.804	4.36468	5.961	4.16181	6.118	3.95222	6.275	3.71033

6.589 3.08980 6.746 2.82016 6.902 2.53049 7.059 2.19766 7.216 1.89302  
 7.550 1.10918 7.587 0.74503 7.844 0.33247 8.001 0.10856 8.157 0.51567  
 8.471 1.19405 8.628 1.53761 8.785 1.53761 8.942 1.53761 9.099 1.53761  
 9.412 3.40310 9.569 3.59321 9.726 3.59321 9.883 3.59321 10.040 3.59321  
 10.384 3.56023 10.511 3.59201 10.667 3.58826 10.824 3.52779 10.981 3.44206  
 11.295 3.20864 11.452 3.09900 11.609 3.00856 11.766 2.90396 11.922 2.81195  
 12.236 2.64387 12.393 2.51651 12.550 2.32325 12.707 2.19766 12.864 2.08800  
 HM = 2.981 MAX = 5.20112 LM = 5.883 MIN = -3.72536  
 MEAN = 4.46324  
 DISTANCE FROM OCEAN END A 33.75000 MILE J = 13

HR. H(N,J) HR. H(N,J) HR. H(N,J) HR. H(N,J) HR. H(N,J)  
 0.0 0.0 0.157 1.87268 0.314 0.314 0.471 0.471 0.627 0.627  
 0.941 0.35465 1.088 0.02597 1.255 1.255 1.412 1.412 1.569 1.569  
 1.882 2.41429 2.039 3.01191 2.196 2.196 2.353 2.353 2.510 2.510  
 2.824 4.21988 2.981 4.32134 3.137 3.137 3.294 3.294 3.451 3.451  
 3.765 4.53592 3.922 4.47044 4.079 4.079 4.236 4.236 4.392 4.392  
 4.706 4.57066 4.863 4.64081 4.917 4.917 5.074 5.074 5.231 5.231  
 5.647 4.11639 5.804 3.93441 5.961 5.961 6.118 6.118 6.275 6.275  
 6.589 2.86157 6.746 2.55451 6.902 6.902 7.059 7.059 7.216 7.216  
 7.530 1.12003 7.687 0.75626 7.844 0.42461 8.001 0.09380 8.157 0.27330  
 8.471 0.89594 8.628 8.628 8.785 8.785 8.942 8.942 9.099 9.099  
 9.412 0.27856 9.569 9.569 9.726 9.726 9.883 9.883 10.040 10.040  
 10.384 0.28919 10.511 10.511 10.667 10.667 10.824 10.824 10.981 10.981  
 11.295 0.27812 11.452 0.26612 11.609 11.609 11.766 11.766 11.922 11.922  
 12.236 0.22952 12.393 0.20940 12.550 12.550 12.707 12.707 12.864 12.864  
 HM = 0.863 MAX = 4.64081 LM = 10.667 MIN = -3.01088  
 MEAN = 3.82574  
 DISTANCE FROM OCEAN END A 39.37500 MILE J = 15

HR. H(N,J) HR. H(N,J) HR. H(N,J) HR. H(N,J) HR. H(N,J)  
 0.0 0.0 0.157 0.64719 0.314 0.314 0.471 0.471 0.627 0.627  
 0.941 0.09765 1.088 0.22817 1.255 1.255 1.412 1.412 1.569 1.569  
 1.882 1.29331 2.039 1.98836 2.196 2.196 2.353 2.353 2.510 2.510  
 2.824 2.01171 2.981 2.09724 3.137 3.137 3.294 3.294 3.451 3.451  
 3.765 2.37184 3.922 2.36731 4.079 4.079 4.236 4.236 4.392 4.392  
 4.706 2.25489 4.863 2.32780 4.917 4.917 5.074 5.074 5.231 5.231  
 5.647 2.06024 5.804 1.93985 5.961 5.961 6.118 6.118 6.275 6.275  
 6.589 1.43588 6.746 1.23974 6.902 6.902 7.059 7.059 7.216 7.216  
 7.530 0.48340 7.687 0.28883 7.844 0.14528 8.001 0.04459 8.157 0.08386  
 8.471 0.49752 8.628 0.61862 8.785 8.785 8.942 8.942 9.099 9.099  
 9.412 0.137178 9.569 1.42880 9.726 9.726 9.883 9.883 10.040 10.040  
 10.384 0.21238 10.511 1.19979 10.667 10.667 10.824 10.824 10.981 10.981  
 11.295 0.10284 11.452 0.94900 11.609 11.609 11.766 11.766 11.922 11.922  
 12.236 0.074879 12.393 0.69572 12.550 12.550 12.707 12.707 12.864 12.864  
 HM = 3.294 MAX = 2.49011 LM = 9.569 MIN = -1.42880  
 MEAN = 1.95546  
 DISTANCE FROM OCEAN END A 45.00000 MILE J = 17

HR. H(N,J) HR. H(N,J) HR. H(N,J) HR. H(N,J) HR. H(N,J)  
 0.0 0.0 0.157 0.70000 0.314 0.314 0.471 0.471 0.627 0.627  
 0.941 0.60000 1.088 0.57000 1.255 1.255 1.412 1.412 1.569 1.569  
 1.882 0.35000 2.039 0.30000 2.196 2.196 2.353 2.353 2.510 2.510  
 2.824 0.10000 2.981 0.07000 3.137 3.137 3.294 3.294 3.451 3.451  
 3.765 0.0 3.922 0.03000 4.079 4.079 4.236 4.236 4.392 4.392  
 4.706 0.20000 4.863 0.25000 4.917 4.917 5.074 5.074 5.231 5.231  
 5.647 0.25000 5.804 0.25000 5.961 5.961 6.118 6.118 6.275 6.275  
 6.589 0.20000 6.746 0.19000 6.902 6.902 7.059 7.059 7.216 7.216  
 7.530 0.15000 7.687 0.11000 7.844 0.09000 8.001 0.03000 8.157 0.0  
 8.471 0.03000 8.628 0.09000 8.785 8.785 8.942 8.942 9.099 9.099  
 9.412 0.25000 9.569 0.30000 9.726 9.726 9.883 9.883 10.040 10.040  
 10.384 0.45000 10.511 0.47000 10.667 10.667 10.824 10.824 10.981 10.981  
 11.295 0.60000 11.452 0.63000 11.609 11.609 11.766 11.766 11.922 11.922  
 12.236 0.68000 12.393 0.69000 12.550 12.550 12.707 12.707 12.864 12.864  
 HM = 1.550 MAX = 0.70000 LM = 5.961 MIN = -0.26000  
 MEAN = 0.48000  
 DISTANCE FROM OCEAN END A 2.81250 MILE J = 2

VARIATIONS OF Q ARE AS FOLLOWS  
 DISTANCE FROM OCEAN END A 2.81250 MILE J = 2

HR.	Q(N,J)	HR.	Q(N,J)	HR.	Q(N,J)	HR.	Q(N,J)
0.078	-102579.50000	0.235	-86182.50000	0.392	-69666.58750	0.549	-52124.63203
0.863	-9550.58672	1.020	-14661.98047	1.177	38888.74809	1.333	62334.41797
1.647	99866.25000	1.804	122025.81250	1.961	174423.31250	2.118	160636.31250
2.432	185009.00000	2.588	275227.50000	2.745	205257.62500	2.902	211760.50000
3.216	227950.61250	3.373	236639.37500	3.530	247395.18750	3.687	261250.06250
4.000	284493.43750	4.157	290635.18750	4.314	287630.25000	4.471	287630.25000
4.785	273030.25000	4.942	265193.37500	5.098	256516.50000	5.255	245787.43750
5.569	222310.56250	5.726	206008.00000	5.883	194871.62500	6.040	185157.60000
6.353	156156.75000	6.510	141145.62500	6.667	127873.43750	6.824	113757.80000
7.138	81172.12500	7.295	63721.45312	7.452	50871.71484	7.608	39432.37851
7.922	4797.10547	8.079	-15496.48047	8.236	-34751.44922	8.393	-11810.35156
8.707	-85564.37500	8.863	-100644.31250	9.020	-115336.37500	9.177	-125563.43750
9.491	-147539.81250	9.648	-155147.25000	9.805	-160689.62500	9.962	-164073.00000
10.275	-171385.25000	10.432	-175159.75000	10.589	-178624.56250	10.746	-183291.75000
11.060	-193164.25000	11.217	-193991.62500	11.373	-191437.56250	11.530	-193014.75000
11.844	-163843.50000	12.001	-153759.12500	12.158	-144561.00000	12.315	-134549.68750
12.628	-102579.56250	12.785	0.00000	12.942	0.00000	13.099	0.00000

HR = 4.157 MAX = 0.29064E 06  
 LM = 11.217 MIN = -0.19399E 06  
 MEAN = 0.24231E 06  
 DISTANCE FROM OCEAN END A 8.43750 MILE J = 4

HR.	Q(N,J)	HR.	Q(N,J)	HR.	Q(N,J)	HR.	Q(N,J)
0.078	-129394.12500	0.235	-112504.43750	0.392	-93868.87500	0.549	-74584.62500
0.863	-35572.59375	1.020	-14513.60637	1.177	9849.83584	1.333	36676.02391
1.647	82853.31250	1.804	101332.50000	1.961	118859.62500	2.118	138439.50000
2.432	171104.62500	2.588	193022.12500	2.745	164872.62500	2.902	203868.68750
3.216	223111.37500	3.373	236541.43750	3.530	246584.12500	3.687	259950.25000
4.000	289033.37500	4.157	290023.00000	4.314	294388.00000	4.471	294052.62500
4.785	284925.87500	4.942	275992.06250	5.098	257314.50000	5.255	236246.93750
5.569	238139.43750	5.726	224644.37500	5.883	209687.93750	6.040	198122.68750
6.353	176297.06250	6.510	163986.12500	6.667	148732.31250	6.824	133650.18750
7.138	104118.81250	7.295	87929.00000	7.452	71323.56250	7.608	56291.61715
7.922	28610.33203	8.079	12318.55859	8.236	-7909.32422	8.393	-30222.85937
8.707	-66963.43750	8.863	-82821.00000	9.020	-96852.37500	9.177	-110562.18750
9.491	-133695.87500	9.648	-143794.56250	9.805	-153175.50000	9.962	-161285.37500
10.275	-172638.25000	10.432	-177832.62500	10.589	-184649.00000	10.746	-191456.12500
11.060	-198168.18750	11.217	-197903.81250	11.373	-197673.00000	11.530	-197541.25000
11.844	-187289.31250	12.001	-177654.93750	12.158	-166198.31250	12.315	-154315.81250
12.628	-129394.00000	12.785	0.00000	12.942	0.00000	13.099	0.00000

HR = 4.314 MAX = 0.29439E 06  
 LM = 11.060 MIN = -0.19817E 06  
 MEAN = 0.24628E 06  
 DISTANCE FROM OCEAN END A 14.06250 MILE J = 6

HR.	Q(N,J)	HR.	Q(N,J)	HR.	Q(N,J)	HR.	Q(N,J)
0.078	-144121.50000	0.235	-130241.06250	0.392	-112706.50000	0.549	-93570.81250
0.863	-58050.98828	1.020	-38569.67187	1.177	16527.46484	1.333	9506.37891
1.647	64494.38281	1.804	83017.06250	1.961	99010.25000	2.118	117834.31250
2.432	157392.50000	2.588	171594.00000	2.745	184045.18750	2.902	169181.93750
3.216	226986.87500	3.373	241565.62500	3.530	246590.00000	3.687	23387.93750
4.000	279825.50000	4.157	249374.93750	4.314	285330.37500	4.471	299287.50000
4.785	291407.31250	4.942	283474.81250	5.098	272610.25000	5.255	264468.12500
5.569	244356.50000	5.726	257048.75000	5.883	232894.12500	6.040	207743.06250
6.353	192134.75000	6.510	178034.56250	6.667	164498.81250	6.824	150857.75000
7.138	121786.68750	7.295	108233.37500	7.452	90403.12500	7.608	72419.25000
7.922	47005.04687	8.079	31815.81641	8.236	13823.76923	8.393	-6705.49609
8.707	-50237.75391	8.863	-66778.93750	9.020	-83228.35060	9.177	-98912.37500
9.491	-124818.68750	9.648	-136673.00000	9.805	-148240.62500	9.962	-158616.37500
10.275	-176560.62500	10.432	-185399.87500	10.589	-193662.10000	10.746	-199507.50000
11.060	-200955.12500	11.217	-201359.37500	11.373	-202575.50000	11.530	-203023.75000
11.844	-198776.62500	12.001	-190990.00000	12.158	-180444.12500	12.315	-168824.56250
12.628	-144121.56250	12.785	0.00000	12.942	0.00000	13.099	0.00000

HR = 4.471 MAX = 0.29924E 06  
 LM = 11.530 MIN = -0.20303E 06  
 MEAN = 0.25113E 06  
 DISTANCE FROM OCEAN END A 19.68750 MILE J = 8

HR.	Q(N,J)	HR.	Q(N,J)	HR.	Q(N,J)	HR.	Q(N,J)
0.078	-168467.68750	0.235	-156512.12500	0.392	-145046.87500	0.549	-131984.87500
0.863	-99387.56250	1.020	-82404.37500	1.177	-63404.22266	1.333	-41060.04687

HR.	Q(N,J)	HR.	Q(N,J)	HR.	Q(N,J)	HR.	Q(N,J)
1.647	14557.14862	1.804	43205.83203	1.961	64584.26562	2.118	81286.18750
2.432	125907.50000	2.588	148255.18750	2.745	186844.37500	2.902	192136.31250
3.216	239424.93750	3.373	282693.31250	3.530	263169.93750	3.687	270480.31250
4.000	275822.12500	4.157	285235.62500	4.314	296302.37500	4.471	300957.93750
4.785	299111.25000	4.942	294039.68750	5.098	284887.50000	5.255	274327.05000
5.569	260128.93750	5.726	252009.25000	5.883	245679.25000	6.040	236992.00000
6.353	212358.43750	6.510	205364.75000	6.667	193827.75000	6.824	179897.31250
7.138	153863.50000	7.295	139827.75000	7.452	125836.31250	7.608	110014.25000
7.922	77036.81250	8.079	64732.35547	8.236	47432.62500	8.393	34452.76562
8.707	-12063.02344	8.863	-36452.62500	9.020	-57018.44141	9.177	-74514.25000
9.491	-108700.75000	9.648	-124446.00000	9.805	-138715.68750	9.962	-153225.25000
10.275	-185950.31250	10.432	-200394.43750	10.589	-208757.37500	10.746	-209952.18750
11.060	-208091.68750	11.217	-209535.93750	11.374	-210785.50000	11.530	-211524.00000
11.844	-211361.68750	12.001	-209156.93750	12.158	-203434.25000	12.315	-193524.31250
12.628	-168447.75000	12.785	-1277279	12.942	*****	13.099	-926733.25000
MEAN = 0.25642E 06		LM=11.687	MIN=-0.21185E 06				

HR.	Q(N,J)	HR.	Q(N,J)	HR.	Q(N,J)	HR.	Q(N,J)
0.078	-181422.75000	0.235	-181153.25000	0.392	-172091.43750	0.549	-153426.87500
1.063	-135308.62500	1.220	-122004.75000	1.377	-104389.31250	1.533	-85748.62500
1.847	-30238.54887	1.804	-8143.50391	1.961	23512.30465	2.118	50650.14844
2.632	42998.87500	2.588	124484.56250	2.745	161424.62500	2.902	193834.43750
3.416	245327.87500	3.373	262864.56250	3.530	268723.75000	3.687	270672.43750
4.200	281745.75000	4.157	285263.93750	4.314	289784.37500	4.471	297721.81250
4.985	302324.18750	4.942	297598.18750	5.098	292418.37500	5.255	286406.75000
5.769	272432.06250	5.726	268487.06250	5.883	263408.87500	6.040	237187.93750
6.553	235967.06250	6.510	224526.18750	6.667	217366.75000	6.824	208879.37500
7.338	182707.50000	7.295	169297.75000	7.452	156443.50000	7.608	142774.87500
8.122	110352.68750	8.079	95101.37500	8.236	86876.43750	8.393	66876.43750
8.907	25333.97656	8.863	-1165.63184	9.020	-27805.14453	9.177	-51607.03125
9.691	-92955.50000	9.648	-112281.37500	9.805	-132202.50000	9.962	-153222.12500
10.475	-194452.43750	10.432	-207558.56250	10.589	-213113.37500	10.746	-215564.18750
11.260	-217801.87500	11.217	-217638.37500	11.374	-218312.50000	11.530	-219209.93750
11.844	-220093.75000	12.001	-219481.37500	12.158	-216589.87500	12.315	-210812.43750
12.628	-191422.68750	12.785	0.0	12.942	0.0	13.099	0.0
MEAN = 0.26170E 06		LM=11.844	MIN=-0.22002E 06				

HR.	Q(N,J)	HR.	Q(N,J)	HR.	Q(N,J)	HR.	Q(N,J)
0.078	-211711.93750	0.235	-205171.37500	0.392	-197667.81250	0.549	-189961.50000
1.063	-171041.75000	1.220	-158494.31250	1.377	-142400.43750	1.533	-124746.00000
1.847	-84759.62500	1.804	-58317.74219	1.961	-25543.10937	2.118	10024.28516
2.632	79615.68750	2.588	111640.87500	2.745	152407.56250	2.902	192673.31250
3.416	245093.56250	3.373	259109.81250	3.530	269662.18750	3.687	276403.75000
4.200	285702.62500	4.157	286925.93750	4.314	288598.25000	4.471	292575.75000
4.985	299872.43750	4.942	300156.67500	5.098	298264.12500	5.255	295447.68750
5.769	287345.25000	5.726	282950.06250	5.883	278720.43750	6.040	272985.31250
6.553	259316.31250	6.510	247949.06250	6.667	237720.43750	6.824	230713.12500
7.338	209739.81250	7.295	197473.25000	7.452	183455.68750	7.608	170016.56250
8.122	143594.56250	8.079	125787.50000	8.236	107980.37500	8.393	91421.81250
8.907	55580.00000	8.863	32823.81641	9.020	4547.07422	9.177	-26484.88047
9.691	-78625.75000	9.648	-103907.62500	9.805	-130615.43750	9.962	-157625.50000
10.475	-196164.00000	10.432	-205162.68750	10.589	-213396.50000	10.746	-220105.62500
11.260	-226138.81250	11.217	-227045.75000	11.374	-226226.00230	11.530	-226403.56250
11.844	-227029.12500	12.001	-225388.31250	12.158	-223324.06250	12.315	-220041.62500
12.628	-211711.87500	12.785	-200000.00000	12.942	24.62999	13.099	22.55999
MEAN = 0.24371E 06		LM=11.687	MIN=-0.22725E 06				

HR.	Q(N,J)	HR.	Q(N,J)	HR.	Q(N,J)	HR.	Q(N,J)
0.078	-219128.06250	0.235	-214996.50000	0.392	-209077.25000	0.549	-201704.12500
1.063	-184143.31250	1.220	-172861.43750	1.377	-158935.31250	1.533	-142228.68750
1.847	-103106.68750	1.804	-78041.00000	1.961	-48138.60937	2.118	-12524.43750
2.632	71082.87500	2.588	110376.58750	2.745	149938.81250	2.902	188843.75000
3.416	241875.62500	3.373	255618.67500	3.530	268739.81250	3.687	279652.31250
4.200	281875.62500	4.157	281875.62500	4.314	281875.62500	4.471	281875.62500
4.985	281875.62500	4.942	281875.62500	5.098	281875.62500	5.255	281875.62500
5.769	281875.62500	5.726	281875.62500	5.883	281875.62500	6.040	281875.62500
6.553	281875.62500	6.510	281875.62500	6.667	281875.62500	6.824	281875.62500
7.338	281875.62500	7.295	281875.62500	7.452	281875.62500	7.608	281875.62500
8.122	281875.62500	8.079	281875.62500	8.236	281875.62500	8.393	281875.62500
8.907	281875.62500	8.863	281875.62500	9.020	281875.62500	9.177	281875.62500
9.691	281875.62500	9.648	281875.62500	9.805	281875.62500	9.962	281875.62500
10.475	281875.62500	10.432	281875.62500	10.589	281875.62500	10.746	281875.62500
11.260	281875.62500	11.217	281875.62500	11.374	281875.62500	11.530	281875.62500
11.844	281875.62500	12.001	281875.62500	12.158	281875.62500	12.315	281875.62500
12.628	281875.62500	12.785	281875.62500	12.942	281875.62500	13.099	281875.62500
MEAN = 0.25642E 06		LM=11.687	MIN=-0.21185E 06				



7.488 0.89988 7.765 0.68819 7.922 0.46545 8.079 0.20259 8.236 0.13161  
 8.350 0.84611 8.707 0.15002 8.863 0.43496 9.020 0.25238 9.177 0.64872  
 9.491 2.33396 9.648 0.27804 9.805 0.49755 10.118 0.29107 10.118 0.62313  
 10.432 3.20441 10.589 0.31420 10.746 0.42217 10.903 0.34579 10.903 0.22313  
 11.373 3.44474 11.530 0.34725 11.687 0.40013 11.844 0.32502 12.001 0.30597  
 12.315 2.60393 12.472 0.39047 12.628 0.42994 12.785 0.40000 12.942 0.60000  
 MEAN = 0.471 MAX = 0.41428 E 01 LN = 11.060 MIN = -0.35190 E 01  
 MEAN = 0.38309 E 01  
 DISTANCE FROM OCEAN END A 14.06250 MILE J = 6

HR. UIN(J) HR. UIN(J) HR. UIN(J) HR. UIN(J) HR. UIN(J)  
 0.078 -1.22588 0.235 -1.10089 0.392 -1.04648 0.549 -0.97732 0.706 -0.92281  
 1.020 -0.31111 1.177 0.13186 1.333 0.07497 1.490 0.30214 1.647 1.647  
 1.961 0.72074 2.118 0.8621 2.275 1.03104 2.432 1.16807 2.588 1.26425  
 2.902 1.45711 3.059 1.56133 3.216 2.13018 3.373 1.77228 3.530 1.87202  
 3.863 2.00601 4.020 2.06106 4.177 2.13018 4.334 2.17454 4.491 2.20464  
 4.785 2.15375 4.942 2.09379 5.098 2.03245 5.255 1.50950 5.412 1.90443  
 5.726 1.78146 5.883 1.69076 6.040 1.57719 6.197 1.52915 6.353 1.47443  
 6.687 0.38896 6.844 0.18010 6.981 1.06326 7.138 0.56632 7.295 0.86573  
 7.608 0.25444 7.765 0.48315 7.922 0.38836 8.079 0.26503 8.236 0.11423  
 8.350 -0.25444 8.507 0.43255 8.663 0.38836 8.819 0.40799 8.976 0.47529  
 9.177 -1.11708 9.334 0.22788 9.491 0.58339 9.648 0.9020 9.805 0.17177  
 10.432 -1.64747 10.589 0.58339 10.746 0.33373 10.903 0.562 10.118 0.15172  
 11.373 -1.79245 11.530 0.73503 11.687 0.17803 11.844 0.10903 11.060 0.17696  
 12.315 -1.45472 12.472 0.34007 12.628 0.17803 11.844 0.17696 12.001 0.16637  
 MEAN = 0.471 MAX = 0.22046 E 01 LN = 11.373 MIN = -0.17925 E 01  
 MEAN = 0.19959 E 01  
 DISTANCE FROM OCEAN END A 19.62750 MILE J = 8

HR. UIN(J) HR. UIN(J) HR. UIN(J) HR. UIN(J) HR. UIN(J)  
 0.078 -1.37215 0.235 -1.26729 0.392 -1.16674 0.549 -1.05281 0.706 -0.91884  
 1.020 -0.64010 1.177 0.48772 1.333 0.32528 1.490 0.11290 1.647 0.10836  
 1.961 0.47142 2.118 0.58881 2.275 0.73588 2.432 0.89845 2.588 1.05257  
 2.902 1.33184 3.059 1.54399 3.216 2.214 3.373 1.75086 3.530 1.86887  
 3.863 2.05281 4.020 1.91281 4.177 2.09359 4.334 2.10727 4.491 2.13958  
 4.785 2.11298 4.942 2.05577 5.098 2.03407 5.255 1.56289 5.412 1.91156  
 5.726 1.81824 5.883 1.77322 6.040 1.72460 6.197 1.63122 6.353 1.56136  
 6.687 0.43964 6.844 0.34538 6.981 0.981 7.138 0.41250 7.295 0.41250  
 7.608 0.30447 7.765 0.72020 7.922 0.60578 8.079 0.51279 8.236 0.62474  
 8.350 0.10447 8.507 0.09890 8.663 0.30310 8.819 0.47503 8.976 0.47503  
 9.177 -0.20318 9.334 0.05742 9.491 0.18167 9.648 0.13070 10.118 0.1118  
 10.432 -1.70228 10.589 0.746 10.746 0.962 10.903 0.75676 11.060 0.75676  
 11.373 -1.78755 11.530 0.77031 11.687 0.77487 11.844 0.77487 12.001 0.77487  
 12.315 -1.57393 12.472 0.48442 12.628 0.17610 11.844 0.17610 12.001 0.17610  
 MEAN = 0.428 MAX = 0.21434 E 01 LN = 10.746 MIN = -0.17769 E 01  
 MEAN = 0.19591 E 01  
 DISTANCE FROM OCEAN END A 25.31250 MILE J = 10

