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MARINA DEL REY:

COMPUTER SIMULATION OF POLLUTANT TRANSPORT IN SEMI-ENCLOSED WATER BODY

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ABSTRACT

Tidal flushing characteristics of Marina del Rey have been investigated by computer simulation. Because of the special geometry of Marina del Rey which can be approximated by one-dimensional segments; the model developed by Fischer (1970) is used for the simulation process.

Individual elements of fluid are followed as they move along one-dimensional channels in response to flows generated by tidal fluctuations. A mass-conservation equation is used with tidal data to compute tidal flows. Dispersion of pollutants between fluid elements is calculated using a modified Elder's equation for dispersion in wide open-channel flow. (Dispersion coefficients obtained range from 2.3 sq. ft./sec. to 44 sq. ft./sec.) Time proceeds in a series of finite steps, each of which has a convective part and a dispersive part. Data for the program is provided from tide recordings made at various points in the marina.

The results show comparitive flushing characteristics for pollutants discharged at various locations in Marina del Rey. The most striking characteristic of the marina is its sensitivity to variations in locations and time of pollutant injections.

Two main conclusions were reached. The main channel has a great deal more flushing activity than the basins. The timing of pollutant injections relative to tidal phases is very important in determining what percentage of material will be flushed out in a given time. Pollutants injected during a high tide experience much more flushing than when injected at low tide.

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I. INTRODUCTION

I.1 Background

The natural harbors formed by bays and estuaries generally give rise to adjacent centers of population and industry. The industrial and public works facilities in such areas place a heavy effluent load on these water bodies.

Water movement in a semi-enclosed basin, such as an estuary, is constrained by the physical boundaries of the basin. Pollutant concentration buildup can occur more rapidly in an estuary than is the case along a straight, featureless coastline, or in the open sea. We may conclude that bays and estuaries are the salt water bodies most easily degraded by the activities of man.

Recent concern with preserving or improving the quality of the water resources has precipitated a need for their intelligent management and regulation. The management function is difficult since any water body is subject to conflicting uses (i.e. use for one purpose may limit or exclude use for another), each of which has socio-economic benefit. Regulatory agencies must decide which use or combination of uses will devolve the greatest benefits to the most people.

Processes affecting water quality (physical, chemical and biological) are extremely complex and not fully understood, even for simple geometry. These are the processes upon which management decisions must be based. It is evident that water-quality authorities must have tools available to assist them in making sound management decisions. The primary tool is the water quality model.

The application of water quality models has been shown to be a powerful technique in water resources management (Orlob, _et._ _al._, 1969). Models can incorporate the complexities of the processes affecting a water body in a form simplified sufficiently to permit tractability for management use. Models provide a diagnostic and quasi-predictive capability. This capability (which is quasi-predictive since, in most cases, dispersion coefficients and water depths due to tides and seiches must be measured in the prototype) may be used to evaluate proposed changes in the geometry of the water body, its inputs or its uses.

There are two basic aspects to the simulation of estuarine processes. The first is hydrodynamic modeling, which uses entrance tide data to compute currents and water levels in the estuary. The second is water quality modeling which simulates the temporal and spatial changes in pollutant concentrations due to convection, dispersion and sources and sinks. A predictive water quality model uses the results of a hydrodynamic model and calculated dispersion coefficients as input data. Calculated dispersion coefficients have historically been one or more orders of magnitude too small

(Fischer, 1966). A quasipredictive water quality model uses the results from a hydrodynamic model or from tide-seiche measurements, and measured dispersion coefficients as inputs.

Two classes of problems face an engineer concerned with the tidal flushing of estuaries:

1.) The development of an equation, computer program or other model to predict the distribution and concentration resulting from the discharge of a pollutant into an existing estuary; or . . .

2.) Prediction of what will happen to such things as salinity intrusion and pollutant concentrations if the estuarine geometry or fresh water discharge are changed permanently.

The work reported herein is concerned with the first of the above mentioned two cases: Formulation of a quasi-predictive water quality model to predict the distribution and concentration resulting from the discharge of pollutants or storm drainage into Marina del Rey, California. This work is a part of an environmental study done at the request of the Los Angeles County Flood Control District and the Marina del Rey Small Craft Harbor Commission. These organizations needed information on the effects of the discharge of storm water drainage into the marine environment, in particular in marinas and harbors in Southern California region.

The design for Marina del Rey was completed in November, 1956. This was one of the first attempts to establish a large harbor for the protection of small, recreational craft with an entrance exposed to a severe wave climate. The U. S. Corps of Engineers project consists of two parallel rubble-mound jetty structures with an outlying rubble-mound breakwater, and a main channel approximately 10,000 feet long, 1000 feet wide, and 10 to 18 feet deep at mean lower low water (M. L. L. W.) extending to the inner basin complex. The harbor was constructed in a Los Angeles County owned marsh. The moles and perimeter lands are spoil material from the harbor excavation. The basin area is 10-15 feet deep at mean lower low water. The perimeter of the marina consists of vertical faced bulkheads constructed of concrete sheet piles. The Ballona Creek Flood Control Channel is located immediately southeast of the marina entrance. Figure 1 illustrates the layout of the marina.

1.2 Objective and Scope of Present Work

The objective of this study is to investigate the pollutant transport characteristics of Marina del Rey by computer simulation. Because of the special feature of the geometry of Marina del Rey which can be approximated by one-dimensional segments; the model developed by Fischer (1970) was used with certain minor modifications.

In Chapter II, previous work on estuary flushing models is surveyed. A general description and discussion of Fischer's one-

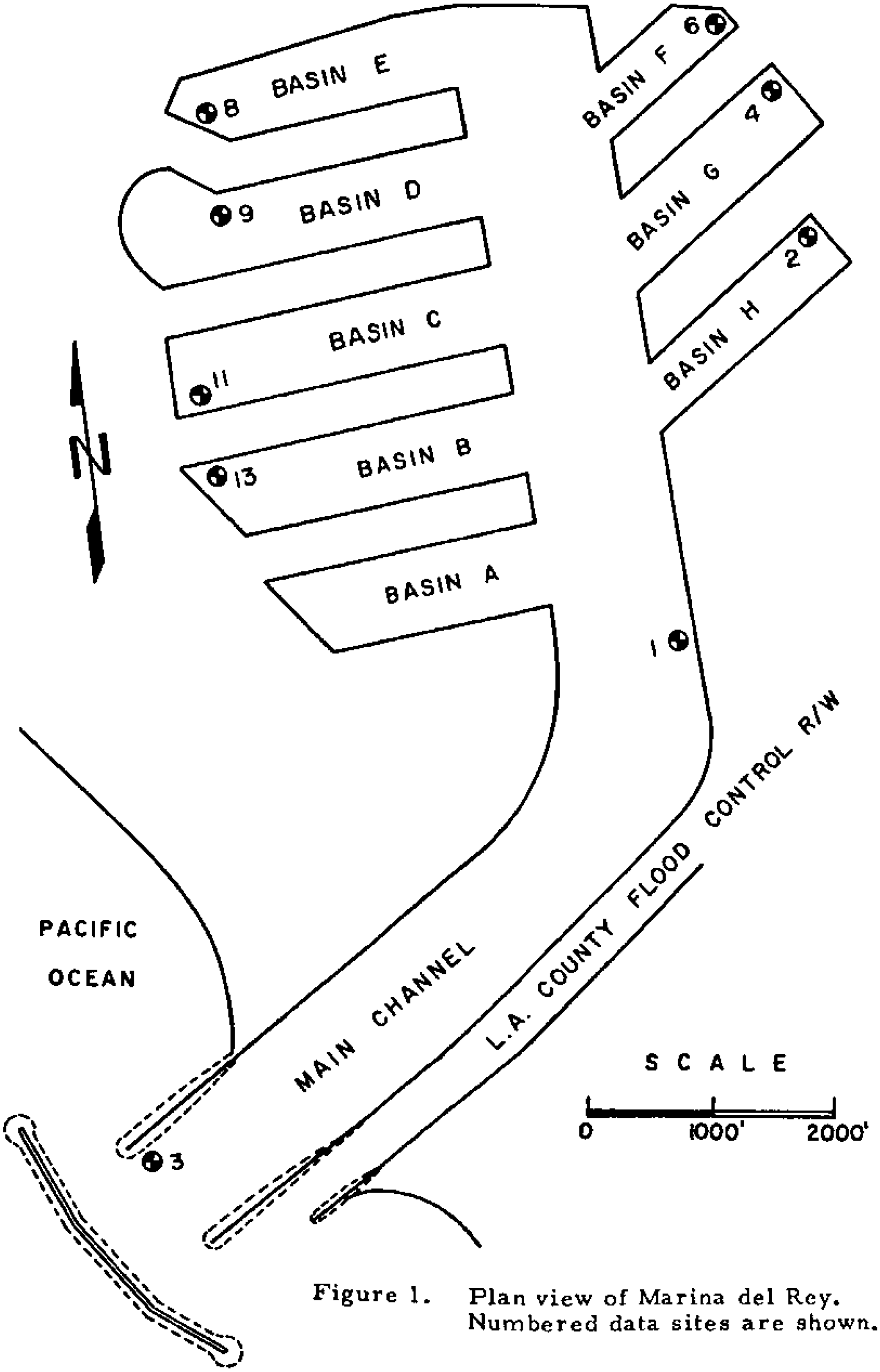


Figure 1. Plan view of Marina del Rey. Numbered data sites are shown.

dimensional model is presented in Chapter III. Work done at Marina del Rey in recording tides for use in the computer model is discussed in Chapter IV. Chapter V details the modeling of Marina del Rey. Results of computer simulation are presented in Chapter VI. Conclusions are stated in Chapter VII.