HR. UIN(J) HR. UIN(J) HR. UIN(J) HR. UIN(J) HR. UIN(J)  
 0.078 -1.54268 0.235 -1.45199 0.392 -1.37114 0.549 -1.29369 0.706 -1.20224  
 1.020 -0.94348 1.177 0.79995 1.333 0.45112 1.490 0.42666 1.647 0.28454  
 1.961 0.17127 2.118 0.36578 2.275 0.59559 2.432 0.86325 2.588 1.08373  
 2.902 1.37113 3.059 1.56068 3.216 1.73705 3.373 1.86214 3.530 1.90521  
 3.863 2.19708 4.020 2.0241 4.177 2.02863 4.334 2.08014 4.491 2.11479  
 4.785 2.19708 4.942 2.11248 5.098 2.0782 5.255 2.05920 5.412 1.98943  
 5.726 1.92755 5.883 1.89751 6.040 1.8851 6.197 1.80570 6.353 1.72177  
 6.687 1.09045 6.844 0.56648 6.981 0.8542 7.138 0.36898 7.295 0.22688  
 7.608 0.38460 7.765 0.97703 7.922 0.48305 8.079 0.74261 8.236 0.65990  
 8.350 -0.27708 8.507 0.20343 8.663 0.09744 8.819 0.22688 8.976 0.42386  
 9.177 -1.72398 9.334 0.63180 9.491 -0.10141 9.648 0.27682 10.118 0.1118  
 10.432 -1.79451 10.589 1.0508 10.746 0.962 10.903 0.75676 11.060 0.75676  
 11.373 -1.79451 11.530 1.0508 11.687 1.0508 11.844 1.0508 12.001 1.0508  
 12.315 -1.71324 12.472 0.63566 12.628 0.18012 11.844 0.18012 12.001 0.18012  
 MEAN = 0.428 MAX = 0.21530 E 01 LN = 11.687 MIN = -0.18012 E 01  
 MEAN = 0.19779 E 01  
 DISTANCE FROM OCEAN END A 30.93750 MILE J = 12

HR. UIN(J) HR. UIN(J) HR. UIN(J) HR. UIN(J) HR. UIN(J)  
 0.078 -1.54268 0.235 -1.45199 0.392 -1.37114 0.549 -1.29369 0.706 -1.20224  
 1.020 -0.94348 1.177 0.79995 1.333 0.45112 1.490 0.42666 1.647 0.28454  
 1.961 0.17127 2.118 0.36578 2.275 0.59559 2.432 0.86325 2.588 1.08373  
 2.902 1.37113 3.059 1.56068 3.216 1.73705 3.373 1.86214 3.530 1.90521  
 3.863 2.19708 4.020 2.0241 4.177 2.02863 4.334 2.08014 4.491 2.11479  
 4.785 2.19708 4.942 2.11248 5.098 2.0782 5.255 2.05920 5.412 1.98943  
 5.726 1.92755 5.883 1.89751 6.040 1.8851 6.197 1.80570 6.353 1.72177  
 6.687 1.09045 6.844 0.56648 6.981 0.8542 7.138 0.36898 7.295 0.22688  
 7.608 0.38460 7.765 0.97703 7.922 0.48305 8.079 0.74261 8.236 0.65990  
 8.350 -0.27708 8.507 0.20343 8.663 0.09744 8.819 0.22688 8.976 0.42386  
 9.177 -1.72398 9.334 0.63180 9.491 -0.10141 9.648 0.27682 10.118 0.1118  
 10.432 -1.79451 10.589 1.0508 10.746 0.962 10.903 0.75676 11.060 0.75676  
 11.373 -1.79451 11.530 1.0508 11.687 1.0508 11.844 1.0508 12.001 1.0508  
 12.315 -1.71324 12.472 0.63566 12.628 0.18012 11.844 0.18012 12.001 0.18012  
 MEAN = 0.428 MAX = 0.21530 E 01 LN = 11.687 MIN = -0.18012 E 01  
 MEAN = 0.19779 E 01  
 DISTANCE FROM OCEAN END A 30.93750 MILE J = 12

MEAN = 0.20609E 01		MAX = 0.22107E 01		MIN = -0.19112E 01		LW = 11.217		MILE		J = 14	
HR.	UIN(J)	HR.	UIN(J)	HR.	UIN(J)	HR.	UIN(J)	HR.	UIN(J)	HR.	UIN(J)
1.941	-0.10167	2.118	0.07528	2.275	4.32553	2.432	0.56106	2.586	0.82656		
2.802	1.62261	3.059	1.65776	3.214	1.60752	3.373	1.60919	3.530	1.98576		
3.663	2.07844	4.000	2.11829	4.187	2.11226	4.341	2.13577	4.471	2.16074		
4.524	2.70919	5.056	2.62994	5.056	2.11930	5.255	2.60870	5.412	2.15928		
5.385	2.10347	5.883	2.07994	6.040	2.04350	6.197	2.60877	6.353	1.95527		
6.246	1.80936	6.824	1.76400	6.981	1.70149	7.159	1.61933	7.255	1.53325		
7.107	1.33551	7.785	1.25833	7.922	1.14226	8.079	1.60723	8.236	0.87011		
8.008	0.69550	8.707	0.45755	8.883	0.27065	9.026	0.63775	9.177	-0.22134		
8.909	-0.08341	9.648	-0.48862	9.805	-1.10310	9.962	-1.83392	10.118	-1.36659		
9.810	-1.75448	10.589	-1.88449	10.746	-1.86067	10.903	-1.85641	11.060	-1.90701		
10.711	-1.90227	11.530	-1.89838	11.687	-1.90220	11.844	-1.85754	12.001	-1.68135		
11.612	-1.83453	12.472	-1.78824	12.628	-2.11711.87500	12.785	-0.00000	12.942	2.467595		
12.513	MEAN = 0.20609E 01	12.472	MAX = 0.22107E 01	12.628	MIN = -0.19112E 01						
13.414	DISTANCE FROM OCEAN END A 36.5625C MILE										
14.315	DISTANCE FROM OCEAN END A 42.18750 MILE										
15.216	DISTANCE FROM OCEAN END A 47.81250 MILE										
16.117	DISTANCE FROM OCEAN END A 53.43750 MILE										
17.018	DISTANCE FROM OCEAN END A 59.06250 MILE										
17.919	DISTANCE FROM OCEAN END A 64.68750 MILE										
18.820	DISTANCE FROM OCEAN END A 70.31250 MILE										
19.721	DISTANCE FROM OCEAN END A 75.93750 MILE										
20.622	DISTANCE FROM OCEAN END A 81.56250 MILE										
21.523	DISTANCE FROM OCEAN END A 87.18750 MILE										
22.424	DISTANCE FROM OCEAN END A 92.81250 MILE										
23.325	DISTANCE FROM OCEAN END A 98.43750 MILE										
24.226	DISTANCE FROM OCEAN END A 104.06250 MILE										
25.127	DISTANCE FROM OCEAN END A 109.68750 MILE										
26.028	DISTANCE FROM OCEAN END A 115.31250 MILE										
26.929	DISTANCE FROM OCEAN END A 120.93750 MILE										
27.830	DISTANCE FROM OCEAN END A 126.56250 MILE										
28.731	DISTANCE FROM OCEAN END A 132.18750 MILE										
29.632	DISTANCE FROM OCEAN END A 137.81250 MILE										
30.533	DISTANCE FROM OCEAN END A 143.43750 MILE										
31.434	DISTANCE FROM OCEAN END A 149.06250 MILE										
32.335	DISTANCE FROM OCEAN END A 154.68750 MILE										
33.236	DISTANCE FROM OCEAN END A 160.31250 MILE										
34.137	DISTANCE FROM OCEAN END A 165.93750 MILE										
35.038	DISTANCE FROM OCEAN END A 171.56250 MILE										
35.939	DISTANCE FROM OCEAN END A 177.18750 MILE										
36.840	DISTANCE FROM OCEAN END A 182.81250 MILE										
37.741	DISTANCE FROM OCEAN END A 188.43750 MILE										
38.642	DISTANCE FROM OCEAN END A 194.06250 MILE										
39.543	DISTANCE FROM OCEAN END A 199.68750 MILE										
40.444	DISTANCE FROM OCEAN END A 205.31250 MILE										
41.345	DISTANCE FROM OCEAN END A 210.93750 MILE										
42.246	DISTANCE FROM OCEAN END A 216.56250 MILE										
43.147	DISTANCE FROM OCEAN END A 222.18750 MILE										
44.048	DISTANCE FROM OCEAN END A 227.81250 MILE										
44.949	DISTANCE FROM OCEAN END A 233.43750 MILE										
45.850	DISTANCE FROM OCEAN END A 239.06250 MILE										
46.751	DISTANCE FROM OCEAN END A 244.68750 MILE										
47.652	DISTANCE FROM OCEAN END A 250.31250 MILE										
48.553	DISTANCE FROM OCEAN END A 255.93750 MILE										
49.454	DISTANCE FROM OCEAN END A 261.56250 MILE										
50.355	DISTANCE FROM OCEAN END A 267.18750 MILE										
51.256	DISTANCE FROM OCEAN END A 272.81250 MILE										
52.157	DISTANCE FROM OCEAN END A 278.43750 MILE										
53.058	DISTANCE FROM OCEAN END A 284.06250 MILE										
53.959	DISTANCE FROM OCEAN END A 289.68750 MILE										
54.860	DISTANCE FROM OCEAN END A 295.31250 MILE										
55.761	DISTANCE FROM OCEAN END A 300.93750 MILE										
56.662	DISTANCE FROM OCEAN END A 306.56250 MILE										
57.563	DISTANCE FROM OCEAN END A 312.18750 MILE										
58.464	DISTANCE FROM OCEAN END A 317.81250 MILE										
59.365	DISTANCE FROM OCEAN END A 323.43750 MILE										
60.266	DISTANCE FROM OCEAN END A 329.06250 MILE										
61.167	DISTANCE FROM OCEAN END A 334.68750 MILE										
62.068	DISTANCE FROM OCEAN END A 340.31250 MILE										
62.969	DISTANCE FROM OCEAN END A 345.93750 MILE										
63.870	DISTANCE FROM OCEAN END A 351.56250 MILE										
64.771	DISTANCE FROM OCEAN END A 357.18750 MILE										
65.672	DISTANCE FROM OCEAN END A 362.81250 MILE										
66.573	DISTANCE FROM OCEAN END A 368.43750 MILE										
67.474	DISTANCE FROM OCEAN END A 374.06250 MILE										
68.375	DISTANCE FROM OCEAN END A 379.68750 MILE										
69.276	DISTANCE FROM OCEAN END A 385.31250 MILE										
70.177	DISTANCE FROM OCEAN END A 390.93750 MILE										
71.078	DISTANCE FROM OCEAN END A 396.56250 MILE										
71.979	DISTANCE FROM OCEAN END A 402.18750 MILE										
72.880	DISTANCE FROM OCEAN END A 407.81250 MILE										
73.781	DISTANCE FROM OCEAN END A 413.43750 MILE										
74.682	DISTANCE FROM OCEAN END A 419.06250 MILE										
75.583	DISTANCE FROM OCEAN END A 424.68750 MILE										
76.484	DISTANCE FROM OCEAN END A 430.31250 MILE										
77.385	DISTANCE FROM OCEAN END A 435.93750 MILE										
78.286	DISTANCE FROM OCEAN END A 441.56250 MILE										
79.187	DISTANCE FROM OCEAN END A 447.18750 MILE										
80.088	DISTANCE FROM OCEAN END A 452.81250 MILE										
80.989	DISTANCE FROM OCEAN END A 458.43750 MILE										
81.890	DISTANCE FROM OCEAN END A 464.06250 MILE										
82.791	DISTANCE FROM OCEAN END A 469.68750 MILE										
83.692	DISTANCE FROM OCEAN END A 475.31250 MILE										
84.593	DISTANCE FROM OCEAN END A 480.93750 MILE										
85.494	DISTANCE FROM OCEAN END A 486.56250 MILE										
86.395	DISTANCE FROM OCEAN END A 492.18750 MILE										
87.296	DISTANCE FROM OCEAN END A 497.81250 MILE										
88.197	DISTANCE FROM OCEAN END A 503.43750 MILE										
89.098	DISTANCE FROM OCEAN END A 509.06250 MILE										
89.999	DISTANCE FROM OCEAN END A 514.68750 MILE										
90.900	DISTANCE FROM OCEAN END A 520.31250 MILE										
91.801	DISTANCE FROM OCEAN END A 525.93750 MILE										
92.702	DISTANCE FROM OCEAN END A 531.56250 MILE										
93.603	DISTANCE FROM OCEAN END A 537.18750 MILE										
94.504	DISTANCE FROM OCEAN END A 542.81250 MILE										
95.405	DISTANCE FROM OCEAN END A 548.43750 MILE										
96.306	DISTANCE FROM OCEAN END A 554.06250 MILE										
97.207	DISTANCE FROM OCEAN END A 559.68750 MILE										
98.108	DISTANCE FROM OCEAN END A 565.31250 MILE										
99.009	DISTANCE FROM OCEAN END A 570.93750 MILE										
99.910	DISTANCE FROM OCEAN END A 576.56250 MILE										
100.811	DISTANCE FROM OCEAN END A 582.18750 MILE										
101.712	DISTANCE FROM OCEAN END A 587.81250 MILE										
102.613	DISTANCE FROM OCEAN END A 593.43750 MILE										
103.514	DISTANCE FROM OCEAN END A 599.06250 MILE										
104.415	DISTANCE FROM OCEAN END A 604.68750 MILE										
105.316	DISTANCE FROM OCEAN END A 610.31250 MILE										
106.217	DISTANCE FROM OCEAN END A 615.93750 MILE										
107.118	DISTANCE FROM OCEAN END A 621.56250 MILE										
108.019	DISTANCE FROM OCEAN END A 627.18750 MILE										
108.920	DISTANCE FROM OCEAN END A 632.81250 MILE										
109.821	DISTANCE FROM OCEAN END A 638.43750 MILE										
110.722	DISTANCE FROM OCEAN END A 644.06250 MILE										
111.623	DISTANCE FROM OCEAN END A 649.68750 MILE										
112.524	DISTANCE FROM OCEAN END A 655.31250 MILE										
113.425	DISTANCE FROM OCEAN END A 660.93750 MILE										
114.326	DISTANCE FROM OCEAN END A 666.56250 MILE										
115.227	DISTANCE FROM OCEAN END A 672.18750 MILE										
116.128	DISTANCE FROM OCEAN END A 677.81250 MILE										
117.029	DISTANCE FROM OCEAN END A 683.43750 MILE										
117.930	DISTANCE FROM OCEAN END A 689.06250 MILE										
118.831	DISTANCE FROM OCEAN END A 694.68750 MILE										
119.732	DISTANCE FROM OCEAN END A 700.31250 MILE										
120.633	DISTANCE FROM OCEAN END A 705.93750 MILE										
121.534	DISTANCE FROM OCEAN END A 711.56250 MILE										
122.435	DISTANCE FROM OCEAN END A 717.18750 MILE										
123.336	DISTANCE FROM OCEAN END A 722.81250 MILE										
124.237	DISTANCE FROM OCEAN END A 728.43750 MILE										
125.138	DISTANCE FROM OCEAN END A 734.06250 MILE										
126.039	DISTANCE FROM OCEAN END A 739.68750 MILE										
126.940	DISTANCE FROM OCEAN END A 745.31250 MILE										
127.841	DISTANCE FROM OCEAN END A 750.93750 MILE										
128.742	DISTANCE FROM OCEAN END A 756.56250 MILE										
129.643	DISTANCE FROM OCEAN END A 762.18750 MILE										
130.544	DISTANCE FROM OCEAN END A 767.81250 MILE										
131.445	DISTANCE FROM OCEAN END A 773.43750 MILE										
132.346	DISTANCE FROM OCEAN END A 779.06250 MILE										
133.247	DISTANCE FROM OCEAN END A 784.68750 MILE										
134.148	DISTANCE FROM OCEAN END A 790.31250 MILE										
135.049	DISTANCE FROM OCEAN END A 795.93750 MILE										
135.950	DISTANCE FROM OCEAN END A 801.56250 MILE										
136.851	DISTANCE FROM OCEAN END A 807.18750 MILE										
137.752	DISTANCE FROM OCEAN END A 812.81250 MILE										
138.653	DISTANCE FROM OCEAN END A 818.43750 MILE										
139.554	DISTANCE FROM OCEAN END A 824.06250 MILE										
140.455	DISTANCE FROM OCEAN END A 829.68750 MILE										
141.356	DISTANCE FROM OCEAN END A 835.31250 MILE										
142.257	DISTANCE FROM OCEAN END A 840.93750 MILE										
143.158	DISTANCE FROM OCEAN END A 846.56250 MILE										
144.059	DISTANCE FROM OCEAN END A 852.18750 MILE										
144.960	DISTANCE FROM OCEAN END A 857.81250 MILE										
145.861	DISTANCE FROM OCEAN END A 863.43750 MILE										
146.762	DISTANCE FROM OCEAN END A 869.06250 MILE										
147.663	DISTANCE FROM OCEAN END A 874.68750 MILE										
148.564	DISTANCE FROM OCEAN END A 880.31250 MILE										
149.465	DISTANCE FROM OCEAN END A 885.93750 MILE										
150.366	DISTANCE FROM OCEAN END A 891.56250 MILE										
151.267	DISTANCE FROM OCEAN END A 897.18750 MILE										
152.168	DISTANCE FROM OCEAN END A 902.81250 MILE										
153.069	DISTANCE FROM OCEAN END A 908.43750 MILE										
153.970	DISTANCE FROM OCEAN END A 914.06250 MILE										
154.871	DISTANCE FROM OCEAN END A 919.68750 MILE										
155.772	DISTANCE FROM OCEAN END A 925.31250 MILE										
156.673	DISTANCE FROM OCEAN END A 930.93750 MILE										
157.574	DISTANCE FROM OCEAN END A 936.56250 MILE										
158.475	DISTANCE FROM OCEAN END A 942.18750 MILE										
159.376	DISTANCE FROM OCEAN END A 947.81250 MILE										
160.277	DISTANCE FROM OCEAN END A 953.43750 MILE										
161.178	DISTANCE FROM OCEAN END A 959.06250 MILE										
162.079	DISTANCE FROM OCEAN END A 964.68750 MILE										
162.980	DISTANCE FROM OCEAN END A 970.31250 MILE										
163.881	DISTANCE FROM OCEAN END A 975.93750 MILE										
164.782	DISTANCE FROM OCEAN END A 981.56250 MILE										
165.683	DISTANCE FROM OCEAN END A 987.18750 MILE										
166.584	DISTANCE FROM OCEAN END A 992.81250 MILE										
167.485	DISTANCE FROM OCEAN END A 998.43750 MILE										
168.386	DISTANCE FROM OCEAN END A 1004.06250 MILE										
169.287	DISTANCE FROM OCEAN END A 1009.68750 MILE										
170.188	DISTANCE FROM OCEAN END A 1015.31250 MILE										
171.089	DISTANCE FROM OCEAN END A 1020.93750 MILE										
171.990	DISTANCE FROM OCEAN END A 1026.56250 MILE										
172.891	DISTANCE FROM OCEAN END A 1032.18750 MILE										
173.792	DISTANCE FROM OCEAN END A 1037.81250 MILE										
174.693	DISTANCE FROM OCEAN END A 1043.43750 MILE										
175.594	DISTANCE FROM OCEAN END A 1049.06250 MILE										
176.495	DISTANCE FROM OCEAN END A 1054.68750 MILE										
177.396	DISTANCE FROM OCEAN END A 1060.31250 MILE										
178.297	DISTANCE FROM OCEAN END A 1065.93750 MILE										
179.198	DISTANCE FROM OCEAN END A 1071.56250 MILE										
180.099	DISTANCE FROM OCEAN END A 1077.18750 MILE										
180.900	DISTANCE FROM OCEAN END A 1082.81250 MILE										
181.801	DISTANCE FROM OCEAN END A 1088.43750 MILE										
182.702	DISTANCE FROM OCEAN END A 1094.06250 MILE										
183.603	DISTANCE FROM OCEAN END A 1099.68750 MILE										
184.504	DISTANCE FROM OCEAN END A 1105.31250 MILE										
185.405	DISTANCE FROM OCEAN END A 1110.93750 MILE										
186.306	DISTANCE FROM OCEAN END A 1116.56250 MILE										
187.207	DISTANCE FROM OCEAN END A 1122.18750 MILE										
188.108	DISTANCE FROM OCEAN END A 1127.81250 MILE										
189.009	DISTANCE FROM OCEAN END A 1133.43750 MILE										
189.910	DISTANCE FROM OCEAN END A 1139.06250 MILE										
190.811	DISTANCE FROM OCEAN END A 1144.68750 MILE										
191.712	DISTANCE FROM OCEAN END A 1150.31250 MILE										
192.613	DISTANCE FROM OCEAN END A 1155.93750 MILE										
193.514	DISTANCE FROM OCEAN END A 1161.56250 MILE										
194.415	DISTANCE FROM OCEAN END A 1167.18750 MILE										
195.316	DISTANCE FROM OCEAN END A 1172.81250 MILE										
196.217	DISTANCE FROM OCEAN END A 1178.43750 MILE										
197.118	DISTANCE FROM OCEAN END A 1184.06250 MILE										
198.019	DISTANCE FROM OCEAN END A 1189.68750 MILE										
198.920	DISTANCE FROM OCEAN END A 1195.31250 MILE										
199.821	DISTANCE FROM OCEAN END A 1200.93750 MILE										
200.722	DISTANCE FROM OCEAN END A 1206.56250 MILE										
201.623	DISTANCE FROM OCEAN END A 1212.18750 MILE										
202.524	DISTANCE FROM OCEAN END A 1217.81250 MILE										
203.425	DISTANCE FROM OCEAN END A 1223.43750 MILE										
204.326	DISTANCE FROM OCEAN END A 1229.06250 MILE										
205.227	DISTANCE FROM OCEAN END A 1234.68750 MILE										
206.128	DISTANCE FROM OCEAN END A 1240.31250 MILE										
207.029	DISTANCE FROM OCEAN END A 1245.93750 MILE										
207.930	DISTANCE FROM OCEAN END A 1251.56250 MILE										
208.831	DISTANCE FROM OCEAN END A 1257.18750 MILE										
209.732	DISTANCE FROM OCEAN END A 1262.81250 MILE										
210.633	DISTANCE FROM OCEAN END A 1268.43750 MILE										
211.534	DISTANCE FROM OCEAN END A 1274.06250 MILE										
212.435	DISTANCE FROM OCEAN END A 1279.68750 MILE										
213.336	DISTANCE FROM OCEAN END A 1285.31250 MILE										
214.237	DISTANCE FROM OCEAN END A 1290.93750 MILE										
215.138	DISTANCE FROM OCEAN END A 1296.56250 MILE										
216.039	DISTANCE FROM OCEAN END A 1302.18750 MILE										
216.940	DISTANCE FROM OCEAN END A 1307.81250 MILE										
217.841	DISTANCE FROM OCEAN END A 1313.43750 MILE										
218.742	DISTANCE FROM OCEAN END A 1319.06250 MILE										
219.643	DISTANCE FROM OCEAN END A 1324.68750 MILE										
220.544	DISTANCE FROM OCEAN END A 1330.31250 MILE										
221.445	DISTANCE FROM										

1-882 2-039 7-45000 2-196 8-00000 2-353 9-00000 2-510  
 2-824 3-922 10-90000 3-137 10-10000 3-294 10-30000 3-451  
 3-715 4-675 9-25000 4-075 10-80000 4-236 10-65000 4-392  
 4-704 4-653 9-25000 5-020 8-80000 5-177 8-35000 5-334  
 4-888 5-806 2-50000 5-961 5-70000 6-275 7-50000 6-427  
 5-130 7-746 2-50000 6-902 1-50000 7-216 0-10000 7-579  
 6-431 7-800 2-50000 7-844 -2-50000 8-001 -4-50000 8-157  
 6-412 8-628 6-800 8-785 -7-10000 8-942 -7-10000 9-099  
 6-412 9-389 8-30000 9-726 -8-50000 9-883 -8-50000 10-040  
 10-334 10-511 -8-50000 10-667 -8-50000 10-824 -7-50000 10-981  
 11-275 11-452 -5-70000 11-609 -5-00000 11-766 -3-60000 11-922  
 12-236 12-393 -3-95000 12-550 0-0 12-707 0-0  
 MEAN = 3.417 MAX = 9.69999 LN = 10.040 MIN = -9.10000  
 DISTANCE FROM OCEAN END A  
 HR. MIN. J  
 0-0 -2-22281 0-157 0-314 0-82940 0-627 0-17344 0-36863  
 0-941 1-80195 1-098 1-255 3-35589 1-412 4-52549 4-56565  
 1-882 3-43493 2-039 2-196 8-34480 2-353 7-92477 7-74331  
 2-824 5-0746 3-922 3-137 8-81230 3-294 8-23677 8-9344  
 3-765 6-82410 4-922 4-075 8-96131 4-236 8-94047 8-82168  
 4-706 8-29368 4-863 5-020 7-92981 5-177 7-55231 5-334  
 5-647 9-14754 5-804 5-961 5-71873 6-275 4-79448 6-275  
 6-589 1-18114 6-746 7-602 1-59515 7-059 4-31617 4-31617  
 7-530 -3-78941 7-687 7-844 -2-64770 8-001 4-79448 4-79448  
 8-471 -6-5085 8-628 -5-00810 8-001 3-04865 8-157  
 9-412 -4-19399 9-569 -7-00810 8-001 -5-70842 9-099  
 10-354 -2-11336 10-511 -6-77897 8-726 -7-31551 10-040  
 11-295 -2-38956 11-452 -4-95021 10-824 -6-23152 10-581  
 12-236 -2-17615 12-393 -1-58015 11-609 -4-57670 11-922  
 MEAN = 3.079 MAX = 9.69924 LN = 9.883 MIN = -3.19991

0-0 0-157 0-314 0-82940 0-627 0-17344 0-36863  
 -2-18335 1-098 1-255 3-35589 1-412 4-52549 4-56565  
 0-74816 2-039 2-196 8-34480 2-353 7-92477 7-74331  
 5-62293 3-922 3-137 8-81230 3-294 8-23677 8-9344  
 6-59197 4-863 5-020 7-92981 5-177 7-55231 5-334  
 5-33372 5-804 5-961 5-71873 6-275 4-79448 6-275  
 3-04933 6-746 7-602 1-59515 7-059 4-31617 4-31617  
 -3-51548 8-628 -5-00810 8-001 3-04865 8-157  
 -5-13145 9-569 -7-00810 8-001 -5-70842 9-099  
 -2-11336 10-511 -6-77897 8-726 -7-31551 10-040  
 -4-11330 11-452 -4-95021 10-824 -6-23152 10-581  
 -2-27750 12-393 -1-58015 11-609 -4-57670 11-922  
 MEAN = 3.137 MAX = 7.58138 LN = 9.726 MIN = -5.83494

0-0 0-157 0-314 0-82940 0-627 0-17344 0-36863  
 -2-18335 1-098 1-255 3-35589 1-412 4-52549 4-56565  
 0-74816 2-039 2-196 8-34480 2-353 7-92477 7-74331  
 5-62293 3-922 3-137 8-81230 3-294 8-23677 8-9344  
 6-59197 4-863 5-020 7-92981 5-177 7-55231 5-334  
 5-33372 5-804 5-961 5-71873 6-275 4-79448 6-275  
 3-04933 6-746 7-602 1-59515 7-059 4-31617 4-31617  
 -3-51548 8-628 -5-00810 8-001 3-04865 8-157  
 -5-13145 9-569 -7-00810 8-001 -5-70842 9-099  
 -2-11336 10-511 -6-77897 8-726 -7-31551 10-040  
 -4-11330 11-452 -4-95021 10-824 -6-23152 10-581  
 -2-27750 12-393 -1-58015 11-609 -4-57670 11-922  
 MEAN = 3.137 MAX = 7.58138 LN = 9.726 MIN = -5.83494

0-0 0-157 0-314 0-82940 0-627 0-17344 0-36863  
 -2-18335 1-098 1-255 3-35589 1-412 4-52549 4-56565  
 0-74816 2-039 2-196 8-34480 2-353 7-92477 7-74331  
 5-62293 3-922 3-137 8-81230 3-294 8-23677 8-9344  
 6-59197 4-863 5-020 7-92981 5-177 7-55231 5-334  
 5-33372 5-804 5-961 5-71873 6-275 4-79448 6-275  
 3-04933 6-746 7-602 1-59515 7-059 4-31617 4-31617  
 -3-51548 8-628 -5-00810 8-001 3-04865 8-157  
 -5-13145 9-569 -7-00810 8-001 -5-70842 9-099  
 -2-11336 10-511 -6-77897 8-726 -7-31551 10-040  
 -4-11330 11-452 -4-95021 10-824 -6-23152 10-581  
 -2-27750 12-393 -1-58015 11-609 -4-57670 11-922  
 MEAN = 3.137 MAX = 7.58138 LN = 9.726 MIN = -5.83494

HW= 3.137 MAX= 7.04837 LW= 9.726 MIN= -5.30362

MEAN = 6.17600

DISTANCE FROM OCEAN END A 22.50000 MILE

HR. H(N,J) J= 9

0.0	0.157	0.314	0.471	0.627	0.784	0.941	1.098	1.255	1.412	1.569	1.726	1.883	2.040	2.197	2.354	2.511	2.668	2.825	2.982	3.139	3.296	3.453	3.610	3.767	3.924	4.081	4.238	4.395	4.552	4.709	4.866	5.023	5.180	5.337	5.494	5.651	5.808	5.965	6.122	6.279	6.436	6.593	6.750	6.907	7.064	7.221	7.378	7.535	7.692	7.849	8.006	8.163	8.320	8.477	8.634	8.791	8.948	9.105	9.262	9.419	9.576	9.733	9.890	10.047	10.204	10.361	10.518	10.675	10.832	10.989	11.146	11.303	11.460	11.617	11.774	11.931	12.088	12.245	12.402	12.559	12.716	12.873	13.030	13.187	13.344	13.501	13.658	13.815	13.972	14.129	14.286	14.443	14.600	14.757	14.914	15.071	15.228	15.385	15.542	15.699	15.856	16.013	16.170	16.327	16.484	16.641	16.798	16.955	17.112	17.269	17.426	17.583	17.740	17.897	18.054	18.211	18.368	18.525	18.682	18.839	18.996	19.153	19.310	19.467	19.624	19.781	19.938	20.095	20.252	20.409	20.566	20.723	20.880	21.037	21.194	21.351	21.508	21.665	21.822	21.979	22.136	22.293	22.450	22.607	22.764	22.921	23.078	23.235	23.392	23.549	23.706	23.863	24.020	24.177	24.334	24.491	24.648	24.805	24.962	25.119	25.276	25.433	25.590	25.747	25.904	26.061	26.218	26.375	26.532	26.689	26.846	27.003	27.160	27.317	27.474	27.631	27.788	27.945	28.102	28.259	28.416	28.573	28.730	28.887	29.044	29.201	29.358	29.515	29.672	29.829	29.986	30.143	30.300	30.457	30.614	30.771	30.928	31.085	31.242	31.399	31.556	31.713	31.870	32.027	32.184	32.341	32.498	32.655	32.812	32.969	33.126	33.283	33.440	33.597	33.754	33.911	34.068	34.225	34.382	34.539	34.696	34.853	35.010	35.167	35.324	35.481	35.638	35.795	35.952	36.109	36.266	36.423	36.580	36.737	36.894	37.051	37.208	37.365	37.522	37.679	37.836	37.993	38.150	38.307	38.464	38.621	38.778	38.935	39.092	39.249	39.406	39.563	39.720	39.877	40.034	40.191	40.348	40.505	40.662	40.819	40.976	41.133	41.290	41.447	41.604	41.761	41.918	42.075	42.232	42.389	42.546	42.703	42.860	43.017	43.174	43.331	43.488	43.645	43.802	43.959	44.116	44.273	44.430	44.587	44.744	44.901	45.058	45.215	45.372	45.529	45.686	45.843	46.000	46.157	46.314	46.471	46.628	46.785	46.942	47.100	47.257	47.414	47.571	47.728	47.885	48.042	48.199	48.356	48.513	48.670	48.827	48.984	49.141	49.298	49.455	49.612	49.769	49.926	50.083	50.240	50.397	50.554	50.711	50.868	51.025	51.182	51.339	51.496	51.653	51.810	51.967	52.124	52.281	52.438	52.595	52.752	52.909	53.066	53.223	53.380	53.537	53.694	53.851	54.008	54.165	54.322	54.479	54.636	54.793	54.950	55.107	55.264	55.421	55.578	55.735	55.892	56.049	56.206	56.363	56.520	56.677	56.834	56.991	57.148	57.305	57.462	57.619	57.776	57.933	58.090	58.247	58.404	58.561	58.718	58.875	59.032	59.189	59.346	59.503	59.660	59.817	59.974	60.131	60.288	60.445	60.602	60.759	60.916	61.073	61.230	61.387	61.544	61.701	61.858	62.015	62.172	62.329	62.486	62.643	62.800	62.957	63.114	63.271	63.428	63.585	63.742	63.899	64.056	64.213	64.370	64.527	64.684	64.841	65.000	65.157	65.314	65.471	65.628	65.785	65.942	66.100	66.257	66.414	66.571	66.728	66.885	67.042	67.200	67.357	67.514	67.671	67.828	67.985	68.142	68.300	68.457	68.614	68.771	68.928	69.085	69.242	69.400	69.557	69.714	69.871	70.028	70.185	70.342	70.500	70.657	70.814	70.971	71.128	71.285	71.442	71.600	71.757	71.914	72.071	72.228	72.385	72.542	72.700	72.857	73.014	73.171	73.328	73.485	73.642	73.800	73.957	74.114	74.271	74.428	74.585	74.742	74.900	75.057	75.214	75.371	75.528	75.685	75.842	76.000	76.157	76.314	76.471	76.628	76.785	76.942	77.100	77.257	77.414	77.571	77.728	77.885	78.042	78.200	78.357	78.514	78.671	78.828	78.985	79.142	79.300	79.457	79.614	79.771	79.928	80.085	80.242	80.400	80.557	80.714	80.871	81.028	81.185	81.342	81.500	81.657	81.814	81.971	82.128	82.285	82.442	82.600	82.757	82.914	83.071	83.228	83.385	83.542	83.700	83.857	84.014	84.171	84.328	84.485	84.642	84.800	84.957	85.114	85.271	85.428	85.585	85.742	85.900	86.057	86.214	86.371	86.528	86.685	86.842	87.000	87.157	87.314	87.471	87.628	87.785	87.942	88.100	88.257	88.414	88.571	88.728	88.885	89.042	89.200	89.357	89.514	89.671	89.828	89.985	90.142	90.300	90.457	90.614	90.771	90.928	91.085	91.242	91.400	91.557	91.714	91.871	92.028	92.185	92.342	92.500	92.657	92.814	92.971	93.128	93.285	93.442	93.600	93.757	93.914	94.071	94.228	94.385	94.542	94.700	94.857	95.014	95.171	95.328	95.485	95.642	95.800	95.957	96.114	96.271	96.428	96.585	96.742	96.900	97.057	97.214	97.371	97.528	97.685	97.842	98.000	98.157	98.314	98.471	98.628	98.785	98.942	99.100	99.257	99.414	99.571	99.728	99.885	100.042	100.200	100.357	100.514	100.671	100.828	100.985	101.142	101.300	101.457	101.614	101.771	101.928	102.085	102.242	102.400	102.557	102.714	102.871	103.028	103.185	103.342	103.500	103.657	103.814	103.971	104.128	104.285	104.442	104.600	104.757	104.914	105.071	105.228	105.385	105.542	105.700	105.857	106.014	106.171	106.328	106.485	106.642	106.800	106.957	107.114	107.271	107.428	107.585	107.742	107.900	108.057	108.214	108.371	108.528	108.685	108.842	109.000	109.157	109.314	109.471	109.628	109.785	109.942	110.100	110.257	110.414	110.571	110.728	110.885	111.042	111.200	111.357	111.514	111.671	111.828	111.985	112.142	112.300	112.457	112.614	112.771	112.928	113.085	113.242	113.400	113.557	113.714	113.871	114.028	114.185	114.342	114.500	114.657	114.814	114.971	115.128	115.285	115.442	115.600	115.757	115.914	116.071	116.228	116.385	116.542	116.700	116.857	117.014	117.171	117.328	117.485	117.642	117.800	117.957	118.114	118.271	118.428	118.585	118.742	118.900	119.057	119.214	119.371	119.528	119.685	119.842	120.000	120.157	120.314	120.471	120.628	120.785	120.942	121.100	121.257	121.414	121.571	121.728	121.885	122.042	122.200	122.357	122.514	122.671	122.828	122.985	123.142	123.300	123.457	123.614	123.771	123.928	124.085	124.242	124.400	124.557	124.714	124.871	125.028	125.185	125.342	125.500	125.657	125.814	125.971	126.128	126.285	126.442	126.600	126.757	126.914	127.071	127.228	127.385	127.542	127.700	127.857	128.014	128.171	128.328	128.485	128.642	128.800	128.957	129.114	129.271	129.428	129.585	129.742	129.900	130.057	130.214	130.371	130.528	130.685	130.842	131.000	131.157	131.314	131.471	131.628	131.785	131.942	132.100	132.257	132.414	132.571	132.728	132.885	133.042	133.200	133.357	133.514	133.671	133.828	133.985	134.142	134.300	134.457	134.614	134.771	134.928	135.085	135.242	135.400	135.557	135.714	135.871	136.028	136.185	136.342	136.500	136.657	136.814	136.971	137.128	137.285	137.442	137.600	137.757	137.914	138.071	138.228	138.385	138.542	138.700	138.857	139.014	139.171	139.328	139.485	139.642	139.800	139.957	140.114	140.271	140.428	140.585	140.742	140.900	141.057	141.214	141.371	141.528	141.685	141.842	142.000	142.157	142.314	142.471	142.628	142.785	142.942	143.100	143.257	143.414	143.571	143.728	143.885	144.042	144.200	144.357	144.514	144.671	144.828	144.985	145.142	145.300	145.457	145.614	145.771	145.928	146.085	146.242	146.400	146.557	146.714	146.871	147.028	147.185	147.342	147.500	147.657	147.814	147.971	148.128	148.285	148.442	148.600	148.757	148.914	149.071	149.228	149.385	149.542	149.700	149.857	150.014	150.171	150.328	150.485	150.642	150.800	150.957	151.114	151.271	151.428	151.585	151.742	151.900	152.057	152.214	152.371	152.528	152.685	152.842	153.000	153.157	153.314	153.471	153.628	153.785	153.942	154.100	154.257	154.414	154.571	154.728	154.885	155.042	155.200	155.357	155.514	155.671	155.828	155.985	156.142	156.300	156.457	156.614	156.771	156.928	157.085	157.242	157.400	157.557	157.714	157.871	158.028	158.185	158.342	158.500	158.657	158.814	158.971	159.128	159.285	159.442	159.600	159.757	159.914	160.071	160.228	160.385	160.542	160.700	160.857	161.014	161.171	161.328	161.485	161.642	161.800	161.957	162.114	162.271	162.428	162.585	162.742	162.900	163.057	163.214	163.371	163.528	163.685	163.842	164.000	164.157	164.314	164.471	164.628	164.785	164.942	165.100	165.257	165.414	165.571	165.728	165.885	166.042	166.200	166.357	166.514	166.671	166.828	166.985	167.142	167.300	167.457	167.614	167.771	167.92
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7.530 0.31305 7.687 0.10563 7.864  
 8.471 -0.90917 8.668 -1.20373 8.785  
 9.412 -1.68484 9.569 -1.50159 9.726  
 10.354 -1.47925 10.511 -1.42333 10.667  
 11.295 -1.26239 11.452 -1.19538 11.604  
 12.236 -0.97187 12.393 -0.69239 12.550  
 HM = 3.294 MAX = 2.93996 LN = 9.256 MIN = -1.81801  
 MEAN = 2.37898  
 DISTANCE FROM OCEAN END A 45.00000 MILE J = 17

HR. H(N,J) HR. H(N,J) HR. H(N,J)  
 0.0 0.70000 0.157 0.70000 0.314 0.70000  
 0.961 0.65000 1.098 0.65000 1.255 0.65000  
 1.882 0.60000 2.039 0.59000 2.197 0.58000  
 2.824 0.56000 2.981 0.55000 3.137 0.54000  
 3.785 0.48000 3.922 0.39000 4.079 0.40000  
 4.706 0.20000 4.863 0.19000 5.020 0.19000  
 5.657 -0.02000 5.804 -0.04000 5.961 -0.07000  
 6.589 -0.20000 6.746 -0.20000 6.902 -0.20000  
 7.520 -0.20000 7.687 -0.21000 7.846 -0.20000  
 8.471 -0.18000 8.628 -0.17000 8.785 -0.15000  
 9.412 -0.02000 9.569 -0.01000 9.726 -0.01000  
 10.354 0.10000 10.511 0.11000 10.667 0.12000  
 11.295 0.17000 11.452 0.17000 11.609 0.18000  
 12.236 0.20000 12.393 0.21000 12.550 0.22000  
 HM = 0.627 MAX = 0.70000 LN = 7.216 MIN = -0.22000  
 MEAN = 0.46000

VARIATIONS OF Q ARE AS FOLLOWS  
 DISTANCE FROM OCEAN END A 2.81250 MILE J = 2

HR. Q(N,J) HR. Q(N,J) HR. Q(N,J)  
 0.078 -102579.56250 0.235 -87135.12500 0.392 -69994.43750  
 0.863 -13820.25391 1.020 13657.88281 1.177 38905.64062  
 1.647 103021.68750 1.804 126568.62500 1.961 148578.68750  
 2.432 190364.68750 2.588 202909.50000 2.745 210957.31250  
 3.216 223239.43750 3.373 230473.62500 3.530 241040.37500  
 4.000 274553.93750 4.157 278131.68750 4.314 277615.87500  
 4.785 259104.93750 4.942 250243.43750 5.098 241473.56250  
 5.569 208104.47500 5.726 194094.75000 5.883 180262.62500  
 6.353 139444.75000 6.510 123899.87500 6.667 109103.18750  
 7.138 54986.96875 7.295 38250.79297 7.451 19223.74609  
 8.022 -44174.16797 8.078 -61674.89844 8.234 -76229.50000  
 8.767 -117462.58250 8.943 -124088.25000 9.020 -128691.31250  
 9.491 -145816.06250 9.648 -148379.00000 9.805 -150038.00000  
 10.275 -165274.50000 10.432 -171021.68750 10.589 -175032.31250  
 11.060 -174914.31250 11.217 -188254.62500 11.373 -182932.56250  
 11.844 -135583.62500 12.001 -122330.25000 12.158 -109651.00000  
 12.628 -56593.89653 12.785 -12785.00000 12.942 -109651.00000  
 HM = 4.157 MAX = 0.27813E 06 LN = 10.903 MIN = -0.17931E 06  
 MEAN = 0.22875E 06

DISTANCE FROM OCEAN END A 8.43750 MILE J = 4

HR. Q(N,J) HR. Q(N,J) HR. Q(N,J)  
 0.078 -129394.00000 0.235 -112504.43750 0.392 -94335.68750  
 0.863 -39178.25781 1.020 -19424.06250 1.177 6189.35547  
 1.647 84714.93750 1.804 104306.06250 1.961 122993.00000  
 2.432 175146.81250 2.588 186904.37500 2.745 198344.62500  
 3.216 223446.56250 3.373 230504.81250 3.530 240065.37500  
 4.000 273133.50000 4.157 280332.43750 4.314 282064.56250  
 4.785 272782.81250 4.942 264381.00000 5.098 254338.56250  
 5.569 223586.68750 5.726 170153.75000 5.883 197623.93750  
 6.353 159495.37500 6.510 147105.68750 6.667 132073.31250  
 7.138 81110.37500 7.295 63495.96875 7.451 45308.14453  
 8.022 -16165.62381 8.078 -39748.82422 8.234 -89492.38881  
 8.701 -88165.62500 8.943 -109077.75000 9.020 -117691.64580  
 9.491 -12340.88250 9.648 -140009.56250 9.805 -144681.75000  
 10.275 -172541.56250 10.432 -179874.43750 10.589 -185745.93750  
 11.060 -184457.06250 11.217 -182971.61250 11.373 -179274.12500  
 HR. Q(N,J) HR. Q(N,J) HR. Q(N,J)  
 0.706 -54662.25000 -75187.75000  
 1.490 61137.35156 35199.17578  
 2.275 164974.68750 143881.50000  
 3.059 219992.18750 206253.43750  
 3.843 263583.06250 251781.43750  
 4.628 277559.12500 282496.43750  
 5.412 267110.50000 283682.68750  
 6.197 153415.43750 18467.81250  
 6.981 74892.25000 116760.37500  
 7.765 -24383.00000 26302.37666  
 8.550 -139815.12500 78489.63750  
 9.334 -139815.12500 91372.37500  
 10.118 -179375.00000 134071.25000  
 10.903 -179375.00000 178181.12500  
 11.687 -155734.75000 182932.56250  
 12.472 -96605.25000 109651.00000  
 13.256 0.00000 0.00000  
 HR. Q(N,J) HR. Q(N,J) HR. Q(N,J)  
 0.706 -56900.64062  
 1.490 61910.02734  
 2.275 162054.37500  
 3.059 215329.50000  
 3.843 262193.00000  
 4.628 280820.93750  
 5.412 234436.43750  
 6.197 171328.18750  
 6.981 99975.93750  
 7.765 7312.07031  
 8.550 -87840.12500  
 9.334 -129058.37500  
 10.118 -163303.62500  
 10.903 -166359.62500  
 11.687 -165259.62500  
 12.472 -165733.36250