II. LITERATURE SURVEY

II.1 Introduction

According to the most widely used definition, an estuary is a semi-closed coastal body of water which has a free connection with the open sea (Pritchard, 1969). The water within the estuary is a non-homogeneous mixture of seawater and fresh runoff water. The fresh water overlies the saline water and the estuary is stratified. Estuaries undergo flushing due to the net seaward flow of fresh water, and due to the oscillatory currents associated with the tidal rise and fall of the water surface. Tidal currents are generally the dominant horizontal motions in estuaries, providing the turbulent energy for mixing. Bowden (1967) considers the primary parameters of circulation and diffusion in estuaries to be: physical dimensions, freshwater flow and tidal conditions.

It should be noted that Marina del Rey is not strictly an estuary as defined above. There is no measurable fresh water influx to the marina except for brief periods (a few days at most) during the winter and spring storms. Therefore the water in Marina del Rey may be considered to be vertically and horizontally homogeneous. This should be kept in mind during the following discussion.

Probably the earliest model of tidal flushing was the tidal prism used by Phelps and Velz (1933) to study pollution of New York Harbor. Since their assumption of complete mixing on each tide is incorrect, an improvement was suggested by Ketchum (1951) in which the estuary is divided into segments, each of which is assumed to be completely mixed. Ketchum's relatively crude method has been used to calculate flushing times as recently as 1970 (Ahrnsbak, 1971).

Since 1951 analysis of estuary pollution has developed primarily in the framework of diffusion and mass transfer theory. The major stepping stone for this development was the publication in 1953 of G. I. Taylor's work on the dispersion of matter in laminar flow through pipes. Taylor showed that dispersion was produced by diffusion across the pipe combined with a diametral variation in the velocity along it, caused by wall friction. He extended the theory (Taylor, 1954) to turbulent pipe flow showing that transverse mixing in this case is due to eddy diffusion in that direction.

II. 2 Diffusion and Dispersion

The meaning of the terms convection, diffusion and dispersion in estuaries will now be discussed. Convection is the transport of a dissolved substance in a flow at the same velocity as the fluid at the point where the substance is located (i. e. following the flow streamlines). Transport associated with molecular action and with turbulence is termed diffusion, while transport associated with the variation of velocity across the flow section is termed dispersion. Prior to 1969, the literature had never clearly defined the difference between these terms as they are used in fluid transport problems. The terms diffusion and dispersion have been used inter-changeably, and it is sometimes unclear which mechanism an author has in mind from the terminology he uses. Holley (1969) has proposed the following definitions. Diffusion is transport in a given direction at a point in the flow due to the difference between true convection in that direction and the time average of convection in that direction. Dispersion is transport in a given direction due to the difference between true convection in that direction and the spatial average of the convection in that direction. For a channel this average is over the channel cross-section.

Molecular diffusion is used only as a basis for analyzing turbulent diffusion by analogy. Its physical magnitude is small enough in comparison with turbulent diffusion that it may be neglected.

II. 3 Continuum Models

Beginning with the basic ideas of Ketchum and of Taylor, Arons and Stommel (1951) developed a mixing length theory of tidal flushing. They proposed the use of the one-dimensional mass transfer equation in which each term is averaged over the tidal period. A brief discussion of the derivation of the one-dimensional mass transfer equation follows.

The three dimensional turbulent mass transfer equation for a conservative substance (also referred to as the advection-diffusion equation), neglecting molecular diffusion, is:

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial X} + v\frac{\partial c}{\partial y} + w\frac{\partial c}{\partial z}$$

$$= \frac{\partial}{\partial x}\left(e_x \frac{\partial c}{\partial x}\right) + \frac{\partial}{\partial y}\left(e_y \frac{\partial c}{\partial y}\right) + \frac{\partial}{\partial z}\left(e_z \frac{\partial c}{\partial z}\right) + \Sigma S \qquad (1)$$

where u, v and w are the time averaged (over a period short in comparison with the tidal period) velocity components associated with the turbulent flow; c is the local concentration; e_x, e_y, e_z are the turbulent diffusion coefficients; and ΣS is the sum of sources and sinks. To obtain the one-dimensional simplification of equation (1), the transverse and vertical velocities, v and w respectively, are assumed to be zero. The longitudinal velocity, u, is averaged over the channel cross-section to get the average velocity U. The local concentration c is averaged over the channel cross-section to get the average concentration C. After simplification, the one-dimensional equation is written:

$$\frac{1}{A}\frac{\partial}{\partial t}(AC) + \frac{1}{A}\frac{\partial}{\partial x}(AUC) - \frac{1}{A}\frac{\partial}{\partial x}\left(AE\frac{\partial C}{\partial x}\right) = \frac{1}{A}\frac{\partial}{\partial x}\left(A\bar{e}_x\frac{\partial C}{\partial x}\right) + \Sigma S \qquad (2)$$

The reader interested in a rigorous derivation is referred to Okubo (1964) or to Holley and Harleman (1965). The negative term on the left side of equation (2) is the longitudinal dispersion term, and E is the dispersion coefficient. The quantity $\bar{e}_x$ is the spatial average of the turbulent diffusion coefficient. Taylor (1954) has shown that E is more than two orders of magnitude larger than $\bar{e}_x$. It is convenient to add the two coefficients and refer to the sum as the longitudinal dispersion coefficient, E_L:

$$E_L = E + \bar{e}_x.$$

Equation (2) then becomes:

$$\frac{1}{A}\frac{\partial}{\partial t}(AC) + \frac{1}{A}\frac{\partial}{\partial x}(AUC) = \frac{1}{A}\frac{\partial}{\partial x}\left(AE_L\frac{\partial C}{\partial x}\right) + \Sigma S \qquad (3)$$

This is the most general form of the one-dimensional mass transfer equation for a channel of variable cross-section.

The continuity equation for a variable area estuary with no tributary flow and no stagnant flow regions is written.

$$\frac{\partial A}{\partial t} + \frac{\partial}{\partial x}(AU) = 0 \qquad (4)$$

After expanding the left side of (3) and using (4) to simplify,

$$\frac{\partial C}{\partial t} + U\frac{\partial C}{\partial x} = \frac{1}{A}\frac{\partial}{\partial x}\left(AE_L\frac{\partial C}{\partial x}\right) + \Sigma S \qquad (5)$$

is obtained. This is the form of the one-dimensional mass transfer equation that is usually treated in the literature. It must be noted that Okubo's derivation assumed a channel of constant cross-section. Theoretically, equation (4) is strictly limited to the case of a one-dimensional channel deep enough to minimize tidal effects on the cross-sectional area.

All simplified models such as equation (4) involve some averaging process which yields two terms describing pollutant transport. The second term on the left is the net convective term, and the first term on the right is the longitudinal dispersion term, which lumps together the remaining effects of averaging. Fischer (1970) has referred to this term as containing the "garbage coefficient," (E_L) meaning that it includes all effects not otherwise accounted for. Those models (i. e. two and three-dimensional models) that specify more details of convection require smaller "garbage coefficients" because less averaging of convection is included in the coefficient.