11.844 -156423.81250 12.001 -145586.62500 12.152 12.315 12.472  
 12.628 -8523.75000 12.785 0.00000 12.942 13.099 13.256  
 HR. 4.471 MAX=0.28250E 06 L=10.746 MIN=-0.18797E C6  
 MEAN = 0.23523E 06  
 DISTANCE FROM OCEAN END A 14.06250 MILE J= 6  
 Q(N,J) Q(N,J) Q(N,J) Q(N,J) Q(N,J)  
 0.078 -144121.56250 0.235 -130241.00000 0.392 -112706.37500 0.549 -94006.63750 0.768 -76544.37500  
 0.863 -59945.25781 1.020 -42900.85156 1.177 -22609.48337 1.333 -9564.71074 1.490 35863.34222  
 1.647 64189.25000 1.804 83162.56250 1.961 103401.75000 2.118 120268.96250 2.275 143953.75000  
 2.432 161805.43750 2.588 173070.50000 2.745 183645.25000 2.902 190110.96250 3.059 213770.75000  
 3.216 226500.37500 3.373 238078.56250 3.530 256248.37500 3.687 263393.87500 3.844 269906.56000  
 4.000 269331.87500 4.157 278337.37500 4.314 287486.25000 4.471 294595.62500 4.628 298510.18750  
 4.785 284147.25000 4.942 272657.00000 5.098 277288.62500 5.255 284443.60000 5.412 284520.68750  
 5.569 231519.37500 5.726 223505.75000 5.883 209300.68750 6.040 190390.00000 6.197 187473.81250  
 6.353 175051.81250 6.510 162441.50000 6.667 150258.62500 6.824 143668.50000 6.981 138188.56250  
 7.138 102576.00000 7.295 84237.43750 7.452 69310.68750 7.609 48588.25000 7.765 25584.67631  
 7.922 -83398.50000 8.079 -55128.18750 8.236 -39894.14453 8.393 -27707.69531 8.550 -20886.60000  
 8.707 -128322.81250 8.864 -138441.75000 9.020 -148675.43750 9.177 -153368.81250 9.334 -155308.60000  
 9.491 -180726.62500 9.648 -188441.75000 9.805 -192228.87500 9.962 -191965.37500 10.119 -191686.56250  
 10.275 -197015.31250 10.432 -190723.56250 10.589 -187935.50000 10.746 -182854.50000 10.903 -176191.87500  
 11.060 -164528.37500 11.217 -159592.25000 11.373 -148189.31250 11.530 -134232.81250 11.687 -119336.50000  
 11.844 -104385.31250 12.001 -8523.75000 12.158 12.315 12.472  
 HR. 4.314 MAX=0.28749E 06 L=10.589 MIN=-0.19223E C6  
 MEAN = 0.23986E 06  
 DISTANCE FROM OCEAN END A 19.68750 MILE J= 8  
 Q(N,J) Q(N,J) Q(N,J) Q(N,J) Q(N,J)  
 0.078 -168467.75000 0.235 -156512.06250 0.392 -145046.75000 0.549 -131884.75000 0.768 -114360.42500  
 0.863 -100196.37500 1.020 -84261.56250 1.177 -67467.25000 1.333 -47534.38672 1.490 -20848.35250  
 1.647 12782.94531 1.804 43671.31250 1.961 64352.14404 2.118 82957.66250 2.275 104986.52500  
 2.432 126221.12500 2.588 145870.62500 2.745 165194.31250 2.902 182229.87500 3.059 206257.62500  
 3.216 236686.31250 3.373 251708.62500 3.530 263937.18750 3.687 266257.00000 3.844 268259.68750  
 4.000 270063.37500 4.157 277032.62500 4.314 286097.87500 4.471 294595.62500 4.628 298510.18750  
 4.785 290535.56250 4.942 287894.25000 5.098 277288.62500 5.255 264013.62500 5.412 254797.37500  
 5.569 247632.93750 5.726 239790.18750 5.883 233179.31250 6.040 224913.56250 6.197 214135.37500  
 6.353 203741.93750 6.510 191762.00000 6.667 178775.75000 6.824 166664.61250 6.981 153242.16750  
 7.138 138509.31250 7.295 123550.81250 7.452 107263.66250 7.609 89460.50000 7.765 73531.61616  
 7.922 51345.11719 8.079 32016.14016 8.236 -81314.81250 8.393 -95071.18750 8.550 -107179.12500  
 8.707 -53223.97656 8.864 -67360.81250 9.020 -81314.81250 9.177 -95071.18750 9.334 -107179.12500  
 9.491 -120650.37500 9.648 -134630.50000 9.805 -146295.25000 9.962 -171880.37500 10.119 -187192.12500  
 10.275 -197015.31250 10.432 -200072.12500 10.589 -195595.93750 10.746 -200405.68750 10.903 -201921.87500  
 11.060 -209266.50000 11.217 -202098.50000 11.373 -199729.31250 11.530 -196561.62500 11.687 -192865.15000  
 11.844 -187857.50000 12.001 -180528.50000 12.158 -171124.50000 12.315 -160368.31250 12.472 -148331.62500  
 12.628 -134201.50000 12.785 12.315 12.472  
 HR. 4.471 MAX=0.29470E 06 L=11.060 MIN=-0.20293E C6  
 MEAN = 0.24881E 06  
 DISTANCE FROM OCEAN END A 25.31250 MILE J= 10  
 Q(N,J) Q(N,J) Q(N,J) Q(N,J) Q(N,J)  
 0.078 -191422.68750 0.235 -181153.25000 0.392 -172091.43750 0.549 -163426.87500 0.768 -153116.43750  
 0.863 -139546.62500 1.020 -123382.50000 1.177 -106715.43750 1.333 -89783.31250 1.490 -70140.93750  
 1.647 -44631.80469 1.804 -11933.81641 1.961 22536.21484 2.118 48427.48647 2.275 66713.56250  
 2.432 89422.53750 2.588 120345.50000 2.745 153928.06250 2.902 183633.12500 3.059 211955.62500  
 3.216 241131.43750 3.373 262568.75000 3.530 269375.56250 3.687 271070.62500 3.844 272577.62500  
 4.000 274921.43750 4.157 280190.25000 4.314 285720.12500 4.471 292153.56250 4.628 298510.18750  
 4.785 298119.50000 4.942 291624.12500 5.098 286845.50000 5.255 279649.31250 5.412 275894.25000  
 5.569 262757.62500 5.726 257572.87500 5.883 253507.18750 6.040 248644.75000 6.197 243959.18750  
 6.353 228126.18750 6.510 217582.37500 6.667 206414.18750 6.824 195171.31250 6.981 184564.50000  
 7.138 172003.68750 7.295 158168.68750 7.452 143939.68750 7.609 128191.37500 7.765 112954.50000  
 7.922 90806.00000 8.079 72150.31250 8.236 52452.30078 8.393 30554.44331 8.550 14922.68594  
 8.707 -11803.38672 8.864 -41951.05469 9.020 -57567.51172 9.177 -70343.06250 9.334 -85508.68594  
 9.491 -119167.62500 9.648 -141881.56250 9.805 -162688.01250 9.962 -180866.25000 10.119 -20554.37500  
 10.275 -203444.43750 10.432 -210206.56250 10.589 -208641.56250 10.746 -210374.60938 10.903 -210514.31250  
 11.060 -210793.18750 11.217 -210228.81250 11.373 -203177.12500 11.530 -207958.443750 11.687 -205658.16750  
 11.844 -201365.06250 12.001 -195686.25000 12.158 -189218.12500 12.315 -181664.16750 12.472 -172964.16750  
 12.628 -163176.18750 12.785 12.315 12.472  
 HR. 4.628 MAX=0.29891E 06 L=10.903 MIN=-0.21031E C6  
 MEAN = 0.24881E 06  
 DISTANCE FROM OCEAN END A 25.31250 MILE J= 10

MEAN = 0.25491E 06  
 DISTANCE FROM OCEAN END A 30.93750 MILE J= 12

HR.	Q(N,J)	HR.	Q(N,J)
0.078	-211711.87500	0.235	-205171.31250
0.863	-172479.43750	1.020	-159878.31250
1.647	-90768.43750	1.804	-64083.81250
2.432	58424.43750	2.588	101274.62500
3.216	240300.06250	3.373	255586.81250
4.000	284735.06250	4.157	284388.31250
4.785	297617.81250	4.942	296089.68750
5.569	279684.50000	5.726	276691.00000
6.353	251014.93750	6.510	240640.18750
7.138	201192.12500	7.295	188529.68750
7.922	126599.00000	8.079	108563.56250
8.707	18341.41806	8.863	-10252.74219
9.491	-119756.12500	9.648	-147525.00000
10.275	-204175.00000	10.432	-211568.75000
11.060	-217868.87500	11.217	-217177.87500
11.844	-211006.43750	12.001	-207588.50000
12.628	-186362.37500	12.785	-160.00000

MIN = 0.29762E 06  
 MAX = 0.25762E 06  
 LN=10.903 MIN=-0.21891E 06

DISTANCE FROM OCEAN END A 36.56250 MILE J= 14

HR.	Q(N,J)	HR.	Q(N,J)
0.078	-219128.06250	0.235	-214996.50000
0.863	-183362.12500	1.020	-174233.12500
1.647	-108285.37500	1.804	-86505.12500
2.432	58745.82031	2.588	96131.18750
3.216	236531.43750	3.373	251631.31250
4.000	287782.75000	4.157	299160.87500
4.785	293981.25000	4.942	297056.00000
5.569	260951.06250	5.726	284152.50000
6.353	212644.43750	6.510	253450.62500
7.138	142693.43750	7.295	200637.50000
7.922	35404.89844	8.079	124347.56250
8.707	-121118.93750	8.863	6110.67578
9.491	-205605.12500	9.648	-149829.25000
10.275	-221445.75000	10.432	-212781.68750
11.060	-214889.31250	11.217	-221435.50000
11.844	-214889.31250	12.001	-212041.43750
12.628	-195938.06250	12.785	12.32000

MIN = 0.25953E 06  
 MAX = 0.29755E 06  
 LN=10.903 MIN=-0.22131E 06

DISTANCE FROM OCEAN END A 42.18750 MILE J= 16

HR.	Q(N,J)	HR.	Q(N,J)
0.078	-221800.68750	0.235	-218831.06250
0.863	-190414.37500	1.020	-178019.00000
1.647	-117156.37500	1.804	-92702.56250
2.432	49243.8422	2.588	12470.37500
3.216	230859.62500	3.373	29342.37500
4.000	291589.06250	4.157	292443.87500
4.785	292818.62500	4.942	295543.62500
5.569	294861.18750	5.726	291086.81250
6.353	26009.81250	6.510	259396.75000
7.138	219007.50000	7.295	201543.75000
7.922	149756.43750	8.079	132033.81250
8.707	42217.97656	8.863	14530.32422
9.491	-128046.56250	9.648	-151176.87500
10.275	-204395.87500	10.432	-214896.06250
11.060	-224394.62500	11.217	-223962.93750
11.844	-216434.25000	12.001	-214518.87500
12.628	-200316.81250	12.785	15.70000

MIN = 0.30049E 06  
 MAX = 0.26244E 06  
 LN=11.060 MIN=-0.22439E 06

Q(N,J) HR.  
 -190189.87500 0.706  
 -126719.48750 1.490  
 -33660.29297 2.275  
 2420.15047 3.059  
 181785.60000 3.843  
 276572.62500 4.628  
 291102.62500 5.412  
 281028.62500 6.197  
 265082.75000 6.981  
 232225.37500 7.765  
 199494.37500 8.550  
 88070.62500 9.334  
 -65100.37500 10.118  
 -188242.75000 10.903  
 -216722.00000 11.687  
 -198729.56250 12.472  
 22.35959 13.256

Q(N,J) HR.  
 -194236.75000 0.706  
 -127167.12500 1.490  
 17667.23828 2.275  
 213864.00000 3.059  
 285416.62500 3.843  
 252156.43750 4.628  
 263179.62500 5.412  
 257106.43750 6.197  
 247171.93750 6.981  
 138612.61250 7.765  
 61102.38672 8.550  
 -50868.37500 9.334  
 -157098.50000 10.118  
 -221511.00000 10.903  
 -217405.12500 11.687  
 -201161.25000 12.472  
 349000 13.256

Q(N,J) HR.  
 -200609.81250 0.706  
 -137440.25000 1.490  
 -1576.36841 2.275  
 203150.43750 3.059  
 285341.25000 3.843  
 250345.68750 4.628  
 258522.75000 5.412  
 271573.37500 6.197  
 225726.00000 6.981  
 166489.37500 7.765  
 -18458.60000 8.550  
 -15500.37500 9.334  
 -158238.75000 10.118  
 -223116.25000 10.903  
 -218942.31250 11.687  
 -204888.50000 12.472  
 540000 13.256

VARIATIONS OF U ARE AS FOLLOWS

ALL VELOCITIES ARE IN KNOTS  
DISTANCE FROM OCEAN END A 2.81250 MILE J= 2

HR.	U(N,J)	HR.	U(N,J)	HR.	U(N,J)	HR.	U(N,J)
0.078	-1.71085	0.235	-1.43345	0.392	-1.13698	0.549	-0.87783
1.020	0.21119	1.177	0.59332	1.333	0.92083	1.490	1.21150
1.961	2.15674	2.118	2.36596	2.275	2.53286	2.432	2.68873
2.902	3.02308	3.059	3.04562	3.216	3.08444	3.373	3.17961
3.843	3.62360	4.000	3.77334	4.157	3.82646	4.314	3.82632
4.785	3.62359	4.942	3.52135	5.098	3.41954	5.255	3.30828
5.726	2.82611	5.883	2.64597	6.040	2.47532	6.197	2.29112
6.667	1.68224	6.824	1.44202	6.981	1.18399	7.138	0.91263
7.608	0.02425	7.765	-0.41263	7.922	-0.75817	8.079	-1.07155
8.550	-1.91427	8.707	-2.12476	8.863	-2.26464	9.020	-2.37008
9.491	-2.73136	9.648	-2.79599	9.805	-2.83935	9.962	-2.90855
10.432	-3.21983	10.589	-3.27617	10.746	-3.31454	10.903	-3.31365
11.373	-2.93215	11.530	-2.77073	11.687	-2.58342	11.844	-2.35273
12.315	-1.61142	12.472	-1.28957	12.628	-56253.85453	12.785	0.00000
MEAN = 4.157	MAX= 0.38265E 01	LM=10.746	MIN=-0.33145E 01				
MEAN = 0.35705E 01							

DISTANCE FROM OCEAN END A 8.43750 MILE J= 4

HR.	U(N,J)	HR.	U(N,J)	HR.	U(N,J)	HR.	U(N,J)
0.078	-2.14516	0.235	-1.84600	0.392	-1.53193	0.549	-1.20906
1.020	-0.30266	1.177	0.09515	1.333	0.53400	1.490	0.52899
1.961	1.79523	2.118	2.08047	2.275	2.32414	2.432	2.45505
2.902	2.88953	3.059	3.00926	3.216	3.12174	3.373	3.22397
3.843	3.67934	4.000	3.83179	4.157	3.93083	4.314	3.95925
4.785	3.86560	4.942	3.76500	5.098	3.63816	5.255	3.50112
5.726	3.06335	5.883	2.89900	6.040	2.72348	6.197	2.54731
6.667	2.01315	6.824	1.79658	6.981	1.55340	7.138	1.28269
7.608	0.42669	7.765	0.12008	7.922	-0.26500	8.079	-0.66962
8.550	-1.52198	8.707	-1.72677	8.863	-1.92273	9.020	-2.08856
9.491	-2.43435	9.648	-2.54628	9.805	-2.66038	9.962	-2.79572
10.432	-3.22194	10.589	-3.31176	10.746	-3.33780	10.903	-3.30147
11.373	-3.12520	11.530	-3.00383	11.687	-2.84934	11.844	-2.66820
12.315	-1.97461	12.472	-1.70298	12.628	-85523.75000	12.785	0.00000
MEAN = 4.471	MAX= 0.39737E 01	LM=10.746	MIN=-0.33378E 01				
MEAN = 0.36558E 01							

DISTANCE FROM OCEAN END A 14.06250 MILE J= 6

HR.	U(N,J)	HR.	U(N,J)	HR.	U(N,J)	HR.	U(N,J)
0.078	-1.22588	0.235	-1.10009	0.392	-0.94453	0.549	-0.78181
1.020	-0.34646	1.177	0.18060	1.333	0.04462	1.490	0.30062
1.961	0.78285	2.118	0.92376	2.275	1.06476	2.432	1.19554
2.902	1.45610	3.059	1.55315	3.216	1.64652	3.373	1.73457
3.843	1.95089	4.000	1.97751	4.157	2.04083	4.314	2.10837
4.785	2.09564	4.942	2.01286	5.098	1.94384	5.255	1.86648
5.726	1.68153	5.883	1.58303	6.040	1.49923	6.197	1.43382
6.667	1.17269	6.824	1.05626	6.981	0.93636	7.138	0.81959
7.608	0.39941	7.765	0.24564	7.922	-0.07900	8.079	-0.12926
8.550	-1.16306	8.707	-0.73576	8.863	-0.84544	9.020	-0.54640
9.491	-1.69078	9.648	-1.24174	9.805	-1.35002	9.962	-1.45655
10.432	-1.65290	10.589	-1.71600	10.746	-1.70914	10.903	-1.70323
11.373	-1.14404	11.530	-1.60287	11.687	-1.53772	11.844	-1.46345
12.315	-1.14404	12.472	-1.00989	12.628	-104365.31250	12.785	0.00000
MEAN = 4.314	MAX= 0.21084E 01	LM=10.589	MIN=-0.17160E 01				
MEAN = 0.19122E 01							

DISTANCE FROM OCEAN END A 19.68750 MILE J= 8

HR.	U(N,J)	HR.	U(N,J)	HR.	U(N,J)	HR.	U(N,J)
0.078	-1.37215	0.235	-1.26729	0.392	-1.16676	0.549	-1.05284
1.020	-0.65482	1.177	0.51940	1.333	-0.36225	1.490	-0.15708
1.961	0.46925	2.118	0.59997	2.275	0.75222	2.432	0.85838
2.902	1.31503	3.059	1.49426	3.216	1.64770	3.373	1.77082
3.843	1.87671	4.000	1.91175	4.157	1.96183	4.314	2.02603
4.785	2.06294	4.942	2.04779	5.098	1.97697	5.255	1.88747
5.726	1.73084	5.883	1.69379	6.040	1.63778	6.197	1.56885
6.667	1.33316	6.824	1.25090	6.981	1.15831	7.138	1.05493
7.608	0.69659	7.765	0.55474	7.922	0.40862	8.079	0.25734

8.550	-0.31137	8.707	-0.46528	8.863	-0.56757	9.020	-0.69459	9.177	-0.81665
9.491	-1.03546	9.668	-1.17251	9.805	-1.32293	9.962	-1.47040	10.118	-1.58600
10.432	-1.69714	10.588	-1.85958	10.745	-1.96018	10.893	-1.70152	11.050	-1.70593
11.373	-1.67082	11.532	-1.65962	11.657	-1.60343	11.844	-1.55581	12.001	-1.48885
12.315	-1.30982	12.472	-1.20376	12.628	-1.35201.50000	12.785	0.77279	12.942	*****
HM= 4.628	MAX= 0.20877E 01	LW=11.066	MIN=-0.17659E 01						
MEAN = 0.18948E 01									
DISTANCE FROM OCEAN END A	25.3125C MILE	J= 10							
HR.	U(N,J)	HR.	U(N,J)	HR.	U(N,J)	HR.	U(N,J)	HR.	U(N,J)
0.078	-1.59168	0.235	-1.45195	0.392	-1.37114	0.549	-1.29367	0.706	-1.20333
1.020	-0.92883	1.177	-0.81788	1.333	-0.68205	1.490	-0.52790	1.647	-0.35253
1.961	0.16403	2.118	0.36513	2.275	0.47705	2.432	0.63524	2.588	0.80283
2.902	1.28929	3.059	1.48362	3.216	1.69572	3.373	1.86739	3.530	1.95613
3.843	1.92290	4.000	1.94263	4.157	1.98213	4.314	2.02217	4.471	2.06747
4.785	2.10991	4.942	2.06565	5.098	2.03434	5.255	1.98765	5.412	1.92417
5.726	1.84914	5.883	1.82720	6.040	1.79564	6.197	1.74075	6.353	1.68720
6.667	1.52491	6.824	1.49050	6.981	1.37861	7.138	1.29459	7.295	1.15887
7.608	0.97141	7.765	0.84249	7.922	-0.34685	8.079	-0.59679	8.236	-0.84524
8.550	0.03554	8.707	-0.17886	8.863	-0.34685	9.020	-0.59679	9.177	-0.84524
9.491	-0.00012	9.648	-1.19006	9.805	-1.36373	9.962	-1.52131	10.118	-1.63955
10.432	-1.71496	10.585	-1.73272	10.746	-1.74471	10.903	-1.74490	11.060	-1.74050
11.373	-1.72055	11.530	-1.70659	11.687	-1.68350	11.844	-1.54395	12.001	-1.52776
12.315	-1.46693	12.472	-1.39004	12.628	-1.63176.18750	12.785	0.0	12.942	0.0
HM= 4.628	MAX= 0.21148E 01	LW=10.903	MIN=-0.17449E 01						
MEAN = 0.19298E 01									
DISTANCE FROM OCEAN END A	30.53750 MILE	J= 12							
HR.	U(N,J)	HR.	U(N,J)	HR.	U(N,J)	HR.	U(N,J)	HR.	U(N,J)
0.078	-1.75163	0.235	-1.68970	0.392	-1.61917	0.549	-1.54997	0.706	-1.47557
1.020	-1.27701	1.177	-1.14317	1.333	-0.92662	1.490	-0.85351	1.647	-0.70202
1.961	-0.35520	2.118	0.01814	2.275	0.26467	2.432	0.48647	2.588	0.74564
2.902	1.33335	3.059	1.58822	3.216	1.76111	3.373	1.87082	3.530	1.96424
3.843	2.06720	4.000	2.08894	4.157	2.08962	4.314	2.11428	4.471	2.14104
4.785	2.18579	4.942	2.17875	5.098	2.14904	5.255	2.14345	5.412	2.11502
5.726	2.05825	5.883	2.02793	6.040	1.98585	6.197	1.85745	6.353	1.89580
6.667	1.77154	6.824	1.62974	6.981	1.62974	7.138	1.56051	7.295	1.47692
7.608	1.26089	7.765	1.04160	7.922	0.88635	8.079	0.81770	8.236	0.72665
8.550	0.36965	8.707	0.15320	8.863	-0.08635	9.020	-0.31738	9.177	-0.53371
9.491	-1.02011	9.648	-1.23562	9.805	-1.46274	9.962	-1.59928	10.118	-1.66825
10.432	-1.76857	10.585	-1.83456	10.746	-1.84844	10.903	-1.84967	11.060	-1.83786
11.373	-1.82821	11.530	-1.81860	11.687	-1.79314	11.844	-1.76417	12.001	-1.73188
12.315	-1.84769	12.472	-1.59650	12.628	-1.63176.18750	12.785	-0.00000	12.942	2.46299
HM= 4.785	MAX= 0.21858E 01	LW=10.903	MIN=-0.18497E 01						
MEAN = 0.20177E 01									
DISTANCE FROM OCEAN END A	36.5625C MILE	J= 14							
HR.	U(N,J)	HR.	U(N,J)	HR.	U(N,J)	HR.	U(N,J)	HR.	U(N,J)
0.078	-3.40168	0.235	-3.32850	0.392	-3.22645	0.549	-3.13058	0.706	-2.95722E
1.020	-2.64431	1.177	-2.42002	1.333	-2.16764	1.490	-1.89845	1.647	-1.60695
1.961	-0.86493	2.118	-0.34429	2.275	0.25367	2.432	0.84154	2.588	1.37510
2.902	2.58518	3.059	3.05611	3.216	3.36713	3.373	3.58161	3.530	3.78744
3.843	4.06895	4.000	4.10453	4.157	4.13065	4.314	4.15017	4.471	4.14676
4.785	4.20100	4.942	4.24247	5.098	4.25169	5.255	4.20569	5.412	4.26555
5.726	4.10072	5.883	4.03758	6.040	3.97926	6.197	3.88726	6.353	3.80746
6.667	3.57626	6.824	3.45744	6.981	3.33128	7.138	3.16481	7.295	2.99823
7.608	2.62135	7.765	2.40426	7.922	2.17406	8.079	1.90455	8.236	1.66807
8.550	0.95091	8.707	0.55409	8.863	0.09416	9.020	-0.42553	9.177	-0.95375
9.491	-1.91868	9.648	-2.37019	9.805	-2.71775	9.962	-2.95034	10.118	-3.14084
10.432	-3.36395	10.589	-3.45166	10.746	-3.49290	10.903	-3.44534	11.060	-3.48995
11.373	-3.46739	11.530	-3.44317	11.687	-3.41003	11.844	-3.36679	12.001	-3.31744
12.315	-3.20453	12.472	-3.12727	12.628	-1.95938.06250	12.785	0.0	12.942	14.55000
HM= 5.098	MAX= 0.42517E 01	LW=10.903	MIN=-0.34939E 01						
MEAN = 0.38735E 01									
DISTANCE FROM OCEAN END A	42.18750 MILE	J= 16							
HR.	U(N,J)	HR.	U(N,J)	HR.	U(N,J)	HR.	U(N,J)	HR.	U(N,J)
0.078	-3.29682	0.235	-3.25070	0.392	-3.18805	0.549	-3.10909	0.706	-2.98052
1.020	-2.66002	1.177	-2.44865	1.333	-2.22938	1.490	-2.04415	1.647	-1.74275
1.961	-1.02731	2.118	-0.59131	2.275	-0.02347	2.432	0.73309	2.588	1.59650

2.902	2.43725	3.059	3.02588	3.216	3.43845	3.373	3.78982	3.530	4.06828
3.883	4.21514	4.000	4.35421	4.137	4.35865	4.314	4.36042	4.471	4.34212
4.785	4.38794	4.942	4.42800	5.098	4.47430	5.255	4.50563	5.412	4.48386
5.726	4.37694	5.883	4.27926	6.040	4.17711	6.197	4.09640	6.353	4.06859
6.667	3.79660	6.824	3.63669	6.981	3.46444	7.138	3.30335	7.295	3.13070
7.608	2.73966	7.765	2.51069	7.922	2.25806	8.079	1.99050	8.236	1.69829
8.550	1.03188	8.707	0.65127	8.863	0.21885	9.020	-0.28421	9.177	-0.86338
9.491	-1.92489	9.648	-2.27222	9.805	-2.53736	9.962	-2.77507	10.118	-2.97609
10.432	-3.22400	10.589	-3.27634	10.746	-3.31414	10.903	-3.34537	11.060	-3.36369
11.373	-3.93337	11.530	-3.30018	11.687	-3.27160	11.844	-3.24274	12.001	-3.21377
12.315	-3.12475	12.472	-3.06822	12.628	-200314.81250	12.785	15.70000	12.942	14.20000

HM= 5.255 MAX= 0.45096E 01 LM= 11.060 MIN= -0.33637E 01  
 MEAN = 0.39367E 01

OUTPUT IS AS FOLLOWS

TRANSIENT SOLUTION CYCLE 2

VARIATIONS OF H ARE AS FOLLOWS

DISTANCE FROM OCEAN END A	H(N,J)	HR.	MILE	H(N,J)	HR.	MILE	H(N,J)	HR.
0.0	0.0	0.157	1.00000	0.314	0.314	0.314	0.00000	0.471
0.941	4.90000	1.098	5.50000	1.255	6.20000	1.255	9.40000	1.412
1.882	8.40000	2.039	8.90000	2.196	9.40000	2.196	11.10000	2.353
2.824	10.70000	2.981	10.90000	3.137	11.20000	3.137	11.20000	3.451
3.765	11.40000	3.922	11.30000	4.079	8.60000	4.079	8.60000	4.392
4.706	9.60000	4.863	9.10000	5.020	5.20000	5.020	5.20000	5.334
5.647	6.50000	5.804	5.85000	5.961	5.20000	5.961	4.55000	6.275
6.589	6.589	6.746	1.50000	6.902	0.70000	6.902	-0.15000	7.216
7.530	-2.50000	7.687	-3.20000	7.844	-3.20000	7.844	-1.55000	8.157
8.471	-9.30000	8.628	-9.40000	9.726	-9.40000	9.726	-7.50000	9.099
9.412	-8.00000	9.569	-8.60000	10.609	-8.60000	10.609	-7.50000	10.040
10.354	-9.00000	10.511	-8.50000	11.452	-8.20000	11.452	-8.50000	10.581
11.295	-1.60000	12.393	-0.80000	12.550	0.0	12.550	-4.60000	11.922
12.235	-1.60000	12.393	-0.80000	12.550	0.0	12.550	0.0	12.864

HM= 3.608 MAX= 11.50000 LM= 9.726 MIN= -9.60000  
 MEAN = 10.55000

0.0	0.941	1.882	2.824	3.765	4.706	5.647	6.589	7.530	8.471	9.412	10.354	11.295	12.236
0.0	-0.90786	3.49219	7.12856	9.20957	9.47691	8.13054	5.89128	2.62440	-1.56472	-5.00045	-7.19864	-6.88539	-5.31604
0.941	3.49219	7.12856	9.20957	9.47691	8.13054	5.89128	2.62440	-1.56472	-5.00045	-7.19864	-6.88539	-5.31604	-2.11350
1.882	7.12856	9.20957	9.47691	8.13054	5.89128	2.62440	-1.56472	-5.00045	-7.19864	-6.88539	-5.31604	-2.11350	9.47691
2.824	9.20957	9.47691	8.13054	5.89128	2.62440	-1.56472	-5.00045	-7.19864	-6.88539	-5.31604	-2.11350	9.47691	8.52597
3.765	9.47691	8.13054	5.89128	2.62440	-1.56472	-5.00045	-7.19864	-6.88539	-5.31604	-2.11350	9.47691	8.52597	-1.45244
4.706	8.13054	5.89128	2.62440	-1.56472	-5.00045	-7.19864	-6.88539	-5.31604	-2.11350	9.47691	8.52597	-1.45244	2.36409
5.647	5.89128	2.62440	-1.56472	-5.00045	-7.19864	-6.88539	-5.31604	-2.11350	9.47691	8.52597	-1.45244	2.36409	6.01211
6.589	2.62440	-1.56472	-5.00045	-7.19864	-6.88539	-5.31604	-2.11350	9.47691	8.52597	-1.45244	2.36409	6.01211	0.941
7.530	-1.56472	-5.00045	-7.19864	-6.88539	-5.31604	-2.11350	9.47691	8.52597	-1.45244	2.36409	6.01211	0.941	1.882
8.471	-5.00045	-7.19864	-6.88539	-5.31604	-2.11350	9.47691	8.52597	-1.45244	2.36409	6.01211	0.941	1.882	0.0
9.412	-7.19864	-6.88539	-5.31604	-2.11350	9.47691	8.52597	-1.45244	2.36409	6.01211	0.941	1.882	0.0	0.0
10.354	-6.88539	-5.31604	-2.11350	9.47691	8.52597	-1.45244	2.36409	6.01211	0.941	1.882	0.0	0.0	0.0
11.295	-5.31604	-2.11350	9.47691	8.52597	-1.45244	2.36409	6.01211	0.941	1.882	0.0	0.0	0.0	0.0
12.236	-2.11350	9.47691	8.52597	-1.45244	2.36409	6.01211	0.941	1.882	0.0	0.0	0.0	0.0	0.0

HM= 3.765 MAX= 9.47691 LM= 9.726 MIN= -7.57504  
 MEAN = 8.52597

2-824 7-5618-4 2-981 7-3345 3-137 7-19727 3-294 7-11345 3-451 7-11003  
 3-740 7-17073 3-922 7-50409 4-076 7-10898 7-60625 4-352 7-60892  
 4-706 6-5927 4-683 6-31632 5-622 6-12663 5-177 5-57797 5-334 5-72272  
 5-647 5-11327 4-883 4-23356 5-651 4-37224 6-118 3-55561 6-275 6-25208  
 6-588 2-68337 8-740 2-15657 6-902 1-65823 7-655 1-13317 7-216 6-25351  
 7-530 -0-86979 8-740 1-27230 7-844 -1-26718 8-001 -2-41744 8-157 6-28428  
 8-471 -3-17175 8-629 4-32884 8-785 -4-22095 6-542 -5-05570 9-195 5-32828  
 9-412 -4-97854 9-545 -5-60832 9-726 -4-67586 10-624 -5-35228  
 10-354 -3-95900 10-511 3-78144 11-452 -3-56781 11-764 -4-35037  
 11-295 -2-72416 12-393 1-72308 12-552 1-14994 12-707 -2-53743  
 12-236 8-8778 7-67645 1-567632  
 MEAN = 6.8778 MIN = 9.569 MAX = -5.67632  
 DISTANCE FROM OCEAN END A 16-87500 MILE J<sub>0</sub> 7  
 O.D. MIN(J) MR.  
 0-0 -1-72216 0-157 1-31176 0-314 0-54356  
 0-941 1-92812 1-078 2-56178 1-255 3-15290  
 1-882 5-71297 2-039 4-72511 2-190 6-80248  
 2-824 6-94028 2-981 6-75743 2-374 8-38667  
 3-765 6-22457 3-922 6-57819 2-574 9-50697  
 4-706 6-25583 4-863 6-41603 3-626 9-91800  
 5-647 4-95953 5-804 4-68411 4-826 1-88997  
 6-589 2-71137 6-744 2-33319 5-902 1-35465  
 7-530 -0-23344 7-689 3-52422 7-644 -4-31345  
 8-471 -3-47316 8-626 5-09218 8-785 -5-02693  
 9-412 -5-10312 9-545 -4-40275 9-726 -4-26504  
 10-354 -4-53988 10-511 -3-52501 10-607 -3-31630  
 11-295 -3-68851 11-452 -2-32501 11-600 -2-15557  
 12-236 -2-32150 12-393 -1-58269 12-552 -1-75557  
 MEAN = 7-510 MAX = 7-07344 MIN = -5-10312  
 DISTANCE FROM OCEAN END A 22-5000 MILE J<sub>0</sub> 9

0-0 -1-88637 0-157 1-51464 0-314 0-11800  
 0-941 1-24693 1-078 2-03199 1-255 2-72842  
 1-882 5-37556 2-039 5-79138 2-190 6-12884  
 2-824 6-23933 2-981 5-93929 2-374 6-50611  
 3-765 5-93119 3-922 5-82780 2-574 5-68104  
 4-706 5-81611 4-863 4-64907 3-626 4-18213  
 5-647 4-71097 5-804 2-33750 4-826 1-58827  
 6-589 2-70999 6-744 0-38819 5-902 -0-92651  
 7-530 0-14210 7-687 -3-49227 8-785 -3-86305  
 8-471 -3-04413 8-626 -4-48606 9-726 -4-39526  
 9-412 -4-48749 9-545 10-251 -0-80257 10-607 -3-87070  
 10-354 -3-31788 11-452 -2-21733 11-600 -3-05690  
 11-295 -2-27850 12-393 -2-01564 12-552 -1-75557  
 MEAN = 7-510 MAX = 7-07344 MIN = -4-49769  
 DISTANCE FROM OCEAN END A 28-12500 MILE J<sub>0</sub> 11

0-0 -1-91287 0-157 1-60520 0-314 0-25406  
 0-941 4-64135 1-078 1-34850 1-255 2-15321  
 1-882 4-82895 2-039 2-039 2-190 5-45561  
 2-824 5-50812 2-981 5-59150 2-374 5-57531  
 3-765 5-33527 3-922 5-32398 2-574 5-34550  
 4-706 5-47342 4-863 5-40001 3-626 5-30426  
 5-647 4-43951 5-804 4-21811 4-826 3-65621  
 6-589 2-71626 6-744 2-34483 5-902 1-98184  
 7-530 0-39611 7-687 -0-98123 6-902 -0-52171  
 8-471 -2-58851 8-626 -2-59801 8-785 -3-34665  
 9-412 -3-83901 9-545 -3-76773 9-726 -3-76103  
 10-354 -3-40359 10-511 -2-32648 10-607 -3-46028  
 11-295 -3-01418 11-452 -2-85859 11-600 -2-76242  
 12-236 -2-14841 12-393 -1-94511 12-552 -1-76076  
 MEAN = 7-510 MAX = 7-07344 MIN = -3-83901  
 DISTANCE FROM OCEAN END A 34-12500 MILE J<sub>0</sub> 13

0-0 -1-91287 0-157 1-60520 0-314 0-25406  
 0-941 4-64135 1-078 1-34850 1-255 2-15321  
 1-882 4-82895 2-039 2-039 2-190 5-45561  
 2-824 5-50812 2-981 5-59150 2-374 5-57531  
 3-765 5-33527 3-922 5-32398 2-574 5-34550  
 4-706 5-47342 4-863 5-40001 3-626 5-30426  
 5-647 4-43951 5-804 4-21811 4-826 3-65621  
 6-589 2-71626 6-744 2-34483 5-902 1-98184  
 7-530 0-39611 7-687 -0-98123 6-902 -0-52171  
 8-471 -2-58851 8-626 -2-59801 8-785 -3-34665  
 9-412 -3-83901 9-545 -3-76773 9-726 -3-76103  
 10-354 -3-40359 10-511 -2-32648 10-607 -3-46028  
 11-295 -3-01418 11-452 -2-85859 11-600 -2-76242  
 12-236 -2-14841 12-393 -1-94511 12-552 -1-76076  
 MEAN = 7-510 MAX = 7-07344 MIN = -3-83901  
 DISTANCE FROM OCEAN END A 40-12500 MILE J<sub>0</sub> 15

7-11003 3-451 7-11345 3-294 7-11345 3-451 7-11003  
 4-56892 4-352 7-60892 4-352 7-60892  
 5-72272 5-334 5-72272 5-334 5-72272  
 6-25208 6-275 6-25208 6-275 6-25208  
 7-11345 7-216 7-11345 7-216 7-11345  
 8-157 8-157 8-157 8-157 8-157  
 9-195 9-195 9-195 9-195 9-195  
 10-607 10-607 10-607 10-607 10-607  
 11-764 11-764 11-764 11-764 11-764  
 12-707 12-707 12-707 12-707 12-707  
 C.O  
 MIN(J) MR.  
 -3-27942 0-627 3-87662 0-627 3-87662 0-627 3-87662  
 3-87662 1-565 6-50774 2-510 6-50774 2-510 6-50774  
 6-50774 3-451 6-50774 3-451 6-50774 3-451 6-50774  
 6-50774 4-352 6-50774 4-352 6-50774 4-352 6-50774  
 5-70945 5-334 5-70945 5-334 5-70945 5-334 5-70945  
 3-53330 6-275 3-53330 6-275 3-53330 6-275 3-53330  
 1-42666 7-216 1-42666 7-216 1-42666 7-216 1-42666  
 -1-93108 8-157 -1-93108 8-157 -1-93108 8-157 -1-93108  
 -4-62310 9-096 -4-62310 9-096 -4-62310 9-096 -4-62310  
 -4-93273 10-607 -4-93273 10-607 -4-93273 10-607 -4-93273  
 -4-61809 11-764 -4-61809 11-764 -4-61809 11-764 -4-61809  
 -3-9500E 12-707 -3-9500E 12-707 -3-9500E 12-707 -3-9500E  
 C.O 12-864 C.O 12-864 C.O 12-864 C.O 12-864

7-11003 3-451 7-11345 3-294 7-11345 3-451 7-11003  
 4-56892 4-352 7-60892 4-352 7-60892  
 5-72272 5-334 5-72272 5-334 5-72272  
 6-25208 6-275 6-25208 6-275 6-25208  
 7-11345 7-216 7-11345 7-216 7-11345  
 8-157 8-157 8-157 8-157 8-157  
 9-195 9-195 9-195 9-195 9-195  
 10-607 10-607 10-607 10-607 10-607  
 11-764 11-764 11-764 11-764 11-764  
 12-707 12-707 12-707 12-707 12-707  
 C.O  
 MIN(J) MR.  
 -0-67121 0-627 3-87662 0-627 3-87662 0-627 3-87662  
 3-87662 1-565 6-50774 2-510 6-50774 2-510 6-50774  
 6-50774 3-451 6-50774 3-451 6-50774 3-451 6-50774  
 6-50774 4-352 6-50774 4-352 6-50774 4-352 6-50774  
 5-70945 5-334 5-70945 5-334 5-70945 5-334 5-70945  
 3-53330 6-275 3-53330 6-275 3-53330 6-275 3-53330  
 1-42666 7-216 1-42666 7-216 1-42666 7-216 1-42666  
 -1-93108 8-157 -1-93108 8-157 -1-93108 8-157 -1-93108  
 -4-62310 9-096 -4-62310 9-096 -4-62310 9-096 -4-62310  
 -4-93273 10-607 -4-93273 10-607 -4-93273 10-607 -4-93273  
 -4-61809 11-764 -4-61809 11-764 -4-61809 11-764 -4-61809  
 -3-9500E 12-707 -3-9500E 12-707 -3-9500E 12-707 -3-9500E  
 C.O 12-864 C.O 12-864 C.O 12-864 C.O 12-864

7-11003 3-451 7-11345 3-294 7-11345 3-451 7-11003  
 4-56892 4-352 7-60892 4-352 7-60892  
 5-72272 5-334 5-72272 5-334 5-72272  
 6-25208 6-275 6-25208 6-275 6-25208  
 7-11345 7-216 7-11345 7-216 7-11345  
 8-157 8-157 8-157 8-157 8-157  
 9-195 9-195 9-195 9-195 9-195  
 10-607 10-607 10-607 10-607 10-607  
 11-764 11-764 11-764 11-764 11-764  
 12-707 12-707 12-707 12-707 12-707  
 C.O  
 MIN(J) MR.  
 -0-67121 0-627 3-87662 0-627 3-87662 0-627 3-87662  
 3-87662 1-565 6-50774 2-510 6-50774 2-510 6-50774  
 6-50774 3-451 6-50774 3-451 6-50774 3-451 6-50774  
 6-50774 4-352 6-50774 4-352 6-50774 4-352 6-50774  
 5-70945 5-334 5-70945 5-334 5-70945 5-334 5-70945  
 3-53330 6-275 3-53330 6-275 3-53330 6-275 3-53330  
 1-42666 7-216 1-42666 7-216 1-42666 7-216 1-42666  
 -1-93108 8-157 -1-93108 8-157 -1-93108 8-157 -1-93108  
 -4-62310 9-096 -4-62310 9-096 -4-62310 9-096 -4-62310  
 -4-93273 10-607 -4-93273 10-607 -4-93273 10-607 -4-93273  
 -4-61809 11-764 -4-61809 11-764 -4-61809 11-764 -4-61809  
 -3-9500E 12-707 -3-9500E 12-707 -3-9500E 12-707 -3-9500E  
 C.O 12-864 C.O 12-864 C.O 12-864 C.O 12-864

7-11003 3-451 7-11345 3-294 7-11345 3-451 7-11003  
 4-56892 4-352 7-60892 4-352 7-60892  
 5-72272 5-334 5-72272 5-334 5-72272  
 6-25208 6-275 6-25208 6-275 6-25208  
 7-11345 7-216 7-11345 7-216 7-11345  
 8-157 8-157 8-157 8-157 8-157  
 9-195 9-195 9-195 9-195 9-195  
 10-607 10-607 10-607 10-607 10-607  
 11-764 11-764 11-764 11-764 11-764  
 12-707 12-707 12-707 12-707 12-707  
 C.O  
 MIN(J) MR.  
 -3-56212 0-627 3-87662 0-627 3-87662 0-627 3-87662  
 3-87662 1-565 6-50774 2-510 6-50774 2-510 6-50774  
 6-50774 3-451 6-50774 3-451 6-50774 3-451 6-50774  
 6-50774 4-352 6-50774 4-352 6-50774 4-352 6-50774  
 5-70945 5-334 5-70945 5-334 5-70945 5-334 5-70945  
 3-53330 6-275 3-53330 6-275 3-53330 6-275 3-53330  
 1-42666 7-216 1-42666 7-216 1-42666 7-216 1-42666  
 -1-93108 8-157 -1-93108 8-157 -1-93108 8-157 -1-93108  
 -4-62310 9-096 -4-62310 9-096 -4-62310 9-096 -4-62310  
 -4-93273 10-607 -4-93273 10-607 -4-93273 10-607 -4-93273  
 -4-61809 11-764 -4-61809 11-764 -4-61809 11-764 -4-61809  
 -3-9500E 12-707 -3-9500E 12-707 -3-9500E 12-707 -3-9500E  
 C.O 12-864 C.O 12-864 C.O 12-864 C.O 12-864

MEAN = 4.71075 DISTANCE FROM OCEAN END A 33.75000 MILE J# 13  
 HR. MIN. J) HR. MIN. J) HR. MIN. J) HR. MIN. J)  
 0.0 -1.40225 0.157 -1.54857 0.314 0.314 0.471 0.471  
 0.941 0.37519 1.098 0.83843 1.255 1.255 1.412 1.412  
 1.882 3.39083 2.039 4.35709 2.196 2.196 2.353 2.353  
 2.824 4.80084 3.081 4.91411 3.137 3.137 3.294 3.294  
 3.765 4.21788 3.922 4.74451 4.079 4.079 4.236 4.236  
 4.706 4.96579 4.843 4.85883 5.020 5.020 5.177 5.177  
 5.647 4.01877 5.804 3.61881 6.118 6.118 6.275 6.275  
 6.589 2.52615 6.746 2.20417 7.844 7.844 8.001 8.001  
 7.530 0.53895 7.687 0.14980 8.844 8.844 9.001 9.001  
 8.471 -1.99039 8.628 -2.34442 9.726 9.726 9.883 9.883  
 9.412 -3.04377 9.569 -3.08721 10.667 10.667 10.824 10.824  
 10.354 -4.04342 10.511 -4.01480 11.609 11.609 11.766 11.766  
 11.295 -2.60612 11.452 -2.48718 12.550 12.550 12.707 12.707  
 12.236 -1.90512 12.393 -1.73521 13.550 13.550 13.707 13.707  
 MEAN = 4.549 MAX = 5.00876 LM = 9.883 MIN = -3.10088  
 MEAN = 4.05482

MEAN = 3.294 DISTANCE FROM OCEAN END A 39.37500 MILE J# 15  
 HR. MIN. J) HR. MIN. J) HR. MIN. J) HR. MIN. J)  
 0.0 -0.79380 0.157 0.67802 0.314 0.314 0.471 0.471  
 0.941 0.18701 1.098 0.43263 1.255 1.255 1.412 1.412  
 1.882 2.30360 2.039 2.24729 2.196 2.196 2.353 2.353  
 2.824 2.50191 3.081 2.58634 3.137 3.137 3.294 3.294  
 3.765 2.45660 3.922 2.39215 4.079 4.079 4.236 4.236  
 4.706 2.57928 4.843 2.50403 5.020 5.020 5.177 5.177  
 5.647 1.02067 5.804 1.85784 6.118 6.118 6.275 6.275  
 6.589 1.74074 6.746 1.10058 7.844 7.844 8.001 8.001  
 7.530 0.31358 7.687 -1.07750 8.844 8.844 9.001 9.001  
 8.471 -0.31182 8.628 -1.11123 9.726 9.726 9.883 9.883  
 9.412 -1.32733 9.569 -1.18935 10.667 10.667 10.824 10.824  
 10.354 -1.19102 10.511 -0.86291 11.609 11.609 11.766 11.766  
 11.295 -0.92452 11.452 -0.49799 12.550 12.550 12.707 12.707  
 12.236 -0.56756 12.393 -0.14427 13.550 13.550 13.707 13.707  
 MEAN = 3.294 MAX = 2.70327 LM = 9.099 MIN = -1.41427  
 MEAN = 2.05832

MEAN = 2.05832 DISTANCE FROM OCEAN END A 45.00000 MILE J# 17  
 HR. MIN. J) HR. MIN. J) HR. MIN. J) HR. MIN. J)  
 0.0 0.22000 0.157 0.23000 0.314 0.314 0.471 0.471  
 0.941 0.22000 1.098 0.28000 1.255 1.255 1.412 1.412  
 1.882 0.25000 2.039 0.24000 2.196 2.196 2.353 2.353  
 2.824 0.16000 3.081 0.13000 3.137 3.137 3.294 3.294  
 3.765 0.0 3.922 0.01000 4.079 4.079 4.236 4.236  
 4.706 -0.18000 4.843 4.863 5.020 5.020 5.177 5.177  
 5.647 -0.18000 5.804 5.804 6.118 6.118 6.275 6.275  
 6.589 -0.10000 6.746 6.746 7.844 7.844 8.001 8.001  
 7.530 0.10000 7.687 7.687 8.844 8.844 9.001 9.001  
 8.471 0.15000 8.628 8.628 9.726 9.726 9.883 9.883  
 9.412 0.25000 9.569 9.569 10.667 10.667 10.824 10.824  
 10.354 0.40000 10.511 10.511 11.609 11.609 11.766 11.766  
 11.295 0.40000 11.452 11.452 12.550 12.550 12.707 12.707  
 12.236 0.48000 12.393 12.393 13.550 13.550 13.707 13.707  
 MEAN = 12.550 MAX = 0.70000 LM = 5.177 MIN = -0.21000  
 MEAN = 0.45500

VARIATIONS OF Q ARE AS FOLLOWS  
 DISTANCE FROM OCEAN END A 2.81250 MILE J# 2  
 HR. MIN. J) HR. MIN. J) HR. MIN. J) HR. MIN. J)  
 0.0 -56293.89453 0.235 -30743.55078 0.392 0.392 0.549 0.549  
 0.863 69693.87500 1.020 101090.43750 1.177 1.177 1.333 1.333  
 1.647 180425.50000 1.804 174568.48750 1.961 1.961 2.118 2.118  
 2.432 226526.12500 2.588 230181.56250 2.745 2.745 2.902 2.902  
 3.216 267458.50000 3.373 280070.75000 3.530 3.530 3.687 3.687  
 4.000 29485.68750 4.157 298806.12500 4.314 4.314 4.471 4.471  
 4.785 262560.37500 4.942 252396.25000 5.098 5.098 5.255 5.255

H(N,J) HR. H(N,J) HR. H(N,J) HR. H(N,J) HR.  
 -0.56037 0.627 -0.56037 0.627 -0.56037 0.627 -0.56037 0.627  
 3.0219 1.565 3.0219 1.565 3.0219 1.565 3.0219 1.565  
 4.63417 2.410 4.63417 2.410 4.63417 2.410 4.63417 2.410  
 4.95251 2.451 4.95251 2.451 4.95251 2.451 4.95251 2.451  
 4.98727 2.451 4.98727 2.451 4.98727 2.451 4.98727 2.451  
 4.48914 2.451 4.48914 2.451 4.48914 2.451 4.48914 2.451  
 3.11025 2.451 3.11025 2.451 3.11025 2.451 3.11025 2.451  
 1.22264 2.451 1.22264 2.451 1.22264 2.451 1.22264 2.451  
 -1.11389 2.451 -1.11389 2.451 -1.11389 2.451 -1.11389 2.451  
 -2.95895 2.451 -2.95895 2.451 -2.95895 2.451 -2.95895 2.451  
 -3.05789 2.451 -3.05789 2.451 -3.05789 2.451 -3.05789 2.451  
 -2.82254 2.451 -2.82254 2.451 -2.82254 2.451 -2.82254 2.451  
 -2.15117 2.451 -2.15117 2.451 -2.15117 2.451 -2.15117 2.451  
 12.864 \*\*\*\*\* 12.864 \*\*\*\*\* 12.864 \*\*\*\*\* 12.864 \*\*\*\*\*