Arons and Stommel (1951) used a form of equation (5) where each term is averaged over a tidal period. The time-averaged mass transfer equation is:

$$\frac{\partial \bar{C}}{\partial t} + U_f \frac{\partial \bar{C}}{\partial x} = \frac{1}{A} \frac{\partial}{\partial x} \left(A E_L \frac{\partial \bar{C}}{\partial x}\right) + \Sigma \bar{S} \ , \qquad (6)$$

where $\bar{C}$ is the concentration averaged over one tidal period, U_f is the non-tidal advective velocity due to freshwater inflow, and $\bar{E}_L$ is the time averaged longitudinal dispersion coefficient. $\bar{A}$ is the time averaged cross-sectional area, and the source and sink terms are also time averaged. Stommel (1953) used a steady state form of equation (6) in finite difference form to determine $\bar{E}_L$ as a function of x from measurements of salinity in the Severn Estuary. He then calculated longitudinal concentration distributions for a pollutant introduced at an arbitrary section of the estuary.

A mathematical model based on a different non-tidal advective concept has been developed by O'Connor (1965). His model applies to instantaneous concentration distributions at slack tide conditions rather than to concentrations averaged over a tidal period. The model, which has the same form as equation (5), is called the slack tide approximation. O'Connor obtained analytic solutions for instantaneous or continuous injection of a pollutant for both constant and variable area estuaries.

Although the two non-tidal advection concepts have governing equations that appear to be identical, the longitudinal dispersion coefficients for the two models have different magnitudes. The serious disadvantage of the non-tidal models is that the dispersion coefficients for the particular reach under consideration must be determined experimentally. This is an expensive and time consuming procedure involving dye injection and observation in the field.

The ease of analysis of models based on non-tidal advective concepts led to their development before large, powerful computers became widely available. The analytic simplifications gained by ignoring tidal motion are more than offset by the difficulties of determining an appropriate dispersion coefficient. For this reason, recent emphasis has been on the development of real time one-dimensional models, where the governing equation is averaged over the channel cross-section, but not over time.

II. 4 Computer Models

The advent of the large, high-speed digital computer has allowed the use of real time models in complex geometries. These generally use finite-difference techniques to solve the one-dimensional equation (5). The first real-time formulation that the writer is aware of is that of Thomann (1963). He used network theory to compute dissolved oxygen distributions in an estuary. Although possible on a digital computer, his solutions were intended to be carried out on an analog machine.

Bella and Dobbins (1968) have performed finite difference calculations for biochemical-oxygen-demand and dissolved-oxygen profiles in the uniform density region of a hypothetical constant-area estuary having a sinusoidal tide. Their results were compared with solutions obtained from the steady-state, non-tidal advective mass transfer equations. Dornheim and Woolhiser (1968) developed a finite-difference scheme for a hypothetical estuary with a cross-sectional area which varies as a linear function of x and which is subject to a sinusoidal tide. In both of the above investigations the numerical values of the real-time dispersion coefficients were arbitrarily assigned. In other words, the relation between the magnitude of the dispersion coefficient and the tidal motion was not considered. Shubinski <u>et al</u> (1965) and Orlob <u>et al</u> (1969) have considered water quality problems in the San Fransisco Bay and the

Sacremento-San Joaquin Delta area. The computational scheme consists of a link-node network of uniform flow channels. The real-time finite difference model considers tidal advection and dispersion in the uniform channel links between nodes. All non-advective and dispersion aspects of the mass balance, such as decay and absorption are assumed to be concentrated at the nodal junctions. The dispersion coefficients and the rate constants of the various source and sink terms must be adjusted to match field data.

The real-time mass transfer mathematical model has been studied by C. H. Lee (1970). Finite-difference forms of the continuity, momentum and mass transfer equations were developed for variable-area estuaries of arbitrary geometry. This permits inclusion of non-linear tidal advection, multiple pollutant sources and time-dependent freshwater flow. The real time longitudinal dispersion coefficients are related to the tidal motion through salinity observations in the salinity intrusion region and through the modified Taylor dispersion equation (to be discussed below) in the constant density tidal region. Water quality parameter observations in several estuaries are used for comparison with the analytic results. Preliminary results have been published by Harleman *et. al.* (1968).

II. 5 Determination of Longitudinal Dispersion Coefficients

There are two methods used in determining longitudinal dispersion coefficients for a real time model. The first of these is an analytic one which considers the fluid mechanics of dispersion in an oscillating flow. The second is an empirical one where the dispersion coefficient is determined by comparing solutions of the mass transfer equation (5) with measured concentration distributions of a substance in the estuary in question. Coefficients determined by the latter method may be used to predict the dispersion of some other substance. A practical requirement of this method is that all the source and sink terms for the substance used must be known fairly accurately. As a consequence, the empirical method is restricted to naturally conservative substances or to tracers with well known decay characteristics.

A physical understanding of longitudinal dispersion may be gained by consideration of steady, uniform density, turbulent pipe flow. Assume an instantaneous injection of a finite amount of tracer material uniformly across the entire flow cross-section. The velocity distribution causes the tracer near the center of the pipe to move downstream much faster than the tracer near the pipe wall. Lateral turbulent mixing maintains uniform concentrations at various cross-sections. There is a large measure of longitudinal spreading due to the shear stress along the pipe wall. The advective term in the one-dimensional mass transfer equation relates to the average longitudinal velocity at the section, but it cannot account for the longitudinal spreading caused by shear stress. The mass transfer due to the velocity distribution is combined with that due to turbulent diffusion, and the total effect is represented by the longitudinal dispersion coefficient. The larger the non-uniformity of the velocity distribution, the larger is the dispersion coefficient.

A prediction is needed of the longitudinal dispersion coefficient in an oscillating flow of uniform density as found in Marina del Rey. Dispersion in steady flows of uniform density will be considered as a preliminary step.

Taylor (1954) first determined a quantitative expression for the longitudinal dispersion coefficient, E_L. His result is written

$$E_L = 10.1\ r_o\ u_* \ , \tag{7}$$

where r_o is the pipe radius and $u_* = \sqrt{\tau_o / \rho}$ is the shear velocity (τ_o is the shear stress at the pipe wall).

Elder (1959) applied Taylor's methods t a steady, uniform, wide open-channel flow having a logarithmic velocity profile in the vertical direction. Elder's coefficient of longitudinal dispersion is given by:

$$E_L = 5.9\ u_*\ d, \tag{8}$$

where d is the depth of flow. The longitudinal dispersion coefficients predicted by the above equations have been confirmed experimentally.

Equations (7) and (8) can be written in terms of the channel flow and friction parameters. In the literature, this is usually done with

Taylor's equation (7) to yield the modified Taylor equation:

$$E_L = 77\ n\ U\ R_h^{5/6} \qquad \text{(sq. ft./sec)}, \qquad (9)$$

where n is Manning's friction coefficient, U is the flow velocity averaged over the cross-section of flow, and R_h is the hydraulic radius. Investigators have used this relation in open-channel flow although Taylor strictly limited his result to turbulent pipe flow. In the case of a channel with width and depth of similar dimensions the use of equation (9) is acceptable.

Since a typical channel cross-section in Marina del Rey has a width to depth ratio which ranges from 30:1 to 60:1, it is appropriate to use Elder's equation (8) for the present work. This equation may be modified to the form of equation (9) as follows. The shear velocity is given by:

$$u_* = \sqrt{\frac{\tau_o}{\rho}} = \sqrt{g\ R_h\ S_e} \quad ,$$

where g = 32.2 ft./sec^2, R_h is the hydraulic radius, and S_e is the slope of the energy gradient. Substitution into (8) yields:

$$E_L = 5.9\ d\ \sqrt{g\ R_h\ S_e}\ .$$

Using the Chezy formula,

$$S_e = U^2/C_c^2 R_h \quad ,$$

where C_c is the Chezy coefficient, we have:

$$E_L = 5.9\ \sqrt{g}\ \frac{d\ U}{C_c} \quad .$$

The Chezy coefficient is related to the Manning coefficient, n, by:

$$C_c = \frac{1.49\ R_h^{1/6}}{n}$$

Substitution yields:

$$E_L = 22.4 \frac{n\ d\ U}{R_h^{1/6}}$$

In a wide channel, the hydraulic radius may be approximated by the water depth, and the required expression is:

$$E_L = 22.4\ n\ d^{5/6}\ U. \qquad (10)$$

There is a question of what velocity to use in applying equation (10) to an oscillating rather than a unidirectional flow. The absolute value of the tidal velocity (Holley and Harleman, 1965) may be used. In an estuary it is expected that bends and intersections will cause an increase in the logitudinal dispersion in comparison with a straight channel. On this basis it is suggested (TRACOR, 1971, p. 56) that the modified Elder equation (10) be increased by a factor of 2. The proposed equation to predict longitudinal dispersion at various points along wide, shallow tidal channels containing water of uniform density is:

$$E_L = 45\ n\ d^{5/6} |U| \quad (\text{ft.}^2/\text{sec.}) \qquad (11)$$

where n is the Manning coefficient, d is the water depth, and U is the magnitude of the water particle velocity at the point of interest averaged over the channel cross-section.