H(N,J) HR. H(N,J) HR. H(N,J) HR. H(N,J) HR.  
 -0.38150 0.627 -0.38150 0.627 -0.38150 0.627 -0.38150 0.627  
 1.20568 1.569 1.20568 1.569 1.20568 1.569 1.20568 1.569  
 2.49131 2.510 2.49131 2.510 2.49131 2.510 2.49131 2.510  
 2.70237 3.451 2.70237 3.451 2.70237 3.451 2.70237 3.451  
 2.53159 3.451 2.53159 3.451 2.53159 3.451 2.53159 3.451  
 2.45247 5.334 2.45247 5.334 2.45247 5.334 2.45247 5.334  
 2.32592 5.334 2.32592 5.334 2.32592 5.334 2.32592 5.334  
 1.78516 6.275 1.78516 6.275 1.78516 6.275 1.78516 6.275  
 0.75283 7.216 0.75283 7.216 0.75283 7.216 0.75283 7.216  
 -0.32767 8.157 -0.32767 8.157 -0.32767 8.157 -0.32767 8.157  
 -1.37137 9.099 -1.37137 9.099 -1.37137 9.099 -1.37137 9.099  
 -1.51850 10.040 -1.51850 10.040 -1.51850 10.040 -1.51850 10.040  
 -1.12227 10.981 -1.12227 10.981 -1.12227 10.981 -1.12227 10.981  
 -0.74656 11.922 -0.74656 11.922 -0.74656 11.922 -0.74656 11.922  
 12.864 \*\*\*\*\* 12.864 \*\*\*\*\* 12.864 \*\*\*\*\* 12.864 \*\*\*\*\*

H(N,J) HR. H(N,J) HR. H(N,J) HR. H(N,J) HR.  
 0.24000 0.627 0.24000 0.627 0.24000 0.627 0.24000 0.627  
 0.30000 1.565 0.30000 1.565 0.30000 1.565 0.30000 1.565  
 0.20000 2.510 0.20000 2.510 0.20000 2.510 0.20000 2.510  
 0.07000 3.451 0.07000 3.451 0.07000 3.451 0.07000 3.451  
 -0.06300 4.392 -0.06300 4.392 -0.06300 4.392 -0.06300 4.392  
 -0.21000 5.334 -0.21000 5.334 -0.21000 5.334 -0.21000 5.334  
 -0.15000 6.275 -0.15000 6.275 -0.15000 6.275 -0.15000 6.275  
 0.0 7.216 0.0 7.216 0.0 7.216 0.0 7.216  
 0.07000 8.157 0.07000 8.157 0.07000 8.157 0.07000 8.157  
 0.15000 9.099 0.15000 9.099 0.15000 9.099 0.15000 9.099  
 0.30000 10.040 0.30000 10.040 0.30000 10.040 0.30000 10.040  
 0.50000 10.981 0.50000 10.981 0.50000 10.981 0.50000 10.981  
 0.65000 11.922 0.65000 11.922 0.65000 11.922 0.65000 11.922  
 34.67999 12.864 34.67999 12.864 34.67999 12.864 34.67999 12.864

Q(N,J) HR. Q(N,J) HR. Q(N,J) HR. Q(N,J) HR.  
 40237.4324 0.708 40237.4324 0.708 40237.4324 0.708 40237.4324 0.708  
 164312.43250 1.490 164312.43250 1.490 164312.43250 1.490 164312.43250 1.490  
 222502.93250 2.275 222502.93250 2.275 222502.93250 2.275 222502.93250 2.275  
 254424.31250 3.055 254424.31250 3.055 254424.31250 3.055 254424.31250 3.055  
 259969.50000 3.843 259969.50000 3.843 259969.50000 3.843 259969.50000 3.843  
 271879.37500 4.628 271879.37500 4.628 271879.37500 4.628 271879.37500 4.628  
 213593.50000 5.412 213593.50000 5.412 213593.50000 5.412 213593.50000 5.412

5.569 199347.00000 5.726 164095.18750 6.883 171042.12500 6.060 156213.62500 6.157 142137.75000  
 6.353 128361.81250 6.810 112297.37500 6.867 93668.56250 6.854 76560.43750 6.981 57695.32812  
 7.138 37742.37881 7.295 17744.74609 7.332 2111.87427 7.668 -2218.35156 7.765 -41689.08203  
 7.922 40696.29287 8.079 18362.68750 8.236 -14720.87500 8.393 -108566.68750 8.550 -159674.62500  
 8.701 128575.87500 8.863 136431.31250 9.020 170593.75000 9.177 148055.75000 9.334 -194451.50000  
 9.491 162051.12500 9.648 166497.25000 9.805 170593.75000 9.962 174244.37500 10.118 178330.87500  
 10.275 182983.50000 10.432 187008.68750 10.589 187546.81250 10.746 185677.50000 10.903 183510.62500  
 11.060 181349.25000 11.217 177110.81250 11.373 171864.31250 11.530 164142.43750 11.687 155197.87500  
 11.844 177137.50000 12.001 133137.81250 12.158 115930.87500 12.315 97974.43750 12.472 82593.75000  
 12.628 67671.50000 12.785 0.00000 13.099 0.00000 13.256 0.00000  
 MEAN = 0.24376E 06 LW=10.589 MIN=-0.18755E 06  
 DISTANCE FROM OCEAN END A 8.43750 MILE J= 4

0.078 -85523.75000 0.235 -63930.13281 0.392 -38054.29297 0.549 -7415.28916 0.706 22587.81641  
 0.863 46991.74609 1.020 72298.87500 1.177 19126.81250 1.333 123350.75000 1.490 142137.75000  
 1.647 163320.68750 1.804 175360.56250 1.961 186476.87500 2.118 196560.81250 2.275 204138.81250  
 2.432 214351.18750 2.588 224640.37500 2.745 237540.12500 2.902 243157.31250 3.059 253352.31250  
 3.216 266624.18750 3.373 277531.06250 3.530 287729.62500 3.687 297099.81250 3.843 304445.37500  
 4.000 304797.81250 4.157 302956.62500 4.314 303169.50000 4.471 296879.06250 4.628 290223.81250  
 4.785 274054.12500 4.942 264002.81250 5.098 253029.43750 5.255 240486.00000 5.412 228651.87500  
 5.569 216864.12500 5.726 263600.87500 5.883 191056.81250 6.040 17137.68750 6.197 162605.50000  
 6.353 149035.93750 6.510 135607.62500 6.667 119261.75000 6.824 103254.53750 6.981 84528.75000  
 7.138 64405.00391 7.295 44015.83584 7.452 23444.37109 7.608 2625.85742 7.765 18390.3203  
 7.922 38826.40234 8.079 113451.18750 8.236 12519.25000 8.393 -89943.18750 8.550 -102645.32500  
 8.701 -113451.18750 8.863 -12519.25000 9.020 -129017.31250 9.177 -136477.81250 9.334 -144144.00000  
 10.275 191980.68750 10.432 182329.06250 10.589 186167.50000 10.746 189522.25000 10.903 187678.31250  
 11.060 191005.18750 11.217 183629.50000 11.373 186167.50000 11.530 195522.18750 11.687 193661.81250  
 11.844 168108.64350 12.001 185129.62500 12.158 185129.62500 12.315 179817.87500 12.472 173442.81250  
 12.628 90374.56350 12.785 137370.37500 12.942 145555.93750 13.099 109512.15000  
 MEAN = 0.25048E 06 LW=10.589 MIN=-0.19617E 06  
 DISTANCE FROM OCEAN END A 10.0250 MILE J= 6

0.078 -104365.31250 0.235 -86667.81250 0.392 -64005.65234 0.549 -36545.98828 0.706 -4359.71875  
 0.863 26318.65937 1.020 47631.67969 1.177 70153.31250 1.333 100884.31250 1.490 125065.00000  
 1.647 141750.18750 1.804 157744.37500 1.961 176211.62500 2.118 176211.62500 2.275 152265.75000  
 2.432 208434.50000 2.588 220853.93750 2.745 237917.68750 2.902 251656.53750 3.059 260603.37500  
 3.216 269767.93750 3.373 277659.43750 3.530 286497.93750 3.687 296047.75000 3.843 304197.12500  
 4.000 308389.31250 4.157 306755.00000 4.314 304317.62500 4.471 304671.18750 4.628 295672.81250  
 4.785 286336.18750 4.942 271125.50000 5.098 258605.81250 5.255 250808.75000 5.412 235342.50000  
 5.569 228009.12500 5.726 217842.56250 5.883 204684.00000 6.040 192647.37500 6.197 179576.00000  
 6.353 66803.31250 6.510 150800.31250 6.667 64554.93750 6.824 121947.37500 6.981 104823.31250  
 7.138 18178.80078 7.295 38291.63281 7.452 55845.25000 7.608 25405.82812 7.765 3923.39355  
 7.922 -98657.75000 8.079 -109216.93750 8.236 -119578.75000 8.393 -129288.06250 8.550 -139233.06250  
 8.701 -150628.25000 8.863 -168150.93750 9.020 -175818.50000 9.177 -186869.37500 9.334 -195130.43750  
 10.275 199847.43750 10.432 192150.00000 10.589 201140.62500 10.746 201243.43750 10.903 200899.75000  
 11.060 198815.93750 11.217 195489.50000 11.373 192133.37500 11.530 186618.68750 11.687 184189.62500  
 11.844 177998.18750 12.001 169594.06250 12.158 162453.00000 12.315 148333.00000 12.472 131039.18750  
 12.628 109928.75000 12.785 0.00000 13.099 0.00000 13.256 0.00000  
 MEAN = 0.25402E 06 LW=10.432 MIN=-0.20123E 06  
 DISTANCE FROM OCEAN END A 19.68750 MILE J= 8

0.078 -135201.50000 0.235 -121709.37500 0.392 -106531.25000 0.549 -86914.68750 0.706 -61860.46875  
 0.863 31680.52187 1.020 197487.75000 1.177 25512.84375 1.333 46581.31641 1.490 73271.25000  
 1.647 90000.37500 1.804 114459.00000 1.961 128768.50000 2.118 148157.56250 2.275 169335.81250  
 2.432 192520.50000 2.588 221466.53750 2.745 247045.50000 2.902 265393.25000 3.059 273168.50000  
 3.216 275250.75000 3.373 280593.37500 3.530 286795.50000 3.687 292102.12500 3.843 299300.50000  
 4.000 307592.93750 4.157 313676.75000 4.314 312031.25000 4.471 305837.00000 4.628 304189.43750  
 4.785 298889.56250 4.942 286155.75000 5.098 274275.18750 5.255 265081.00000 5.412 258142.37500  
 5.569 250486.25000 5.726 240039.25000 5.883 231427.43750 6.040 220783.68750 6.197 208040.25000  
 6.353 195506.50000 6.510 182035.50000 6.667 168227.68750 6.824 155249.31250 6.981 140942.81250  
 7.138 125254.18750 7.295 108504.18750 7.452 89920.62500 7.608 67330.16750  
 MEAN = 0.25402E 06 LW=10.432 MIN=-0.20123E 06  
 DISTANCE FROM OCEAN END A 19.68750 MILE J= 8

7.922 25132.78125 8.079 3389.56372 8.234 -17567.99605 8.393 -36742.80078 8.550 -53244.42578  
8.707 -69418.81250 8.865 -85877.81250 9.020 -101288.31250 9.177 -117134.25000 9.334 -133985.68750  
9.491 -151450.31250 9.648 -188053.81250 9.805 -211877.68750 9.962 -238783.56250 10.118 -265330.93750  
10.275 -200250.75000 10.432 -241323.86250 10.589 -268438.50000 10.746 -284338.00000 10.903 -299788.56250  
11.060 -209908.18750 11.217 -207056.25000 11.373 -204038.00000 11.530 -193798.50000 11.687 -200416.81250  
11.844 -195912.68750 12.001 -189595.87500 12.158 -182338.00000 12.315 -173785.00000 12.472 -163206.81250  
12.628 -148221.56250 12.785 -127279.077279 12.942 \*\*\*\*\*  
HM= 4.157 MAX= 0.31368E 06 LW=10.432 MIN=-0.21153E 06  
MEAN = 0.26262E 06

25.31250 MILE Q(N,J) HR. Q(N,J) HR. Q(N,J) HR. Q(N,J) HR. Q(N,J) HR.  
0.078 -163176.18750 0.235 -151930.68750 0.392 -139782.87500 0.549 -126706.06250 0.706 -110246.68750  
0.863 -07855.00000 1.020 -59060.76172 1.177 -26912.25000 1.333 1536.18823 1.490 20000.33356  
1.647 41430.52344 1.804 70489.37500 1.961 99131.68750 2.118 125026.82500 2.275 154888.36000  
2.432 190094.75000 2.588 285387.43750 2.745 251382.68750 2.902 267280.87500 3.059 29476.37500  
3.216 285980.31250 3.373 285425.75000 3.530 286402.06250 3.687 291839.62500 3.843 298641.00000  
4.000 305574.50000 4.157 311025.06250 4.314 314220.62500 4.471 31859.12500 4.628 309663.37500  
4.785 300981.00000 4.942 298335.56250 5.098 263511.62500 5.255 282369.50000 5.412 275745.50000  
5.789 249189.87500 5.946 210455.75000 6.103 197080.06250 6.260 184549.00000 6.417 173056.56250  
6.713 149718.37500 6.870 143564.93750 7.027 126114.25000 7.184 107253.00000 7.341 85288.87500  
7.922 63308.65126 8.079 44423.28125 8.236 -23289.92578 8.393 1578.01367 8.550 -26497.46194  
8.707 -42042.89062 8.863 -173081.25000 9.020 -85447.68750 9.177 -105073.93750 9.334 -132461.43750  
9.491 -153815.81250 9.648 -219264.62500 9.805 -189720.06250 9.962 -201819.56250 10.118 -205635.68750  
10.275 -215197.36250 10.432 -219264.62500 10.589 -221441.62500 10.746 -221282.81250 10.903 -219326.37500  
11.060 -217768.81250 11.217 -217756.56250 11.373 -217272.75000 11.530 -214871.62500 11.687 -211890.31250  
11.844 -209131.50000 12.001 -205556.18750 12.158 -200302.43750 12.315 -192265.75000 12.472 -185034.81250  
12.628 -176188.75000 12.785 -171888.75000 12.942 -161888.75000 13.099 -159265.75000 13.256 -148503.81250  
HM= 4.314 MAX= 0.31422E 06 LW=10.559 MIN=-0.22144E 06  
MEAN = 0.26783E 06

30.693750 MILE Q(N,J) HR. Q(N,J) HR. Q(N,J) HR. Q(N,J) HR. Q(N,J) HR.  
0.235 -178401.75000 0.392 -164901.37500 0.549 -158918.43750 0.706 -146989.68750  
1.020 -112366.06250 1.177 -81561.75000 1.333 -56207.01203 1.490 -31132.07812  
1.804 26320.68750 1.961 61322.87500 2.118 15205.43750 2.275 142356.43750  
2.588 221178.31250 2.745 243388.31250 2.902 267171.25000 3.059 28541.93750  
3.216 292554.25000 3.373 309123.31250 3.530 329759.56250 3.687 359541.93750  
4.000 305895.75000 4.157 305895.75000 4.314 308225.50000 4.471 302876.43750  
4.785 305556.93750 4.942 305556.93750 5.098 299502.50000 5.255 295790.87500  
5.789 280199.68750 5.946 274297.50000 6.103 255790.31250 6.260 23475.62500  
6.713 235570.37500 6.870 225076.37500 7.027 213475.62500 7.184 190213.43750  
7.922 176122.68750 8.079 158429.18750 8.236 141724.81250 8.393 123377.81250  
8.707 83120.81250 8.863 61910.19522 8.920 38059.80469 9.077 103566.53750  
9.491 -44637.12891 9.648 -74567.31250 9.805 -103666.53750 9.962 -130538.31250  
10.432 -173355.50000 10.589 -192451.00000 10.746 -203451.00000 10.903 -227619.43750  
11.060 -224203.68750 11.217 -227334.25000 11.373 -227019.43750 11.530 -225016.12500  
11.844 -221196.75000 12.001 -226159.06250 12.158 -225016.12500 12.315 -208603.81250  
12.628 -217113.00000 12.785 -213635.87500 12.942 -223359.56250 13.099 -223359.56250  
HM= 4.471 MAX= 0.30933E 06 LW=10.746 MIN=-0.22762E 06  
MEAN = 0.26872E 06

36.56250 MILE Q(N,J) HR. Q(N,J) HR. Q(N,J) HR. Q(N,J) HR. Q(N,J) HR.  
0.235 -189566.68750 0.392 -181797.31250 0.549 -172657.37500 0.706 -161765.68750  
1.020 -133618.62500 1.177 -114166.00000 1.333 -89215.31250 1.490 -58235.96875  
1.804 11195.50218 1.961 53499.74319 2.118 104276.75000 2.275 152051.93750  
2.588 217389.56250 2.745 262813.18750 2.902 298286.18750 3.059 328336.18750  
3.216 293372.68750 3.373 307867.06250 3.530 304787.06250 3.687 312389.62500  
4.000 303263.81250 4.157 304787.06250 4.314 306537.25000 4.471 312389.62500  
4.785 308891.87500 4.942 308891.87500 5.098 306537.25000 5.255 312389.62500  
5.789 287474.50000 5.946 287474.50000 6.103 287474.50000 6.260 287474.50000  
6.713 272320.00000 6.870 272320.00000 7.027 272320.00000 7.184 272320.00000  
7.922 186388.93750 8.079 186388.93750 8.236 186388.93750 8.393 186388.93750  
8.707 100390.43750 8.863 100390.43750 8.920 100390.43750 9.077 100390.43750  
9.491 -37249.48828 9.648 -176448.68750 9.805 -192047.31250 9.962 -203584.00000  
10.118 -212667.86250 10.275 -222758.56250 10.432 -227589.56250 10.589 -232758.56250  
10.746 -232758.56250 10.903 -232758.56250 11.060 -232758.56250 11.217 -232758.56250  
11.373 -232758.56250 11.530 -232758.56250 11.687 -232758.56250 11.844 -232758.56250  
12.001 -232758.56250 12.158 -232758.56250 12.315 -232758.56250 12.472 -232758.56250  
12.628 -232758.56250 12.785 -232758.56250 12.942 -232758.56250 13.099 -232758.56250  
HM= 4.471 MAX= 0.30933E 06 LW=10.746 MIN=-0.22762E 06  
MEAN = 0.26872E 06

187275 -220208.50000 10.437 -235303.93750 10.589 -228088.31250 10.745 -230079.25000 10.803 -231404.25000  
 11946 -231720.02500 11.217 -231103.93750 11.373 -230271.40000 11.530 -228769.68750 11.697 -227658.31250  
 11844 -224802.93750 12.001 -221504.06250 12.159 -218272.25000 12.315 -215017.50000 12.472 -210894.12500  
 12628 -205784.18750 12.820 -212300.12500 12.942 14.35000 13.099 7.10000 3.40000  
 HM= 4.785 MAX= 0.31047E 06 LM=11.060 MIN=-0.23175E 06  
 MEAN = 0.27110E 06  
 DISTANCE FROM OCEAN END A 42.18750 MILE J= 16  
 HR. QIN+J1 QIN+J2 QIN+J3 QIN+J4  
 0.078 -200314.81250 0.235 -194712.81250 0.392 -187881.25000 0.549 -179211.87500  
 1.020 -156829.06250 1.020 -142904.31250 1.177 -126576.62500 1.333 -106030.25000  
 1.647 -40929.72266 1.804 5123.40234 1.961 56628.28516 2.118 102011.56250  
 2.432 186006.31250 2.588 219245.06250 2.745 282529.80000 2.902 296799.43750  
 3.216 287392.12500 3.373 296449.81250 3.530 302522.00000 3.687 302047.43750  
 4.000 299182.43750 4.157 300273.62500 4.314 303634.50000 4.471 307032.50000  
 4.785 313309.93750 4.942 313259.18750 5.098 310493.50000 5.255 307759.00000  
 5.569 301202.93750 5.726 293630.31250 5.883 284867.06250 6.040 277718.81250  
 6.353 263637.68750 6.510 253449.56250 6.667 242509.93750 6.824 231123.53750  
 7.138 206323.56250 7.295 192181.50000 7.452 177890.93750 7.608 163656.06250  
 7.922 159215.25000 8.079 108431.06250 8.236 85297.12500 8.393 59718.46004  
 8.707 1703.82495 8.863 -12147.63750 9.020 -101856.31250 9.177 -102582.37500  
 9.491 -156727.56250 9.648 -176332.43750 9.805 -191856.31250 9.962 -204903.12500  
 10.275 -221376.43750 10.432 -225366.00000 10.589 -228807.50000 10.746 -231845.81250  
 11.040 -234192.62500 11.217 -233886.87500 11.373 -232680.43750 11.530 -231109.12500  
 11.844 -224495.12500 12.001 -223895.68750 12.159 -221019.37500 12.315 -217663.00000  
 12.628 -209791.75000 12.785 15.70000 12.942 14.40000 13.099 18.00000  
 HM= 4.785 MAX= 0.31331E 06 LM=11.060 MIN=-0.2319E 06  
 MEAN = 0.27375E 06

VARIATIONS OF U ARE AS FOLLOWS

ALL VELOCITIES ARE IN KNOTS

DISTANCE FROM OCEAN END A 2.81250 MILE J= 2

HR. UIN+J1 UIN+J2 UIN+J3 UIN+J4  
 0.078 -0.91134 0.235 -0.48966 0.392 -0.04571 0.549 -0.29675  
 1.020 1.51287 1.177 1.88046 1.333 1.88046 1.490 1.647  
 1.647 2.01796 2.118 2.22272 2.275 2.22272 2.332 2.275  
 2.902 3.34454 3.059 3.48226 3.216 3.66111 3.373 3.83282  
 3.843 4.09345 4.000 4.09345 4.157 4.157 4.314 4.314  
 4.785 4.67935 4.942 4.942 5.098 5.098 5.255 5.255  
 5.569 5.726 5.883 5.883 6.040 6.040 6.197 6.197  
 6.667 6.824 6.981 6.981 7.138 7.138 7.295 7.295  
 7.608 -0.37562 7.765 7.765 7.922 7.922 8.079 8.079  
 8.550 -2.16574 8.707 -2.34869 8.863 -2.51437 8.920 -2.65245  
 9.491 -3.08248 9.648 -3.18005 9.805 -3.26797 9.962 -3.34266  
 10.432 -3.51837 10.589 -3.50555 10.746 -3.44862 10.903 -3.38657  
 11.373 -3.09503 11.530 -2.92648 11.687 -2.73788 11.844 -2.56331  
 12.315 -1.62814 12.472 -1.35855 12.628 -0.76711  
 HM= 4.157 MAX= 0.41081E 01 LM=10.432 MIN=-0.35184E 01  
 MEAN = 0.38133E 01  
 DISTANCE FROM OCEAN END A 8.43750 MILE J= 4  
 HR. UIN+J1 UIN+J2 UIN+J3 UIN+J4  
 0.078 -1.39034 0.235 -1.02641 0.392 -0.40271 0.549 -0.11586  
 1.020 1.80932 1.177 1.98113 1.333 1.80932 1.490 1.647  
 1.647 2.60250 2.118 2.78177 2.275 2.78177 2.332 2.78177  
 2.902 3.39165 3.059 3.56702 3.216 3.56702 3.373 3.56702  
 3.843 4.48489 4.000 4.48489 4.157 4.48489 4.314 4.48489  
 4.785 5.18942 4.942 5.18942 5.098 5.18942 5.255 5.18942  
 5.569 5.89395 5.726 5.89395 5.883 5.89395 6.040 5.89395  
 6.667 6.59848 6.824 6.59848 6.981 6.59848 7.138 6.59848  
 7.608 -0.44314 7.765 -0.44314 7.922 -0.44314 8.079 -0.44314  
 8.550 -1.79254 8.707 -1.99688 8.863 -2.16013 8.920 -2.28254  
 9.491 -2.75050 9.648 -2.93558 9.805 -3.08119 9.962 -3.16622  
 10.432 -3.48066 10.589 -3.41149 10.746 -3.22179 10.903 -2.98079  
 11.373 3.22179 11.530 3.11149 11.687 2.98079 11.844 2.82961  
 12.315 -2.13741 12.472 -1.79733 12.628 -0.90374  
 HM= 4.000 MAX= 0.42587E 01 LM=10.585 MIN=-0.34910E 01  
 MEAN = 0.38745E 01

DISTANCE FROM OCEAN END A 14.06250 MILE J= 6  
 HR. UIN(J) HR. UIN(J) UIN(J) HR.  
 0.078 -0.87637 0.235 -0.72132 0.392 -0.52722 0.549 0.706  
 1.020 0.37411 1.333 1.4491 1.490 0.95055 1.647 1.06710  
 1.961 1.24003 2.118 1.29419 2.275 1.77459 2.588 1.66322  
 2.902 1.83252 3.059 1.90226 3.216 1.40363 3.530 2.05761  
 3.843 2.21746 4.000 2.25539 4.314 1.97347 4.471 2.23776  
 4.785 2.11380 4.942 2.00652 5.098 1.97155 5.255 1.79118  
 5.726 1.04784 6.824 1.55426 6.040 1.47164 6.353 1.27407  
 6.667 1.08848 7.765 0.83522 7.981 0.65964 8.236 0.54148  
 7.608 0.21099 8.707 0.03292 9.079 -1.07385 9.177 -0.48555  
 8.550 -0.78592 9.648 -0.87520 9.805 -1.07385 9.962 -1.16581  
 9.491 -1.79746 10.589 -1.47327 10.746 -1.58880 10.903 -1.75409  
 10.432 -1.79746 11.530 -1.79746 11.687 -1.58880 11.844 -1.75409  
 11.373 -1.68583 12.472 -1.64882 12.628 -1.46102 12.785 -1.46102  
 12.315 -1.26141 12.472 -1.10515 12.628 -0.08000 12.785 -0.08000  
 HW= 4.000 MAX= 0.22554E 01 LM=10.432 MIN=-0.17975E 01  
 MEAN = 0.20264E 01

DISTANCE FROM OCEAN END A 19.68750 MILE J= 8  
 HR. UIN(J) HR. UIN(J) UIN(J) HR.  
 0.078 -1.08987 0.235 -0.37392 0.392 -0.84542 0.549 0.706  
 1.020 0.00015 1.177 0.19119 1.333 0.34590 1.490 1.490  
 1.961 0.91671 2.118 1.04816 2.275 1.19247 2.432 2.432  
 2.902 1.86707 3.059 1.92480 3.216 1.94347 3.373 3.373  
 3.843 2.11532 4.000 2.17310 4.157 2.21624 4.314 4.314  
 4.785 2.10541 4.942 2.03371 5.098 1.95551 5.255 5.255  
 5.726 1.75824 6.824 1.68441 6.040 1.61566 6.197 1.85646  
 6.667 1.26211 7.765 1.17263 7.981 1.07421 8.079 7.138  
 7.608 0.53040 8.707 0.36656 8.863 0.20191 9.020 8.236  
 8.550 -0.44417 9.648 -0.58353 9.805 -0.72396 9.962 -0.86118  
 9.491 -1.29457 10.589 -1.43531 10.746 -1.55573 10.903 -1.77552  
 10.432 -1.76041 11.530 -1.78578 11.687 -1.78092 11.844 -1.77552  
 11.373 -1.70431 12.472 -1.68531 12.628 -1.66002 12.785 -1.65955  
 12.315 -1.41462 12.472 -1.32065 12.628 -1.48221 12.785 -1.48221  
 HW= 4.157 MAX= 0.22162E 01 LM=10.432 MIN=-0.17904E 01  
 MEAN = 0.20033E 01

DISTANCE FROM OCEAN END A 25.31250 MILE J= 10  
 HR. UIN(J) HR. UIN(J) UIN(J) HR.  
 0.078 -1.30395 0.235 0.235 0.392 0.392 0.549 0.549  
 1.020 -0.44773 1.177 1.177 1.333 1.333 1.490 1.490  
 1.961 0.70404 2.118 2.118 2.275 2.275 2.432 2.432  
 2.902 1.88059 3.059 3.059 3.216 3.216 3.373 3.373  
 3.843 2.11083 4.000 4.000 4.157 4.157 4.314 4.314  
 4.785 2.12571 4.942 4.942 5.098 5.098 5.255 5.255  
 5.726 1.89679 6.824 5.883 6.040 6.040 6.197 6.197  
 6.667 1.46362 7.765 6.824 7.981 7.981 8.079 8.079  
 7.608 0.83120 8.707 7.765 8.863 8.863 9.020 9.020  
 8.550 -0.16768 9.648 8.707 9.805 9.805 9.962 9.962  
 9.491 -1.28430 10.589 9.648 10.746 10.746 10.903 10.903  
 10.432 -1.81946 11.530 10.589 11.687 11.687 11.844 11.844  
 11.373 -1.78049 12.472 11.530 12.628 12.628 12.785 12.785  
 12.315 -1.55456 12.472 12.472 12.628 12.628 12.785 12.785  
 HW= 4.314 MAX= 0.22173E 01 LM=10.589 MIN=-0.18343E 01  
 MEAN = 0.20258E 01

DISTANCE FROM OCEAN END A 30.93750 MILE J= 12  
 HR. UIN(J) HR. UIN(J) UIN(J) HR.  
 0.078 -1.53207 0.235 0.235 0.392 0.392 0.549 0.549  
 1.020 -0.88496 1.177 1.177 1.333 1.333 1.490 1.490  
 1.961 0.49808 2.118 2.118 2.275 2.275 2.432 2.432  
 2.902 1.95754 3.059 3.059 3.216 3.216 3.373 3.373  
 3.843 2.20134 4.000 4.000 4.157 4.157 4.314 4.314  
 4.785 2.24686 4.942 4.942 5.098 5.098 5.255 5.255  
 5.726 2.08890 6.824 5.883 6.040 6.040 6.197 6.197  
 6.667 1.72407 7.765 6.824 7.981 7.981 8.079 8.079  
 7.608 -1.12605 8.707 8.707 8.863 8.863 9.020 9.020  
 8.550 0.09896 9.648 8.707 9.805 9.805 9.962 9.962  
 9.491 -1.53207 10.589 9.648 10.746 10.746 10.903 10.903  
 10.432 -1.81946 11.530 10.589 11.687 11.687 11.844 11.844  
 11.373 -1.78049 12.472 11.530 12.628 12.628 12.785 12.785  
 12.315 -1.55456 12.472 12.472 12.628 12.628 12.785 12.785  
 HW= 4.314 MAX= 0.22173E 01 LM=10.589 MIN=-0.18343E 01  
 MEAN = 0.20258E 01

9.491	-1.32462	9.648	-1.50314	9.805	-1.63031	9.962	-1.73245	10.118	-1.82838	10.274	-1.91527	10.430	-2.00000	10.586	-2.08496	10.742	-2.16983	10.898	-2.25470	11.054	-2.33957	11.210	-2.42444	11.366	-2.50931	11.522	-2.59418	11.678	-2.67905	11.834	-2.76392	11.990	-2.84879	12.146	-2.93366	12.302	-3.01853	12.458	-3.10340	12.614	-3.18827	12.770	-3.27314	12.926	-3.35801	13.082	-3.44288	13.238	-3.52775	13.394	-3.61262	13.550	-3.69749	13.706	-3.78236	13.862	-3.86723	14.018	-3.95210	14.174	-4.03697	14.330	-4.12184	14.486	-4.20671	14.642	-4.29158	14.798	-4.37645	14.954	-4.46132	15.110	-4.54619	15.266	-4.63106	15.422	-4.71593	15.578	-4.80080	15.734	-4.88567	15.890	-4.97054	16.046	-5.05541	16.202	-5.14028	16.358	-5.22515	16.514	-5.31002	16.670	-5.39489	16.826	-5.47976	16.982	-5.56463	17.138	-5.64950	17.294	-5.73437	17.450	-5.81924	17.606	-5.90411	17.762	-5.98898	17.918	-6.07385	18.074	-6.15872	18.230	-6.24359	18.386	-6.32846	18.542	-6.41333	18.698	-6.49820	18.854	-6.58307	19.010	-6.66794	19.166	-6.75281	19.322	-6.83768	19.478	-6.92255	19.634	-7.00742	19.790	-7.09229	19.946	-7.17716	20.102	-7.26203	20.258	-7.34690	20.414	-7.43177	20.570	-7.51664	20.726	-7.60151	20.882	-7.68638	21.038	-7.77125	21.194	-7.85612	21.350	-7.94099	21.506	-8.02586	21.662	-8.11073	21.818	-8.19560	21.974	-8.28047	22.130	-8.36534	22.286	-8.45021	22.442	-8.53508	22.598	-8.61995	22.754	-8.70482	22.910	-8.78969	23.066	-8.87456	23.222	-8.95943	23.378	-9.04430	23.534	-9.12917	23.690	-9.21404	23.846	-9.29891	24.002	-9.38378	24.158	-9.46865	24.314	-9.55352	24.470	-9.63839	24.626	-9.72326	24.782	-9.80813	24.938	-9.89299	25.094	-9.97786	25.250	-10.06273	25.406	-10.14760	25.562	-10.23247	25.718	-10.31734	25.874	-10.40221	26.030	-10.48708	26.186	-10.57195	26.342	-10.65682	26.498	-10.74169	26.654	-10.82656	26.810	-10.91143	26.966	-10.99630	27.122	-11.08117	27.278	-11.16604	27.434	-11.25091	27.590	-11.33578	27.746	-11.42065	27.902	-11.50552	28.058	-11.59039	28.214	-11.67526	28.370	-11.76013	28.526	-11.84500	28.682	-11.92987	28.838	-12.01474	28.994	-12.10461	29.150	-12.18948	29.306	-12.27435	29.462	-12.35922	29.618	-12.44409	29.774	-12.52896	29.930	-12.61383	30.086	-12.69870	30.242	-12.78357	30.398	-12.86844	30.554	-12.95331	30.710	-13.03818	30.866	-13.12305	31.022	-13.20792	31.178	-13.29279	31.334	-13.37766	31.490	-13.46253	31.646	-13.54740	31.802	-13.63227	31.958	-13.71714	32.114	-13.80201	32.270	-13.88688	32.426	-13.97175	32.582	-14.05662	32.738	-14.14149	32.894	-14.22636	33.050	-14.31123	33.206	-14.39610	33.362	-14.48097	33.518	-14.56584	33.674	-14.65071	33.830	-14.73558	33.986	-14.82045	34.142	-14.90532	34.298	-14.99019	34.454	-15.07506	34.610	-15.15993	34.766	-15.24480	34.922	-15.32967	35.078	-15.41454	35.234	-15.50000
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## I. Plotting Program

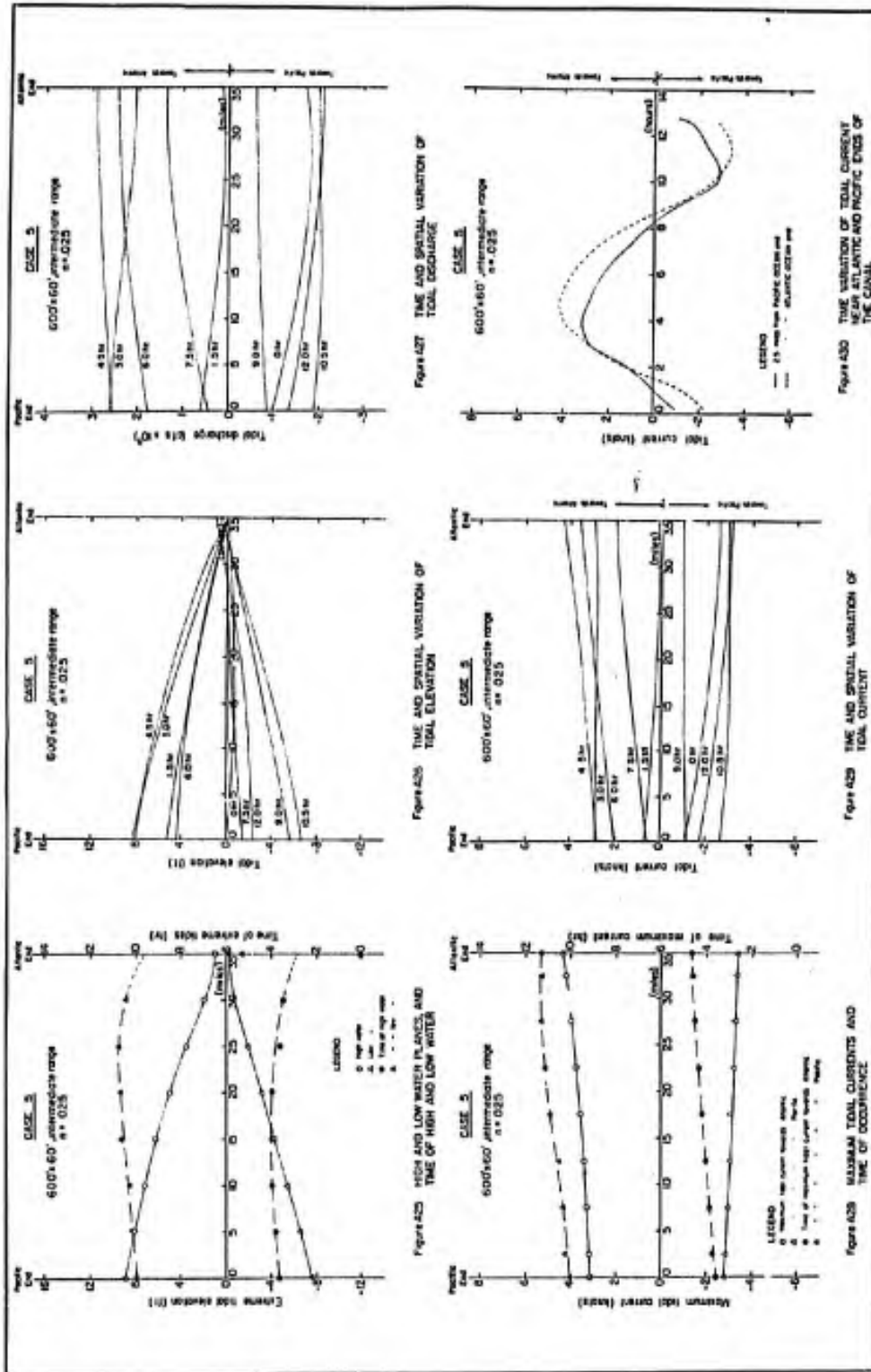
The plotting program is written for an IBM 1130 computer. The language of the program is 1130 Fortran V. The computer must have a Calcomp plotter and plotting subroutines in its library. The plotter may be either the large model or small model of Calcomp type.

The user specifies the scales of the graphs to be plotted on a scale parameter card (see input format). It is the user's responsibility to insure that the initial pen setting and scales do not cause the plotter to exceed its limits.

The initial pen position should be at center of the graph paper on the Calcomp plotter. The flow chart, complete listing of the computer program, and sample input data are presented in Section J. A sample output giving six typical output graphs obtainable from this plotting program (see also Ref. No. 18) is included in this section.

The following are the nine different types of graphical outputs obtainable from the plotting program:

<u>Graph Number</u>	<u>Description</u>
1	Values and time of maximum and minimum tidal elevation versus distance along the channel.
2	Tidal elevation versus distance along channel for values of time at 1.5 hour intervals starting at $t = 0$ .
3	Tidal elevation vs. time at given stations.
4	Same as 1 for discharge.
5	Same as 2 for discharge.
6	Same as 3 for discharge.
7	Same as 1 for velocity.
8	Same as 2 for velocity.
9	Same as 3 for velocity.



SAMPLE GRAPHICAL OUTPUT FROM PLOTTING PROGRAM (REF. NO.18)

The input format is as given in the following table:

Type of Data	Content of Card	Format	No. of Cards
Formating Parameters	SHI,SQI,SVI,SXI,STI,XX,YY,PP1,SP1,PP2,SP2	5F10.5,2I5,4F5.2	1
H,Q and/or U value input data cards	These cards are obtainable as card outputs punched by main programs.		

The following is a list of important symbols used in the plotting program:

SHI	Tidal elevation scale - ft/inch
SQI	Discharge scale - cfs/inch
SVI	Velocity scale - knots/inch
SXI	Distance scale - miles/inch
STI	Time scale - hours/inch
XX	Length of x-axis of graph - inches
YY	Length of y-axis of graph - inches
PP1	Distance from x-axis to top line of printing - inches
SP1	Size of lettering of top line of printing - inches
PP2	Distance from x-axis to second line of printing - inches
SP2	Size of lettering of second line of printing - inches

The following list explains the legend used for the graphs:

On Graphs 1, 4, and 7:

- ▽ Maximum elevation, discharge or velocity
- ◁ Time of maximum elevation, discharge or velocity
- △ Minimum elevation, discharge or velocity
- ▷ Time of minimum elevation, discharge or velocity

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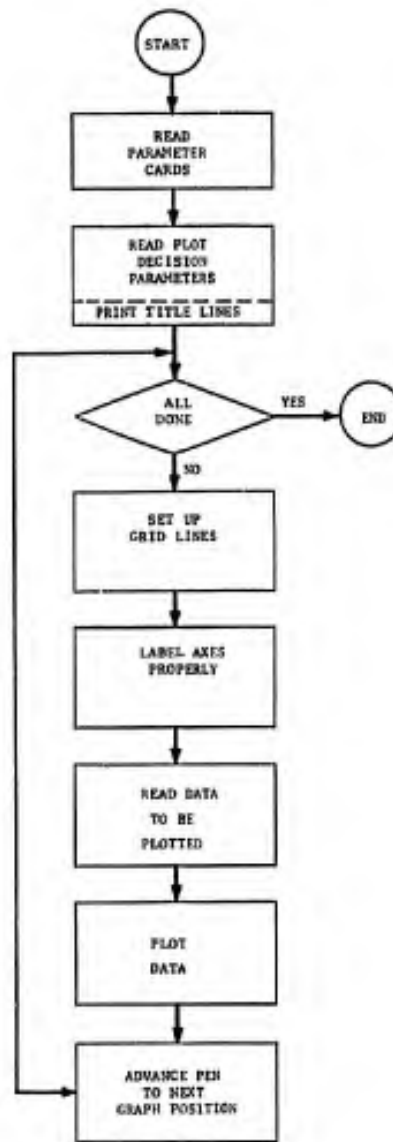
On Graphs 2, 5, and 8:

<u>Symbol</u>	<u>Time after beginning of tidal period</u>
+	0 hours
x	1-1/2 hours
▽	3 hours
◁	4-1/2 hours
△	6 hours
▷	7-1/2 hours
*	9 hours
=	10-1/2 hours
\$	12 hours

On Graphs 3, 6, and 9:

The station number is indicated along the y-axis.

J. Flow Chart, Listing of Program, and  
Sample Input for Plotting Program



FLOW CHART FOR PLOTTING PROGRAM

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LISTING OF PLOTTING PROGRAM

(Applicable for IBM 1130 Computer Only)

```

C   GENERAL PLOT ROUTINE FOR TIDAL COMPUTATION OUTPUT
C   THIS ROUTINE WILL PLOT NINE TYPES OF GRAPHS - IDENTIFIED BY NUMBER
C   1-- HMAX AND TIME OF HMAX VS. DISTANCE
C   2-- H VS. DISTANCE AT 1.5 HOUR INTERVALS
C   3-- H VS. TIME AT SELECTED STATIONS
C   4-- QMAX AND TIME OF QMAX VS. DISTANCE
C   5-- Q VS. DISTANCE AT 1.5 HOUR INTERVALS
C   6-- Q VS. TIME AT SELECTED STATIONS
C   7-- VMAX AND TIME OF VMAX VS. DISTANCE
C   8-- V VS. DISTANCE AT 1.5 HOUR INTERVALS
C   9-- V VS. TIME AT SELECTED STATIONS
C   INPUT COMES DIRECTLY FROM THE 360 EXCEPT FOR THE SCALE CARD
C   SCALES INDICATE NUMBER OF UNITS PER INCH ON THE GRAPH
C   XX=LENGTH OF X AXIS IN INCHES   YY=LENGTH OF Y AXIS IN INCHES
C   PP1 AND PP2 GIVE THE STARTING POSITION OF THE TWO TITLE LINES
C   SP1 AND SP2 GIVE THE SIZE OF THE PRINTING IN THE TITLE LINES
C   INTEGER A,B
C   INTEGER XX,YY
C   DIMENSION ITEM(60,26)
C   DIMENSION U(1000)
C   DIMENSION V(60,14)
1004 FORMAT (5F10.5,2I5,4F5.2)
C   A= READER UNIT NUMBER ----- B= PLOTTER UNIT NUMBER
C   A=8
C   A= INPUT UNIT NUMBER ----- B= PLOTTER UNIT NUMBER
C   B=7
C   READ (A,1004) SHI,SQI,SVI,SXI,STI,XX,YY,PP1,SP1,PP2,SP2
C   SH=1./SHI
C   SQ=1./SQI
C   SV=1./SVI
C   SX=1./SXI
C   ST=1./STI
99999 READ (A,1006)
1006 FORMAT (80H
)
)
C   READ (A,1010) JMAX,NMAX,DELX,DELT
1010 FORMAT (I3,I4,2F10.3)
C   CALL SCALF(1.,1.,0.,0.)
C   CALL FCHAR(0.,PP1,SP1,SP1,0.)
C   WRITE (B,1006)
C   CALL FCHAR(.4,PP2,SP2,SP2,0.)
C   WRITE (B,1020) SHI,SQI,SVI,SXI,STI
1020 FORMAT (21H SCALE-- 1 INCH= H- ,F5.2,9H FT, Q- ,F9.0,10H CFS, V
1- ,F5.2,12H KNOTS, X- ,F5.2,12H MILES, T- ,F5.2,6H HOURS)
C   CALL FPLOT(1,0.,0.)
C   READ (A,1005) NPUN
1005 FORMAT (26I3)
C   READ (A,1005) ((ITEM(I,J), J=1,26), I=1,NPUN)
C   READ (A,1030) NTR
1030 FORMAT (I3)
C   NTR=NTR+1
C   DO 10 LLL=1,NTR
C   DO 10 K=1,NPUN
C   CALL SCALF(1.,1.,0.,0.)
C   CALL FGRID(3,0.,(1.*(YY/2)),1.,YY)
C   CALL FGRID(0,0.,0.,1.,XX)
C   CALL FGRID(3,(1.*XX),(1.*(YY/2)),1.,YY)

```

```

KM=ITEM(K,1)
X1=(1.*XX)+.5
Y1=(1.*(YY/2))-0.5
GO TO (500,510,505,500,510,505,500,510,505),KM
500 CALL FCHAR(X1,Y1,.2,.2,0.)
WRITE (0,1200)
1200 FORMAT (1HT)
GO TO 510
505 CALL FCHAR(X1,0.,0.2,0.2,0.)
WRITE (8,1200)
GO TO 515
510 CALL FCHAR(X1,0.,0.2,0.2,0.)
WRITE (8,1205)
1205 FORMAT (1HX)
515 CALL FCHAR(-.5,Y1,0.2,0.2,0.)
GO TO (520,520,520,524,524,524,525,525,525),KM
520 WRITE (8,1220)
1220 FORMAT (1HH)
GO TO 530
524 WRITE (8,1210)
1210 FORMAT (1HQ)
GO TO 530
525 WRITE (8,1215)
1215 FORMAT (1HV)
530 CALL FPLOT(1,0.,0.)
GO TO (535,535,535,540,540,540,545,545,545),KM
535 DY=SH
GO TO 550
540 DY=SQ
GO TO 550
545 DY=SV
550 GO TO (551,551,552,551,551,552,551,551,552),KM
551 DX=SX
GO TO 555
552 DX=ST
555 CALL SCALF(DX,DY,0.,0.)
GO TO (560,563,570,560,563,570,560,563,570),KM
560 JJ=0
561 JJ=JJ+1
READ (A,1225) J,T1,T2,T3,T4
1225 FORMAT (I3,4E10.3)
V(JJ,1)=(J-1)*DELX/5280.
V(JJ,2)=T1
V(JJ,3)=T2
V(JJ,4)=T3
V(JJ,5)=T4
IF (ITEM(K+1,1)-KM-1) 576,575,576
575 READ (A,1230) (V(JJ,N), N=6,14)
576 IF (J-JMAX+1) 561,562,562
562 DO 1 J=1, JJ
DIST=V(J,1)
V(J,3)=ST/DY*(V(J,3)-6.0)
V(J,5)=ST/DY*(V(J,5)-6.0)
DO 1 N=2,5
CALL FPLOT(-2,DIST,V(J,N))
CALL POINT(N)
CALL FPLOT(1,DIST,V(J,N))