II. 6 Box Models

Another approach to the modeling of estuaries is the so called "box" model as described by Keeling and Bolin (1967). Briefly, a water body is divided up by a series of control volumes (boxes) fixed in space. The fluid within each box is assumed completely mixed and containing a certain concentration of dissolved substance. Exchange is allowed between each box and to external sources and sinks. A conservation of mass equation is written for each box relating the amount of dissolved material within the box to the mass transfer rates through its boundaries and to internal decay. Each equation is solved to obtain a time history of concentrations within each box. The analytic simplicity of the box model is counterbalanced by the large amount of field work required to determine the rate constants.

Objections may be raised to the loss of rigor when using the box model method (Leendertse in TRACOR, 1971, p. 307), i.e. replacing a differential equation with intuitive ideas on exchange processes and rates. One difference between numerical models and box models is that the former has governing equations which contain diffusion coefficients (eddy diffusivities), while the latter represents diffusion processes as empirically determined rates. According to Okubo and Pritchard (1969) exchange rate constants in the box model have "... no clearly defined physical basis, but, to be honest about it, neither do eddy diffusivities."

II. 7 A LaGrangian Model

It should be noted that all of the modeling methods discussed thus far are in Eulerian form; concentrations are predicted for all points in the modeling space. Fischer (1970) has reported a model which is unique (to the writer's knowledge) in that a LaGrangian viewpoint is used. This model, which is executed on a digital computer, follows individual elements of fluid as they move along one-dimensional channels in response to flows. It is assumed that the water is homogeneous vertically and horizontally.

Fischer has given up mathematical rigor and complexity in favor of an intuitive model capable of modeling complex geometries, at the cost of a significant increase in computer time required. Only the slightest changes in programming are required to apply the program to a new geometry. The program can be set up (with no change in programming) to model any combination of pollutant inputs, decay and chemical interactions in a widely differing geometries.

Although the program as listed in Fischer (1970) contained a major logical error and an assortment of minor ones, the method appeared to be a practical and powerful tool for the modeling of estuaries. Therefore it was decided to use this method to simulate Marina del Rey. A description and discussion of the model is presented in the following chapter.

III. GENERAL DESCRIPTION AND DISCUSSION OF ONE-DIMENSIONAL LAGRANGIAN MODEL

III.1 Overview

The computer model used in the present work is a modification of the LaGrangian model reported by Fischer (1970). The estuarine geometry is represented by a series of one-dimensional segments connected end to end. A hypothetical estuary and its schematic representation are shown in Figure 2.

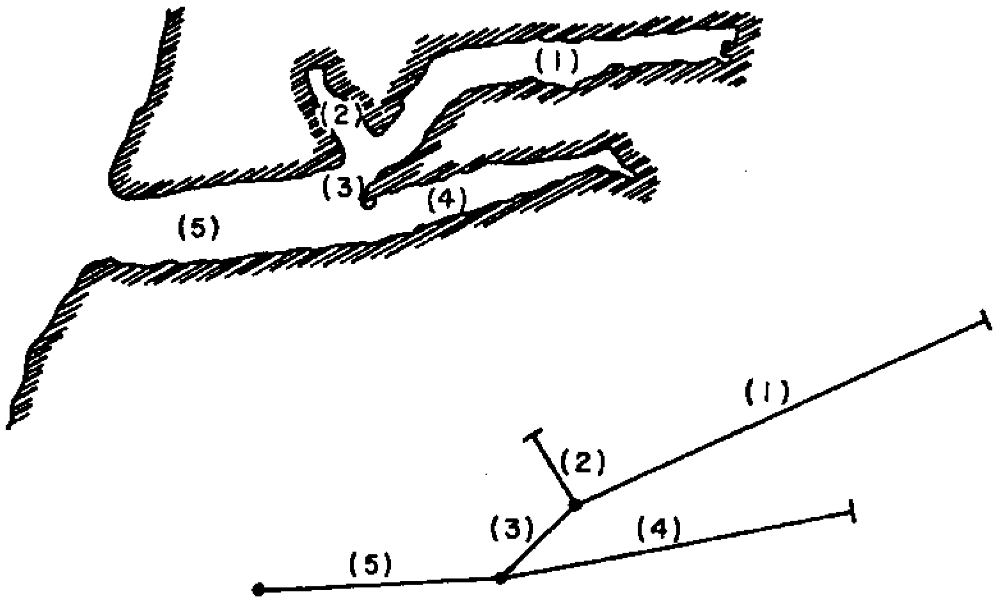


Figure 2. Schematic Representation of an Estuary

The segments are numbered starting at the landward segment and proceeding seaward. Each segment has a characteristic width and depth. Each segment is divided into several water volume elements, numbered sequentially. Pollutant concentrations in the elements are stored in a two-dimensional array, and are identified by the segment number and element number. Time proceeds in a series of finite steps. During each time step these volume elements are moved within a segment and between connecting segments in accordance with flows calculated using a conservation of mass routine and tidal elevation data. Dispersion of pollutants between volume elements is calculated and takes place during each time step. In this manner, the concentration distribution stored in the two-dimensional array is modified during each time step according to the calculated convection and dispersion. The concentration array and other storage arrays a are initialized to zero before program execution begins.

The program user may select the format in which results are to be presented, whether in numerical printouts or graphical plots showing pollutant concentrations.

A description of the basic functions of the program follows. The program is written with the Fortran IV language. A listing of the program along with input data and typical numerical results for Marina del Rey is presented in Appendix 3. The computer used for the present work is an IBM model 370/155.

III. 2 Main Program

The primary program, referred to as MAIN, is a management program. This program examines the tidal conditions, performs preliminary operations accordingly, and calls subroutine River which actually performs the simulation. Program divisions are shown in Figure 3.

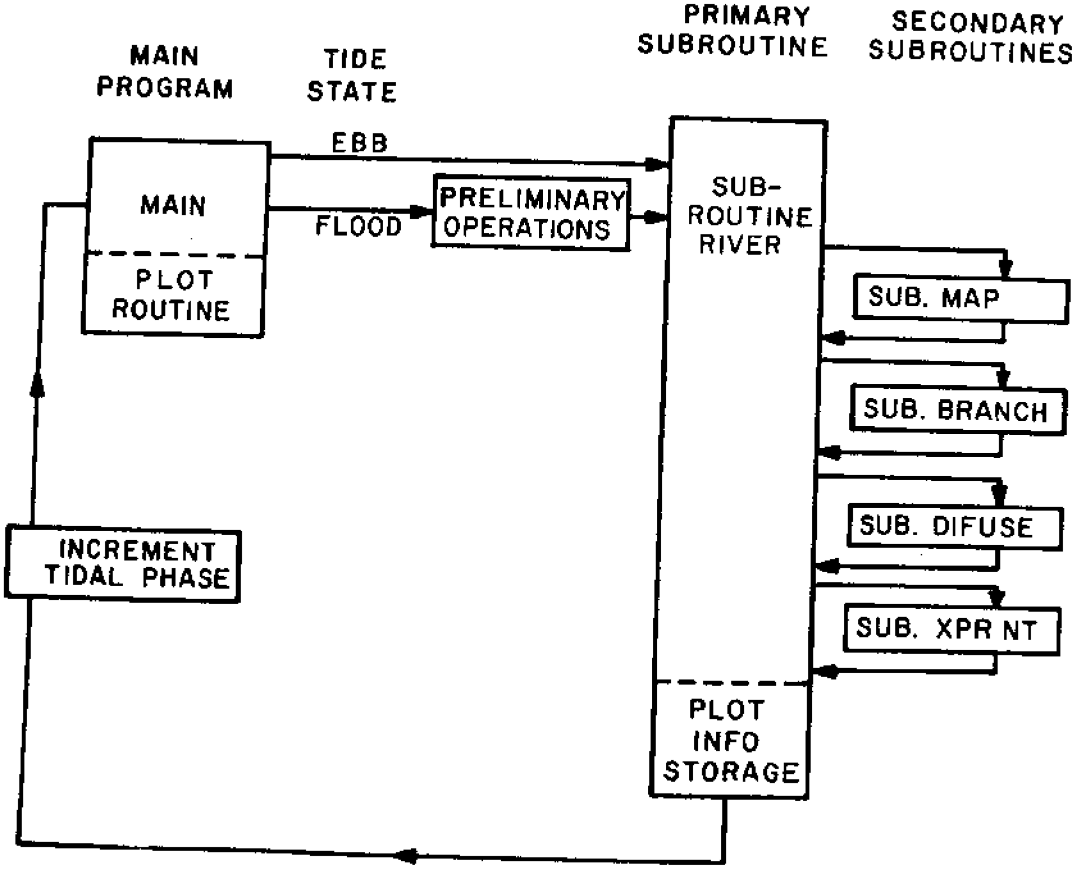


Figure 3. Block diagram of water quality program for estuaries which may be approximated by a one-dimensional geometry.

Numerical quantitities are stored in COMMON block storage areas, so that several subroutines may refer to the same variables.

When program execution begins, MAIN reads the following data:

1. Prototype identification,
2. The number of tidal cycles to be run,
3. Concentration in the ocean of the pollutants being modeled (constant since the ocean is considered an infinite sink),
4. Tidal cycle numbers for which output is to be printed and/or plotted at the end of each phase,
5. The number of hours in each tidal phase of the 25 hour tidal cycle (for example, 6, 6, 6, 7),
6. The number of water quality parameters being modeled (from 1 up to 3),
7. An alphameric description of each parameter (12 characters) and its decay constant.

MAIN prints the site identification and lists each parameter name with its decay constant. If a plot is requested, a plot identifier is set up along with preliminary specifications.

Simulation now begins with tidal cycle number 1. A labeled CONTINUE statement ("A") is placed here to act as a reentry point for ensuing cycles. If a printout or a plot is requested for this cycle, logical indicators are set accordingly.

The program now enters a DO loop which iterates once for each of the four tidal phases. The number of hours in the phase being executed is set. If the tide is flooding, parameter concentrations at the estuary entrance are specified (from the concentrations in the ocean), and subroutine RIVER is called. If the tide is ebbing, subroutine RIVER is called without any preliminary steps. In either case, the tide indicator is reversed in preparation for the following phase. This is the end of the DO loop.

At this point all four phases of the cycle have been completed. If requested previously, plot data on the distributions of each water quality parameter at the end of each phase, stored by subroutine RIVER, is plotted now. This provides four concentration curves in one plot frame, and one plot frame for each water quality parameter. If this is the last tidal cycle to be simulated, the program stops. If not, the cycle indicator is incremented and control is returned to CONTINUE statement "A" to begin another iteration.

III. 3 Subroutine RIVER

This section describes, in order, the functions of subroutine RIVER. There are two sections in this subroutine. The first is executed only once; the first time RIVER is called, data is read and preliminary operations to prepare the simulation are performed. On subsequent calls during a simulation, the first section is skipped.

The second section performs the actual steps of the simulation.

The behavior of up to three water quality parameters may be modeled simultaneously. To do this, any program step in RIVER that directly effects water quality parameters is executed once for each parameter being modeled. The same is true for similar steps in the secondary subroutines called by RIVER.

The functions of the first section of subroutine RIVER are listed in order:

1. Set logical indicator to skip the first section of RIVER on subsequent calls,
2. Read the number of time steps per hour and the printing control parameters for the description of flow volumes and segment geometry,
3. Read external water inflows for each segment (volume/time step) and the concentrations (PPM) of the dissolved material contained therein,
4. A series of cards containing pollutant injection information is read. There may be any combination of a single instantaneous injection, one or more continuous injections lasting one day or more, or one or more continuous injections lasting through the entire simulation,
5. Read data describing the geometry of the prototype. Read the following information for each segment in sequence:

the number of volume elements in the segment (this is the initial value since the number of volume elements varies during the simulation), the segment length, the numbers identifying upstream connecting segments (there may be 0 up up to 3 segments connected upstream), downstream segment number (there may be only one).

6. Read the widths and depths of the-one-dimensional segments for each hour of the 25 hour cycle. Interpolate between hourly data on the segment widths and depths to provide data at each time step. (This section will be revised in the future to allow direct reading of raw data for each time step). If requested, a description of the flow system will be printed. Compute the volume of each segment, and divide it into starting elements.

This completes the operations of the first section of subroutine RIVER. These operations are executed only once, the first time subroutine RIVER is called. The information generated is stored for use during subsequent iterations.

The following steps make up the second section, the iterative procedure executed for each time step of the simulation. This section performs the detailed operations of the simulation during which the secondary subroutines MAP, BRANCH, and DIFUSE are called. Another secondary subroutine, XPRNT is called when numerical results are to be printed. The major operations are listed below:

7. Begin time step iteration. (This point is the CONTINUE statement labeled 200 in the subroutine RIVER listing in Appendix 3 .) Program control skips to here on the second and subsequent calls to RIVER. A DO loop which iterates once for each time step of the current phase begins here.
8. Beginning with the upstream segments and treating each segment down to the one furthest downstream, call subroutine MAP. Return with flow and concentration information for flow into and out of each segment. (See page 33 for a description of subroutine MAP.)
9. For each segment, call subroutine BRANCH. This routine moves volume elements to account for the flows determined in subroutine MAP. MAP determines the changes required in the segment to correspond to changing conditions, and BRANCH performs the "bookkeeping" to make the change. The number of volume elements in the segment may increase or decrease here. (See page 36 for a description of subroutine BRANCH.)
10. For each segment, call subroutine DIFUSE. This routine adjusts element concentrations to accomplish the dispersive action. This routine includes provisions for combining very

small elements, and determines element locations within each segment. The latter information is used in locating elements into which pollutant injections are made, and in presenting numerical or graphical results.

11. At this point the injection (if any at this time) of pollutants is performed by the simulated addition of material to the volume elements located at injection locations. Decay coefficients for the dissolved materials used in the simulation are applied to the concentration distribution(s). Reactions between water quality parameters, or chemical absorption form the atmosphere, or adsorption on silt particles may be accounted for by inserting appropriate statements here.
12. Concentrations of flow out of the seaward end of the seaward segment are stored here, primarily for future use when the program is expanded to treat two-dimensional geometries connected to one-dimensional geometries.
13. The percentage of parameter number 1 (NQ = 1) flushed out as of the current time step is computed here.
14. This is the end of the time step DO loop. If this is not the last time step of the current phase, return to step 7 for another iteration. If this is the last time step of a phase, continue.
15. If a printout is requested for this phase, subroutine XPRNT

is called, and a stylized diagram of the estuary is printed, showing concentration distributions along each segment.

16. If a plot is requested for this phase, store volume element concentrations and locations in separate arrays for later use by the plotting routine in MAIN.
17. Return program control to MAIN.

III.4 Secondary Subroutines

III.4.1 Subroutine MAP

This routine is called, using four arguments, by subroutine RIVER to compute flows and their concentrations due to tidal elevation changes and external inputs. The first argument is the segment number. The second, third, and fourth are the segment numbers of upstream connecting segments. There may be 0 to 3 upstream segments. Segments numbered 0 are treated as non-existent.

A conservation of mass equation is used to calculate flows in each segment. The segments furthest upstream are treated first. The flow through the landward end of these segments is zero. The flow through the seaward end is equal to the product of the segment length and the difference of water levels in successive time steps, plus any external inflow.

In the general case, the flow through the landward of a segment is computed as the sum of the flow through the seaward ends of the upstream connecting segments. Figure 4 illustrates a typical segment junction of a segment, "M", with three upstream segments, "M1," "M2," and "M3."

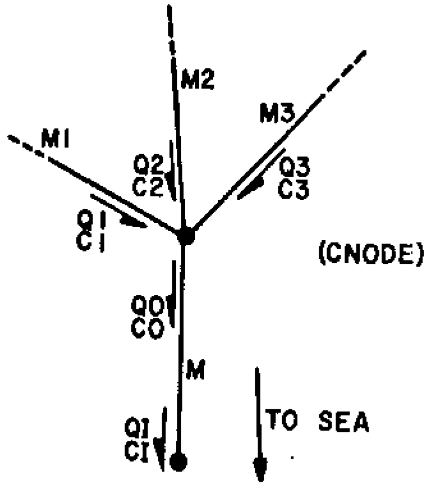


Figure 4. Typical segment connection. Q's represent flow volume, C's represent concentrations.

The flow through the seaward end of each segment is computed as the segment volume change due to the tide between successive time steps, plus the flow through the landward end, plus the effect of any external flows. For example, in the above case Q0 = Q1 + Q2 + Q3, and QI = Q0 + Volume change of segment M + External flows.