```

```

1 CONTINUE
GO TO 9
563 IF (KM-1-ITEM(K-1,1)) 577,565,577
577 JJ=0
564 JJ=JJ+1
      READ (A,1230) (V(JJ,N), N=6,14),J
1230 FORMAT (8E10.3/E10.3,I3)
      V(JJ,1)=(J-1)*DELX/5280.
      IF (J-JMAX+1) 564,565,565
565 DD 2 J=1, JJ
      DD 2 N=6,14
      DIST=V(J,1)
      IF (N-11) 566,566,567
566 CALL FPL0T(-2,DIST,V(J,N))
      CALL POINT(N-6)
      CALL FPL0T(1,DIST,V(J,N))
      GO TO 2
567 CALL FCHAR(DIST,V(J,N),0.1,0.1,0.)
      IF (N-13) 568,569,571
568 WRITE (B,1235)
      GO TO 2
569 WRITE (B,1240)
      GO TO 2
571 WRITE (B,1245)
2 CONTINUE
1235 FORMAT (1H*)
1240 FORMAT (1H=)
1245 FORMAT (1H$)
GO TO 9
570 DO 6 I=2,26
      IF (ITEM(K,I)) 9,9,572
572 NMAXQ=(NMAX+1)/2
      DT =DELX/1800.
      IF (KM-3) 573,573,574
573 READ (A,1231) (U(N), N=1,NMAXQ)
1231 FORMAT (8F10.5)
      CALL FCHAR(-0.2/DX,U(1),0.075,0.075,0.)
      WRITE (B,1232) ITEM(K,I)
1232 FORMAT (I2)
      CALL FPL0T(-2,0.,U(1))
      DD 4 N=2,NMAXQ
      CALL FPL0T(0,(N-1)*DT,U(N))
4 CONTINUE
GO TO 6
574 NMAXQ=NMAXQ-1
      READ (A,1231) (U(N), N=1,NMAXQ)
      CALL FCHAR(-0.2/DX,U(1),0.075,0.075,0.)
      WRITE (B,1232) ITEM(K,I)
      CALL FPL0T(-2,DT,U(1))
      DD 6 N=2,NMAXQ
      CALL FPL0T(0,N*DT,U(N))
6 CONTINUE
9 CALL FPL0T(1,0.,0.)
      CALL SCALF(1.,1.,0.,0.)
      CALL FPL0T(0,((1.*XX)*4.),0.)
10 CONTINUE
GO TO 99999
END

```

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4 0.414E 01 0.447E 01-0.352E 01 0 111E 02  
 -0.250E 01 0.957E 00 0.294E 01 0.414E 01 0.295E 01 0.106E 01-0.166E 01-0.325E 01  
 -0.306E 01 4  
 6 0.220E 01 0.447E 01-0.179E 01 0.114E 02  
 -0.140E 01 0.314E 00 0.152E 01 0.220E 01 0.161E 01 0.686E 00-0.713E 00-0.170E 01  
 -0.167E 01 6  
 8 0.214E 01 0.463E 01-0.177E 01 0.107E 02  
 -0.154E 01-0.992E-01 0.147E 01 0.214E 01 0.174E 01 0.931E 00-0.453E 00-0.173E 01  
 -0.174E 01 8  
 10 0.215E 01 0.463E 01-0.180E 01 0.117E 02  
 -0.167E 01-0.470E 00 0.149E 01 0.212E 01 0.187E 01 0.116E 01-0.199E 00-0.174E 01  
 -0.179E 01 10  
 12 0.221E 01 0.494E 01-0.191E 01 0.112E 02  
 -0.182E 01-0.815E 00 0.157E 01 0.217E 01 0.205E 01 0.140E 01 0.679E-01-0.176E 01  
 -0.188E 01 12  
 14 0.431E 01 0.510E 01-0.362E 01 0.114E 02  
 -0.347E 01-0.183E 01 0.300E 01 0.418E 01 0.408E 01 0.288E 01 0.327E 00-0.328E 01  
 -0.355E 01 14  
 16 0.457E 01 0.526E 01-0.348E 01 0.114E 02  
 -0.334E 01-0.196E 01 0.302E 01 0.439E 01 0.430E 01 0.302E 01 0.403E 00-0.312E 01  
 -0.339E 01 16  
 -0.171E 01-0.142E 01-0.113E 01-0.836E 00-0.510E 00-0.149E 00 0.227E 00 0.593E 00  
 0.940E 00 0.122E 01 0.148E 01 0.179E 01 0.210E 01 0.231E 01 0.247E 01 0.262E 01  
 0.278E 01 0.288E 01 0.295E 01 0.304E 01 0.316E 01 0.327E 01 0.342E 01 0.360E 01  
 0.380E 01 0.391E 01 0.400E 01 0.399E 01 0.397E 01 0.389E 01 0.341E 01 0.372E 01  
 0.362E 01 0.349E 01 0.339E 01 0.320E 01 0.299E 01 0.285E 01 0.272E 01 0.254E 01  
 0.234E 01 0.213E 01 0.195E 01 0.176E 01 0.153E 01 0.128E 01 0.102E 01 0.821E 00  
 0.643E 00 0.389E 00 0.800E-01-0.262E 00-0.595E 00-0.899E 00-0.122E 01-0.152E 01  
 -0.181E 01-0.209E 01-0.230E 01-0.252E 01-0.275E 01-0.291E 01-0.303E 01-0.311E 01  
 -0.318E 01-0.325E 01-0.332E 01-0.338E 01-0.346E 01-0.354E 01-0.362E 01-0.362E 01  
 -0.355E 01-0.336E 01-0.314E 01-0.293E 01-0.271E 01-0.251E 01-0.231E 01-0.203E 01  
 -0.137E 01-0.127E 01-0.117E 01-0.105E 01-0.919E 00-0.779E 00-0.640E 00-0.488E 00  
 -0.313E 00-0.113E 00 0.108E 00 0.318E 00 0.471E 00 0.589E 00 0.730E 00 0.898E 00  
 0.105E 01 0.119E 01 0.136E 01 0.154E 01 0.169E 01 0.179E 01 0.187E 01 0.192E 01  
 0.194E 01 0.196E 01 0.203E 01 0.211E 01 0.214E 01 0.214E 01 0.213E 01 0.210E 01  
 0.203E 01 0.196E 01 0.191E 01 0.187E 01 0.182E 01 0.178E 01 0.172E 01 0.163E 01  
 0.156E 01 0.152E 01 0.144E 01 0.134E 01 0.126E 01 0.117E 01 0.107E 01 0.967E 00  
 0.852E 00 0.722E 00 0.606E 00 0.513E 00 0.412E 00 0.277E 00 0.104E 00-0.989E-01  
 -0.303E 00-0.475E 00-0.625E 00-0.773E 00-0.920E 00-0.106E 01-0.118E 01-0.131E 01  
 -0.144E 01-0.158E 01-0.170E 01-0.177E 01-0.177E 01-0.176E 01-0.175E 01-0.176E 01  
 -0.177E 01-0.177E 01-0.177E 01-0.176E 01-0.174E 01-0.168E 01-0.159E 01-0.148E 01  
 -0.330E 01-0.325E 01-0.318E 01-0.309E 01-0.296E 01-0.281E 01-0.265E 01-0.246E 01  
 -0.226E 01-0.198E 01-0.165E 01-0.129E 01-0.885E 00-0.392E 00 0.231E 00 0.100E 01  
 0.177E 01 0.236E 01 0.279E 01 0.317E 01 0.356E 01 0.389E 01 0.408E 01 0.418E 01  
 0.428E 01 0.434E 01 0.436E 01 0.437E 01 0.438E 01 0.440E 01 0.444E 01 0.450E 01  
 0.455E 01 0.457E 01 0.455E 01 0.450E 01 0.444E 01 0.436E 01 0.427E 01 0.418E 01  
 0.409E 01 0.399E 01 0.387E 01 0.371E 01 0.354E 01 0.338E 01 0.325E 01 0.309E 01  
 0.289E 01 0.265E 01 0.240E 01 0.217E 01 0.193E 01 0.165E 01 0.134E 01 0.101E 01  
 0.685E 00 0.361E 00-0.206E-01-0.507E 00-0.107E 01-0.161E 01-0.206E 01-0.239E 01  
 -0.264E 01-0.287E 01-0.306E 01-0.320E 01-0.330E 01-0.337E 01-0.342E 01-0.346E 01  
 -0.348E 01-0.348E 01-0.345E 01-0.342E 01-0.339E 01-0.337E 01-0.335E 01-0.333E 01  
 1 0.109E 02 0.392E 01-0.910E 01 0.100E 02  
 -0.180E 01 0.532E 01 0.992E 01 0.102E 02 0.555E 01-0.146E 01-0.725E 01-0.862E 01  
 -0.303E 01 1  
 3 0.900E 01 0.408E 01-0.732E 01 0.988E 01  
 -0.222E 01 0.434E 01 0.883E 01 0.870E 01 0.514E 01-0.661E 00-0.602E 01-0.679E 01  
 -0.312E 01 3

5 0.756E 01 0.314E 01-0.583E 01 0.973E 01  
 -0.219E 01 0.328E 01 0.753E 01 0.682E 01 0.458E 01 0.576E-01-0.493E 01-0.496E 01  
 -0.287E 01 5  
 7 0.705E 01 0.314E 01-0.530E 01 0.973E 01  
 -0.231E 01 0.266E 01 0.706E 01 0.675E 01 0.451E 01 0.394E 00-0.453E 01-0.451E 01  
 -0.290E 01 7  
 9 0.639E 01 0.314E 01-0.476E 01 0.937E 01  
 -0.237E 01 0.202E 01 0.636E 01 0.584E 01 0.434E 01 0.650E 00-0.412E 01-0.416E 01  
 -0.284E 01 9  
 11 0.566E 01 0.361E 01-0.410E 01 0.941E 01  
 -0.232E 01 0.155E 01 0.563E 01 0.526E 01 0.405E 01 0.812E 00-0.371E 01-0.373E 01  
 -0.258E 01 11  
 13 0.509E 01 0.361E 01-0.333E 01 0.941E 01  
 -0.207E 01 0.120E 01 0.471E 01 0.471E 01 0.370E 01 0.853E 00-0.307E 01-0.321E 01  
 -0.241E 01 13  
 15 0.294E 01 0.329E 01-0.182E 01 0.926E 01  
 -0.647E 00 0.870E 00 0.255E 01 0.254E 01 0.187E 01 0.347E 00-0.161E 01-0.143E 01  
 -0.107E 01 15  
 17 0.700E 00 0.627E 00-0.220E 00 0.722E 01  
 0.700E 00 0.624E 00 0.550E 00 0.266E 00-0.799E-01-0.220E 00-0.119E 00 0.109E 00  
 0.190E 00 17  
 -0.674E 05 0.826E 05 0.219E 06 0.274E 06 0.171E 06 0.142E 05-0.128E 06-0.173E 06  
 -0.123E 06 2  
 -0.946E 05 0.633E 05 0.212E 06 0.282E 06 0.188E 06 0.394E 05-0.117E 06-0.182E 06  
 -0.146E 06 4  
 -0.112E 06 0.401E 05 0.209E 06 0.286E 06 0.200E 06 0.609E 05-0.104E 06-0.190E 06  
 -0.160E 06 6  
 -0.142E 06-0.188E 05 0.203E 06 0.295E 06 0.227E 06 0.102E 06-0.800E 05-0.200E 06  
 -0.181E 06 8  
 -0.168E 06-0.686E 05 0.201E 06 0.293E 06 0.250E 06 0.138E 06-0.555E 05-0.207E 06  
 -0.196E 06 10  
 -0.190E 06-0.108E 06 0.204E 06 0.292E 06 0.267E 06 0.169E 06-0.339E 05-0.214E 06  
 -0.208E 06 12  
 -0.199E 06-0.126E 06 0.201E 06 0.290E 06 0.275E 06 0.184E 06-0.226E 05-0.215E 06  
 -0.212E 06 14  
 -0.203E 06-0.136E 06 0.193E 06 0.290E 06 0.279E 06 0.191E 06-0.146E 05-0.216E 06  
 -0.215E 06 16  
 2 0.383E 01 0.416E 01-0.331E 01 0.107E 02  
 -0.145E 01 0.123E 01 0.304E 01 0.380E 01 0.252E 01 0.234E 00-0.236E 01-0.324E 01  
 -0.210E 01 2  
 4 0.397E 01 0.447E 01-0.334E 01 0.107E 02  
 -0.184E 01 0.949E 00 0.296E 01 0.397E 01 0.277E 01 0.634E 00-0.207E 01-0.326E 01  
 -0.246E 01 4  
 6 0.211E 01 0.431E 01-0.172E 01 0.106E 02  
 -0.108E 01 0.313E 00 0.152E 01 0.210E 01 0.152E 01 0.497E 00-0.933E 00-0.170E 01  
 -0.138E 01 6  
 8 0.209E 01 0.463E 01-0.171E 01 0.111E 02  
 -0.126E 01-0.142E 00 0.143E 01 0.209E 01 0.165E 01 0.789E 00-0.678E 00-0.169E 01  
 -0.149E 01 8  
 10 0.211E 01 0.463E 01-0.174E 01 0.109E 02  
 -0.143E 01-0.516E 00 0.141E 01 0.208E 01 0.181E 01 0.106E 01-0.462E 00-0.172E 01  
 -0.159E 01 10  
 12 0.219E 01 0.478E 01-0.185E 01 0.109E 02  
 -0.162E 01-0.844E 00 0.150E 01 0.214E 01 0.200E 01 0.133E 01-0.287E 00-0.181E 01  
 -0.173E 01 12  
 14 0.425E 01 0.510E 01-0.350E 01 0.109E 02  
 -0.317E 01-0.188E 01 0.288E 01 0.415E 01 0.399E 01 0.276E 01-0.358E 00-0.340E 01

-0.332E 01 14  
 16 0.451E 01 0.526E 01-0.336E 01 0.111E 02  
 -0.310E 01-0.203E 01 0.288E 01 0.434E 01 0.420E 01 0.288E 01-0.219E 00-0.325E 01  
 -0.321E 01 16  
 -0.171E 01-0.143E 01-0.114E 01-0.878E 00-0.572E 00-0.217E 00 0.211E 00 0.593E 00  
 0.921E 00 0.121E 01 0.152E 01 0.185E 01 0.216E 01 0.237E 01 0.253E 01 0.269E 01  
 0.285E 01 0.294E 01 0.302E 01 0.305E 01 0.308E 01 0.318E 01 0.332E 01 0.345E 01  
 0.362E 01 0.377E 01 0.383E 01 0.383E 01 0.382E 01 0.372E 01 0.362E 01 0.352E 01  
 0.342E 01 0.331E 01 0.318E 01 0.301E 01 0.283E 01 0.265E 01 0.248E 01 0.229E 01  
 0.210E 01 0.189E 01 0.168E 01 0.144E 01 0.118E 01 0.913E 00 0.621E 00 0.327E 00  
 0.242E-01-0.413E 00-0.758E 00-0.107E 01-0.134E 01-0.162E 01-0.191E 01-0.212E 01  
 -0.226E 01-0.237E 01-0.248E 01-0.261E 01-0.273E 01-0.280E 01-0.284E 01-0.291E 01  
 -0.303E 01-0.313E 01-0.322E 01-0.328E 01-0.331E 01-0.331E 01-0.321E 01-0.306E 01  
 -0.293E 01-0.277E 01-0.258E 01-0.235E 01-0.210E 01-0.185E 01-0.161E 01-0.129E 01  
 -0.137E 01-0.127E 01-0.117E 01-0.105E 01-0.921E 00-0.786E 00-0.655E 00-0.519E 00  
 -0.362E 00-0.157E 00 0.952E-01 0.321E 00 0.469E 00 0.600E 00 0.752E 00 0.898E 00  
 0.103E 01 0.116E 01 0.132E 01 0.149E 01 0.165E 01 0.177E 01 0.186E 01 0.188E 01  
 0.188E 01 0.191E 01 0.196E 01 0.203E 01 0.209E 01 0.209E 01 0.206E 01 0.205E 01  
 0.198E 01 0.189E 01 0.183E 01 0.178E 01 0.173E 01 0.169E 01 0.164E 01 0.157E 01  
 0.150E 01 0.142E 01 0.133E 01 0.125E 01 0.116E 01 0.105E 01 0.949E 00 0.831E 00  
 0.697E 00 0.555E 00 0.409E 00 0.257E 00 0.767E-01-0.130E 00-0.311E 00-0.445E 00  
 -0.568E 00-0.695E 00-0.811E 00-0.918E 00-0.104E 01-0.117E 01-0.132E 01-0.147E 01  
 -0.160E 01-0.168E 01-0.170E 01-0.169E 01-0.169E 01-0.170E 01-0.171E 01-0.169E 01  
 -0.167E 01-0.164E 01-0.160E 01-0.156E 01-0.149E 01-0.140E 01-0.131E 01-0.120E 01  
 -0.329E 01-0.325E 01-0.319E 01-0.310E 01-0.298E 01-0.283E 01-0.266E 01-0.249E 01  
 -0.229E 01-0.204E 01-0.174E 01-0.140E 01-0.103E 01-0.591E 00-0.235E-01 0.733E 00  
 0.155E 01 0.219E 01 0.263E 01 0.303E 01 0.344E 01 0.379E 01 0.401E 01 0.415E 01  
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 0.447E 01 0.451E 01 0.448E 01 0.443E 01 0.438E 01 0.428E 01 0.418E 01 0.410E 01  
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 0.274E 01 0.251E 01 0.226E 01 0.199E 01 0.170E 01 0.138E 01 0.103E 01 0.651E 00  
 0.219E 00-0.284E 00-0.863E 00-0.144E 01-0.192E 01-0.227E 01-0.254E 01-0.278E 01  
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 1 0.115E 02 0.361E 01-0.960E 01 0.973E 01  
 0.496E-04 0.714E 01 0.109E 02 0.102E 02 0.504E 01-0.236E 01-0.792E 01-0.863E 01  
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 3 0.948E 01 0.376E 01-0.758E 01 0.973E 01  
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 -0.323E 01 3  
 5 0.768E 01 0.267E 01-0.568E 01 0.957E 01  
 -0.145E 01 0.473E 01 0.732E 01 0.681E 01 0.427E 01-0.551E 00-0.515E 01-0.482E 01  
 -0.278E 01 5  
 7 0.707E 01 0.251E 01-0.510E 01 0.941E 01  
 -0.172E 01 0.427E 01 0.674E 01 0.638E 01 0.422E 01-0.126E 00-0.472E 01-0.441E 01  
 -0.275E 01 7  
 9 0.635E 01 0.251E 01-0.450E 01 0.941E 01  
 -0.189E 01 0.374E 01 0.620E 01 0.592E 01 0.409E 01 0.237E 00-0.424E 01-0.401E 01  
 -0.262E 01 9  
 11 0.559E 01 0.298E 01-0.383E 01 0.941E 01  
 -0.191E 01 0.333E 01 0.559E 01 0.552E 01 0.387E 01 0.478E 00-0.365E 01-0.354E 01  
 -0.240E 01 11  
 13 0.501E 01 0.455E 01-0.310E 01 0.988E 01  
 -0.180E 01 0.275E 01 0.492E 01 0.499E 01 0.356E 01 0.608E 00-0.291E 01-0.302E 01  
 -0.209E 01 13  
 15 0.270E 01 0.329E 01-0.141E 01 0.910E 01  
 -0.794E 00 0.149E 01 0.260E 01 0.258E 01 0.177E 01 0.340E 00-0.139E 01-0.119E 01

-0.672E 00 15  
 17 0.700E 00 0.125E 02-0.210E 00 0.518E 01  
 0.220E 00 0.300E 00 0.126E 00-0.127E 00-0.158E 00 0.100E-01 0.194E 00 0.458E 00  
 0.665E 00 17  
 -0.753E 05 0.165E 06 0.250E 06 0.284E 06 0.160E 06-0.832E 04-0.142E 06-0.187E 06  
 -0.133E 06 2  
 -0.100E 06 0.147E 06 0.251E 06 0.296E 06 0.181E 06 0.170E 05-0.128E 06-0.195E 06  
 -0.158E 06 4  
 -0.120E 06 0.126E 06 0.257E 06 0.303E 06 0.196E 06 0.395E 05-0.118E 06-0.201E 06  
 -0.170E 06 6  
 -0.156E 06 0.749E 05 0.270E 06 0.306E 06 0.223E 06 0.823E 05-0.993E 05-0.212E 06  
 -0.190E 06 8  
 -0.181E 06 0.213E 05 0.275E 06 0.311E 06 0.246E 06 0.120E 06-0.826E 05-0.220E 06  
 -0.206E 06 10  
 -0.200E 06-0.295E 05 0.275E 06 0.310E 06 0.268E 06 0.153E 06-0.707E 05-0.226E 06  
 -0.217E 06 12  
 -0.208E 06-0.567E 05 0.272E 06 0.308E 06 0.277E 06 0.167E 06-0.656E 05-0.227E 06  
 -0.222E 06 14  
 -0.212E 06-0.758E 05 0.269E 06 0.308E 06 0.280E 06 0.173E 06-0.635E 05-0.227E 06  
 -0.224E 06 16  
 2 0.411E 01 0.416E 01-0.352E 01 0.104E 02  
 -0.149E 01 0.239E 01 0.343E 01 0.393E 01 0.238E 01-0.140E 00-0.263E 01-0.351E 01  
 -0.229E 01 2  
 4 0.426E 01 0.400E 01-0.349E 01 0.106E 02  
 -0.197E 01 0.215E 01 0.350E 01 0.416E 01 0.268E 01 0.276E 00-0.228E 01-0.349E 01  
 -0.266E 01 4  
 6 0.226E 01 0.400E 01-0.180E 01 0.104E 02  
 -0.118E 01 0.958E 00 0.188E 01 0.222E 01 0.149E 01 0.326E 00-0.106E 01-0.179E 01  
 -0.146E 01 6  
 8 0.222E 01 0.416E 01-0.179E 01 0.104E 02  
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 -0.156E 01 8  
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 -0.167E 01 10  
 12 0.227E 01 0.447E 01-0.192E 01 0.107E 02  
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 -0.180E 01 12  
 14 0.443E 01 0.478E 01-0.364E 01 0.109E 02  
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 -0.345E 01 14  
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 -0.333E 01 16  
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APPENDIX III: LIST OF SYMBOLS

A	=	area of cross section of flow
	=	$b_s (d + \eta)$ for a schematized, transverse cross-section
A'	=	complete cross-sectional area
$a_o$	=	amplitude of incoming tidal wave at end of the channel
b	=	width of water surface
$b_o$	=	bottom width of a trapezoidal channel
$b_x$	=	width of prismatic channel at x
$b_s$	=	width of a schematized rectangular cross section of flow
$b_e$	=	width of prismatic channel at entrance to an exponentially varying width channel
C	=	Chezy coefficient
c	=	celerity of tidal wave for frictionless flow
d	=	depth of water below mean water level
$d_e$	=	depth of water below mean water level at entrance
$F_x$	=	forces acting on body of water at x
$(F_f)_x$	=	frictional resistance force exerted by boundaries
f	=	Darcy's resistance coefficient
g	=	gravitational acceleration
h	=	height of water surface above a reference datum plane
k	=	tidal wave number = $\frac{2\pi}{L}$
L	=	tidal wave length
M	=	$\frac{f u_{\max} }{3\pi gR} = \frac{\sigma}{g} \tan 2\alpha$
n	=	Manning's coefficient
P	=	resultant hydrostatic pressure force
$(P_w)_x$	=	x-component of horizontal pressure force exerted by converging boundaries of the section

$Q$	=	total tidal discharge across a transverse cross section in the x-direction
$Q_{\text{trib}}$	=	inflow due to tributary streams entering the tidal channel
$q$	=	inflow of water across the lateral boundaries per linear foot of channel
$R$	=	hydraulic radius
$S_E$	=	slope of the energy gradient
$s_o$	=	hydraulic gradient at time of zero net tidal flow
$t$	=	time
$t_H$	=	time of high water
$t_o$	=	initial time
$T$	=	tidal wave period
$u$	=	average velocity in the x-direction
$u_{\text{max}}$	=	maximum average tidal velocity in x-direction
$V_x$	=	absolute wind speed at x
$x$	=	horizontal distance, along the longitudinal axis of a tidal channel, from a specified point (say, ocean entrance to the channel)
$z_o$	=	height of the bottom of the schematized channel above a reference datum
$z_b$	=	height of the true bottom of the channel above a reference datum
$\eta$	=	water surface with respect to mean water level
$\eta_{\text{max}}$	=	maximum tidal amplitude
$\eta_e$	=	tidal amplitude of ocean tide at entrance
$\eta_{oH}$	=	tidal amplitude at closed end
$\eta_{xH}$	=	local tidal amplitude at x
$\beta_w$	=	wind resistance coefficient
$\sigma$	=	frequency number = $\frac{2\pi}{T}$

- $\psi_x$  = angle between the direction of wind and the longitudinal axis of channel ( $4 < 90^\circ$  for wind blowing landwards,  $180^\circ > 4 > 90^\circ$  for wind blowing seawards)
- $\tau_o$  = average frictional shear stress on the boundary of the section
- $\delta$  = constant defining exponential variation of channel width
- $\mu$  = amplitude attenuation coefficient
- $\tan\alpha = \frac{\mu}{k}$
- $\rho$  = density of water
- $\rho_a$  = density of air