Computations of concentrations depend upon the direction of flow through a segment. The concentrations of outflows from a segment are computed by averaging the concentrations of the elements needed to make up the flow. The concentrations of inflows to the segment are not computed here. They are computed as outflows from the connecting segments.

If there are no upstream connecting segments, subroutine MAP returns program control to subroutine RIVER. If there are upstream connecting segments, the concentrations at the upstream end of the segment being considered are calculated. If the tide is ebbing, the concentrations of flow from the upstream segments (C1, C2, C3) are weighted by volume of flow and averaged together to yield the concentration of the material flowing into segment M, which is temporarily stored in the array named CNODE. If the flow is upstream, the concentrations in the volume elements of segment M used in the flow are weighted by volume and stored in CNODE. These concentrations will be used to characterize the flow into the upstream segments.

To summarize: the results provided by subroutine MAP for each segment for each time step are the flow volumes through the upstream and downstream ends of the segments and the concentration at the upstream node.

At this time, no fluid elements have moved, and the concentration distribution stored in memory has not changed. It is the function of the next subroutine to move fluid elements and thus modify the concentration distributions.

III. 4. 2 Subroutine BRANCH

This subroutine performs the bookkeeping task of moving fluid elements to satisfy the flow requirements computed by subroutine MAP. The calling arguments are the number of the segment to be treated, and the number of the next segment downstream. Each segment is composed of from 1 to 29 fluid elements numbered starting with 1 at the upstream end increasing consecutively downstream. The number of elements varies during the simulation.

The direction of flow at the upstream end of a segment is examined first. If the flow is upstream, then one or more fluid elements are moved out of the upstream end to make up the required flow volume computed for that time step by subroutine MAP. Generally, only part of the last element used is required to meet the flow requirements. The remaining fraction of this element is renumbered, and it becomes the first element in the segment. The rest of the remaining elements in the segment are renumbered in sequence down to the end element which will have a lower number than originally. The individual elements which are moved out are lost. The only information retained is the flow volume and concentration computed by subroutine MAP.

Subroutine BRANCH then considers the flow direction at the downstream end of the segment. If the flow here is upstream, then a single element equivalent to the flow volume for that time step is created in the downstream end, and its number is one higher than that of the former last element. The concentrations in this element are equal to the concentrations of the upstream node of the downstream connecting segment, stored in the array CNODE by subroutine MAP. Figure 5 illustrates the movement of volumes in a typical segment when the flow direction is upstream.

If the flow direction is downstream at the upstream end of the segment, then the entire flow volume for that time step is created in the upstream end and called element number 1. Its concentration, which is computed by subroutine MAP and stored in the array CNODE, is now stored in the concentration array. The other elements are renumbered in order, the former number 1 becoming number 2, the former number 2 becoming number 3, and so on. The number of elements in the segment increases by one.

If the flow is downstream at the downstream end, then one or more elements are moved out to make up the flow volume. The remaining fractional part of the last element used in the flow keeps the same element number and becomes the new end element is the segment. Typical volume element movements for a downstream flow are illustrated in Figure 6.

Each segment is treated in this manner once during each time step. This routine provides the convective transport for the model.

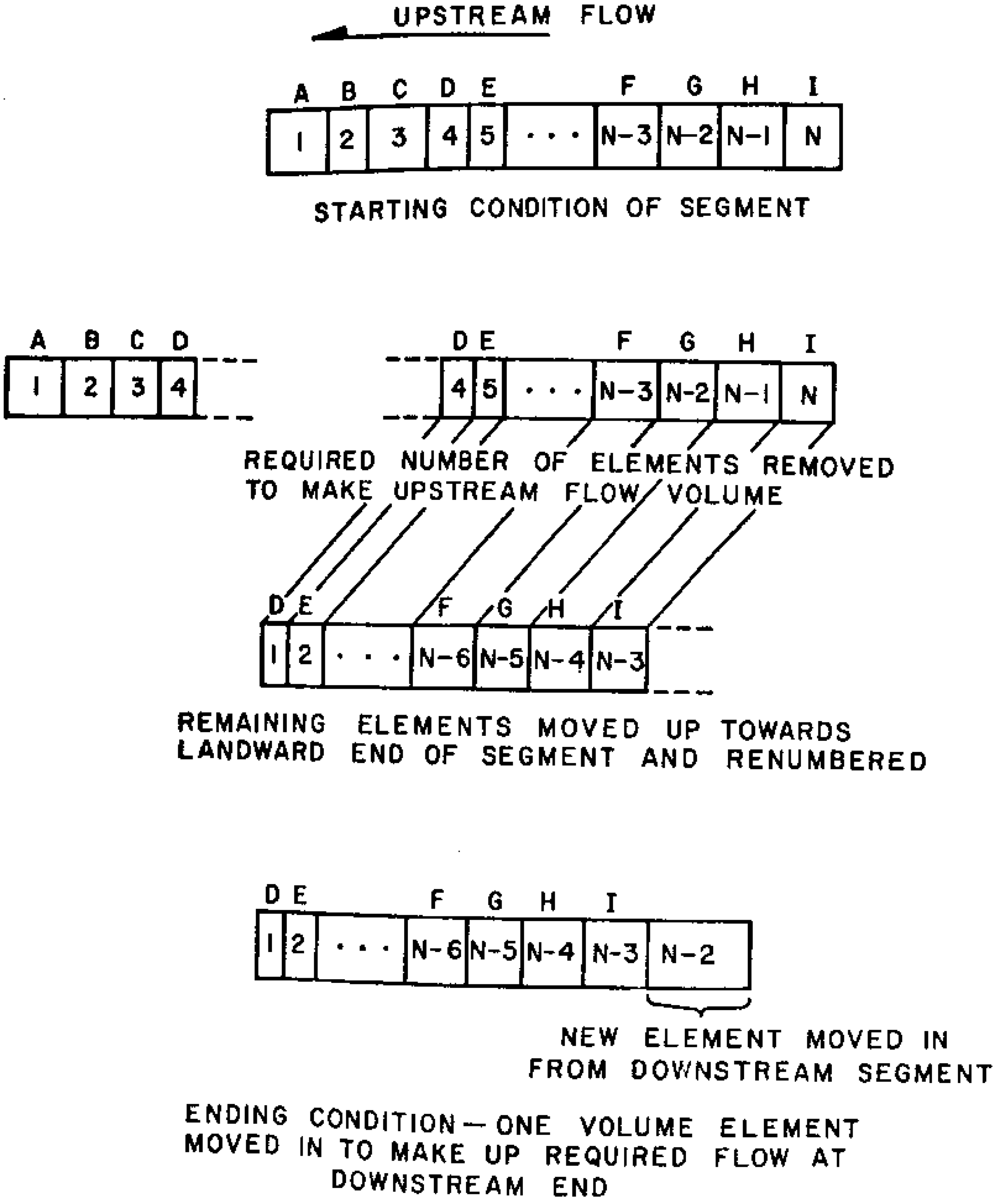


Figure 5. Sequence of operations by subroutine BRANCH in moving volume elements to make up upstream flows computed by subroutine MAP. Letters are identifiers supplied for illustrative purposes. The total number of elements in the segment shows a net decrease of 2 for this time step.

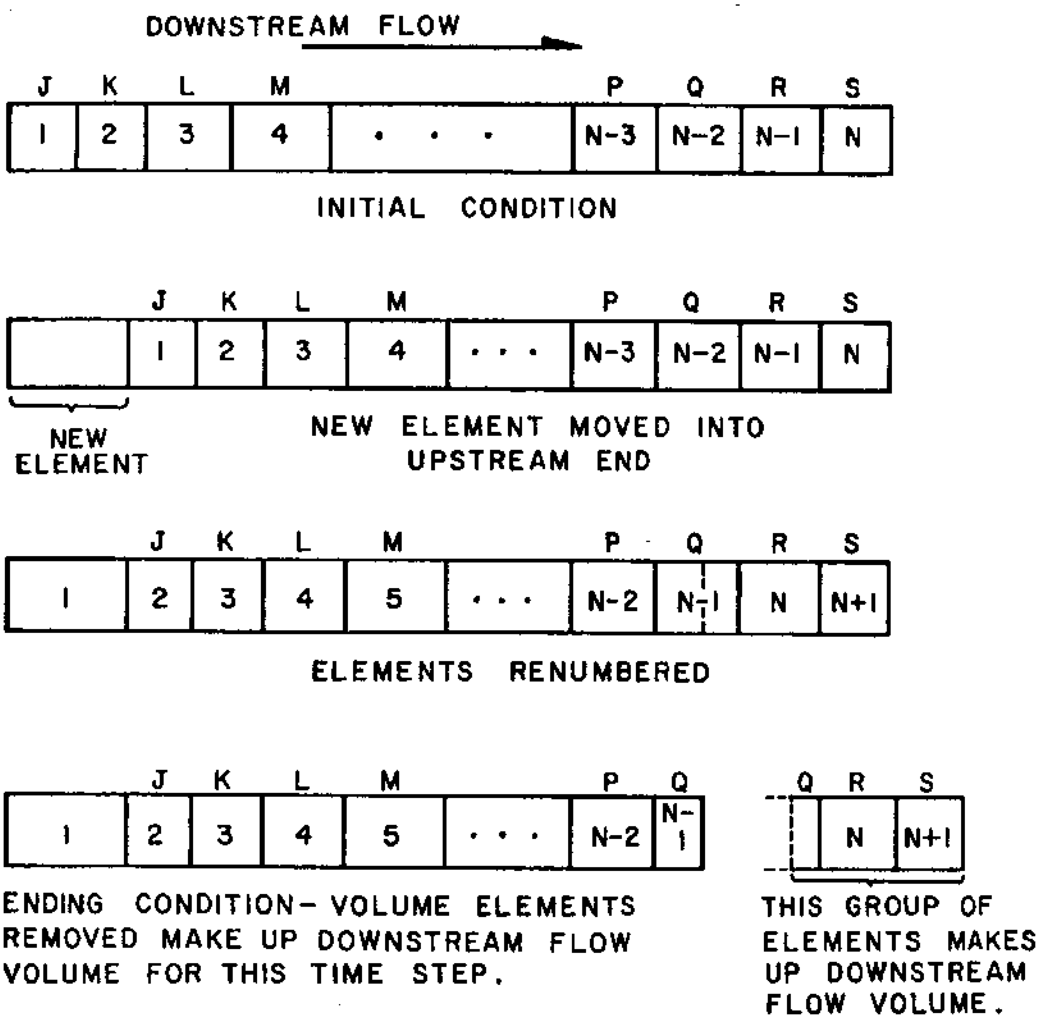


Figure 6. Operations of subroutine BRANCH in moving volume elements to make up downstream flows computed by subroutine MAP. Letters are tracers supplied for illustrative purposes. The total number of elements in the segment shows a net decrease of 1 for this time step.

III. 4. 3 Subroutine DIFUSE

This subroutine provides for dispersion of dissolved material between fluid elements. The calling argument is the number of the segment to be treated. The lengths of each element and the locations of their midpoints are calculated for later use when various pollutant injections occur. When an injection occurs at a certain location in a segment, the lengths and midpoint locations are used to determine which element the injection falls in. If any element is shorter than one-third of the segment width, or if there are 29 or more elements, a routine is executed to combine shorter elements.

The major step of this subroutine is to compute the mass transfer coefficient. This coefficient determines the amount of dissolved material exchanged between elements by dispersion and diffusion. The dimensionless mass transfer coefficient is computed by the following formula (see Appendix 1):

$$\text{D. M. T. C.} = \frac{E_L * \text{Time increment} * \text{Channel cross-section area}}{\text{Distance between elements} + \text{Element volume}}$$

where E_L is the dispersion coefficient (units of sq. ft. /sec.). This coefficient is computed for the boundary between each element pair in the segment (ie, between elements 1 and 2, elements 2 and 3, etc.).

The D. M. T. C. is used to compute the dispersive concentration changes between element pairs during one time step, assuming they are of equal size. This result is adjusted according to the relative sizes of the adjacent elements. The direction of mass transport depends upon the sign of the concentration difference between adjacent elements. Subroutine DIFUSE modifies the concentrations of each element pair in turn in a segment, beginning with elements 1 and 2, and ending with elements N-1 and N. This is the end of the basic function of this subroutine.

There are four more parts to subroutine DIFUSE. The first three use the element lengths and midpoint locations to identify the elements that are to receive pollutant injections from continuous sources, continuous sources of short duration, or single instantaneous injections. The last section combines elements when criteria at the start of this routine indicate the elements are too small because of element splitting by subroutine BRANCH.

DIFUSE is the last of the subroutines used in the simulation procedure. There is one more subroutine which performs a data handling function only.

III.4.4 Subroutine XPRNT

This routine performs the printing out of concentration data after being instructed by subroutine RIVER. Its only function is to present data in an organized form. The blocks of data (one for each segment) are presented schematically in a form which corresponds to the geometry of the prototype. Each data block consists of a heading and four columns of data. The first column lists the distance of the midpoint of each element from the landward end of its segment. The following three columns give concentrations of three different pollutants or other parameters such as dissolved oxygen. In the event less than three parameters are treated in the simulation, the unused columns are printed as zeros to simplify the formatting problem. In the present model, concentration distributions are printed out after each tidal phase, although printouts may be easily specified at any time desired.

At the main computing facility of the University of Southern California, a high speed digital incremental plotter is available for plotting of program output. This plotter was used to supply graphs of concentration distributions in the main channel and basin E of Marina del Rey. The plotting routine is located in the main program, MAIN.

III. 5 Program Expansion Capability

To permit application to a wider range of prototype situations, the program is set up in a manner that easily allows it to be coupled to a program treating a two dimensional case. This would allow treatment of the general case of a narrow tidal river flowing into a bay or wide estuary connected with the ocean.

The two-dimensional routine would be embodied in another primary subroutine (comparable to RIVER). The management program, MAIN, would then call each primary subroutine in a sequence which depends upon the state of the tide. Each primary subroutine would be called once during each tidal phase. The results would be contained in printouts showing a complete concentration map of the prototype.

IV. FIELD WORK AND DATA REDUCTION

IV.1 Introduction

Tidal data for the modeling program was accumulated empirically. Time histories over a 25 hour cycle are needed for every segment of the model. The tacit assumption is that the tidal elevation is not a uniform level above a datum plane, which is the mean lower low water level (M. L. L. W.). The general procedure is to examine the tidal elevation at various points in the marina, and in some way relate tidal elevations in the interior to tidal elevations at the entrance. Then, given some tidal function at the entrance, the tidal elevations in the interior may be computed.

The easiest way to generate a set of tidal data would have been to install two or three tide gauges in each basin, several more in the main channel, and one at the entrance to the marina. Data from all the gauges, recorded synoptically every few minutes on magnetic tape, could be processed by computer and be ready for use by the modeling program. Due to monetary limitations, a procedure requiring only a small amount of equipment was used. Such a procedure is described below.

The tidal function at the entrance is a type denoted as mixed (mixed diurnal and semi-diurnal). The tidal function varies from day to day. At first glance, this would seem quite a difficulty. However, since the tide may be viewed as a small amplitude wave of long period, we may consider the tides in the marina to be linear phenomena. This means that for a certain tide function at the entrance, there should be a certain response at a given interior point. A repeated identical input should cause a repeated identical response. This should hold for any point in the marina. If each tide recording made at an interior point of such a linear system were referred to a baseline recording made at one point in the system (even though tides recorded at the baseline location varied daily), the tide response at individual interior points could be determined as a function of the tide at the baseline point. A series of such functional relations for various points in the marina should allow computation of tides at these points as a function of an arbitrary tide at the baseline point. For purposes of the simulation, a tide recorded for one day at the baseline point is picked, and tides in the rest of the marina are computed from it. This empirical tide is used as data for the computer model.

IV. 2 Instrumentation

IV. 2. 1 Level Sensing Tide Gauges

The tide gauges used for most of the data collection utilized a float containing a magnet which individually activates a series of magnetic reed switches and resistors in a voltage divider network. This network contains 77 reed switches on 4 centimeter centers, and

77 one-hundred ohm resistors. It is enclosed in a sealed 1/4 inch I.D. Schedule 80 poly-vinyl chloride pipe, 12 feet long, with an electrical connector at one end. This pipe is fastened to a 1 1/2 inch I.D. Schedule 40 PVC pipe 14 feet long. The larger pipe is open at both ends and contains a float with a magnet. In use, the assembly is attached to a piling so as to cover the tidal range of interest. The float moves vertically in response to tides and harbor surges and the magnet in the float activates the reed switches. The output signal is proportional to the water level. Figure 7 shows the gauge a assembly and its enclosed circuitry. The associated circuitry consists of a power supply and an operational amplifier follower used to drive the recorder pen.

IV.2.2 Pressure Sensing Tide Gauge

In the late stages of the field work another type of tide gauge, having been constructed, became available for field use. This pressure sensing gauge was built because at many locations in the marina, the level sensing gauge cannot be installed. The gauge consists of a 50 PSIG strain gauge pressure transducer (Statham #10-50G-350) and a strain gauge signal conditioner enclosed in a PVC pressure case. A neoprene clad sea cable carries power and transmits the pressure signal to shore electronics consisting of a power supply and an operational amplifier follower with "SPAN" and "ZERO" controls which drives the recorder pen. The analog output

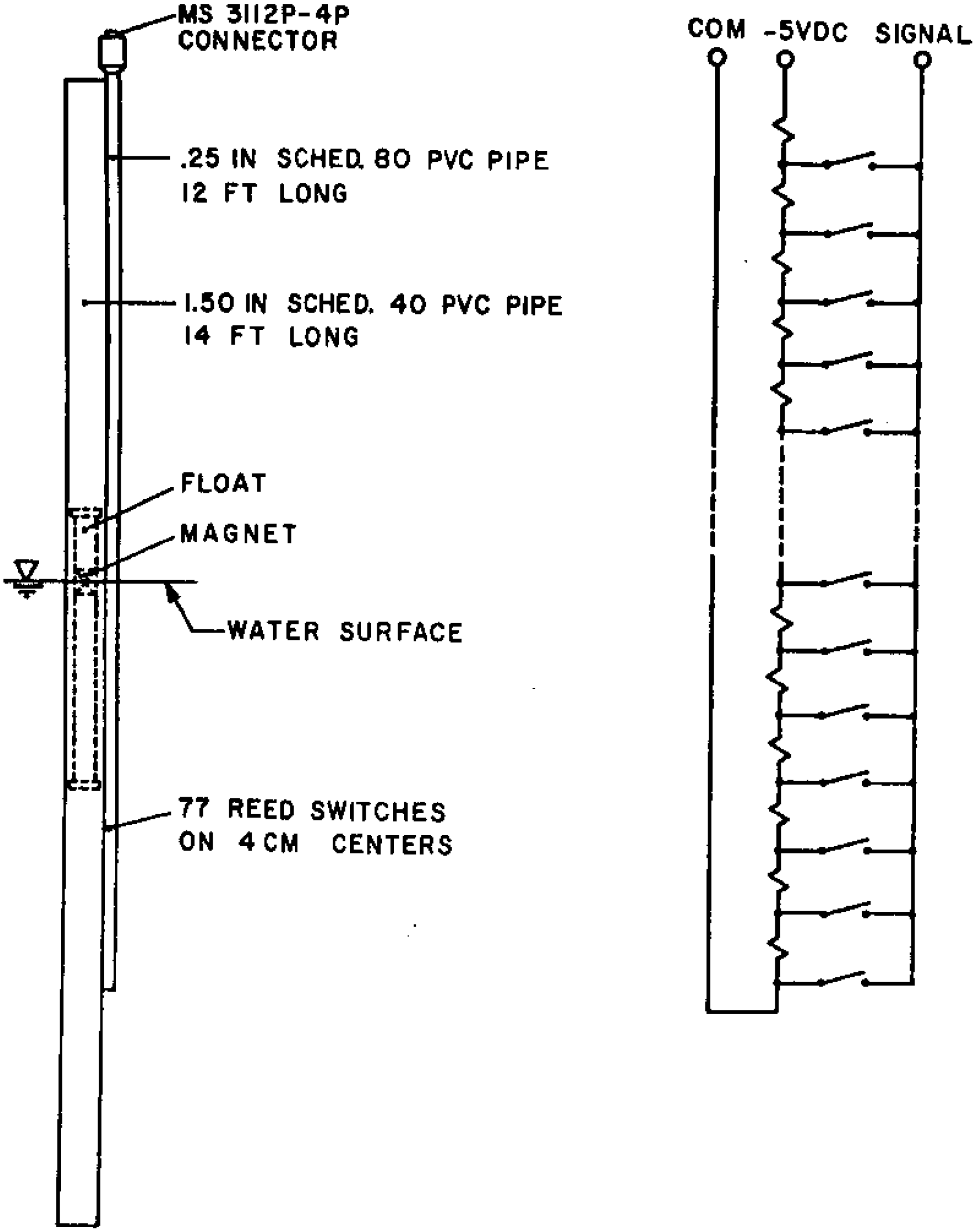


Figure 7. Level Sensing Tide Gauge assembly.

is directly proportional to the distance from the gauge up to the water surface. The output is adjusted using the "ZERO" control to relate it to the M. L. L. W. datum. In use, the pressure case is weighted and placed on the bottom below the tidal range at the point of interest.

IV. 2. 3 Data Recorders

All data was recorded on two strip chart recorders. This required data reduction by hand, which was a long and tedious procedure. The first recorder was an Esterline-Angus Recording D. C. Milliammeter, which had chart drive speeds of 3/4" per hour, 1 1/2" per hour, and up. A day's continuous data could be recorded on 3 feet of 4 1/2 inch wide chart paper. The recorder was enclosed in a hermetically sealed container which contained a desiccant. This was intended as protection from corrosive salt air.

The other recorder was a Honeywell-Brown "Electronik" servo-recorder. An electric timer-switch was installed in the recorder. This timer was "ON" for 10 seconds every 15 minutes, and caused the recorder pen to go to zero, providing timing marks on the paper chart.

The two types of tide gauges and the two recorders were fully interchangable.

IV. 3 Tidal Data Collection and Reduction

The best site to record baseline tidal data is at the entrance to the marina. This site was not used for practical reasons. No A.C. power is available at the marina entrance on a continuing basis. No funds were available to purchase the several thousand feet of cable necessary to carry power and signal to and from a sensor at the entrance to the nearest source of power. There is nowhere a point at the entrance where a level sensing tide gauge (the only kind available for most of the field work) could be installed.

A level sensing tide gauge was installed at the nearest practicable location to the entrance, the marina's Harbor Patrol Dock, 5900 feet from the entrance. This gauge supplied data which was used as baseline data. The tidal data gathered at other points in the marina is all related to the baseline data, as is data gathered later at the marina entrance. The pressure sensing tide gauge installed at the entrance supplied qualitative, but not quantitative data. Figure 1 shows the site locations used in gathering data.

The data gathering results in two synoptic tidal charts for each pair of stations, one station being always at the Harbor Patrol Dock. The readings of both gauges were referred to the mean lower low water (M. L. L. W.) datum by the following procedure. The working reference level for all data gathering was the top of the seawall, which is 12.0 feet above M. L. L. W. at the Harbor Patrol dock and 10.0 feet above M. L. L. W. everywhere else. Once a gauge is installed so as to cover the tidal range, the distance from the top of the seawall to the water surface is measured and noted at the pen position on the recording chart. This must be done quickly since the water level is generally changing in response to tidal harmonics and surges. Many of these distance readings are taken for each data station and are averaged together to yield a correction factor used to correct the gauge level to the actual water level.

Data was digitalized by hand from analog data recorded on paper charts (!). Readings were taken from both records (baseline site and interior site) at 15 minute intervals. Each reading was corrected by a factor appropriate to the individual gauge as installed. This operation was tedious and time consuming; but in the absence of funds for computer compatible magnetic tape data recorders, there were no alternatives. The digitalized data was punched onto computer cards for later computer smoothing and plotting. One run consisted of 29 hours of synoptic data for both the baseline data gauge and the other gauge at an interior point. Each run was processed by computer individually.

Because of the presence of a harmonic component with a 45 minute period in the data (to be discussed later), an iterative graphical curve smoothing routine was programmed for the computer. This routine required an extra 2 hours worth of data before and after the 25 hour tidal period of interest. The routine is described in the following. The data for every 15 minutes of the tidal period is read into a subscripted array, each subscript increment corresponds to a 15 minute time increment. A linear interpolation is performed between every other data point (i. e. data point pairs subscripted 1 and 3, 3 and 5, 5 and 7, etc.) to find the midpoints of lines drawn between these points. The midpoints fall on 15 minute time increments (subscripted 2, 4, 6, 8, etc.). These midpoints (call them points "A") are connected with a series of straight line segments. Now again interpolate to find the midpoints of the lines drawn between points "A". Label the new set of midpoints "B", and connect them with straight line segments. (These points are subscripted 3, 5, 7, etc.) Carry on in this manner for four iterations. The result is a curve faired smoothly through all the data points. It should be noted that the first and last data points of each iteration are lost at the end of that iteration. This routine is aimed only at smoothing the approximately 45 minute period component of the tide in Marina del Rey.

After smoothing, the data was plotted on the digital incremental plotter available at the main computing facility of the University of Southern California. First the digitalized raw data was plotted, then smoothed data and then the difference between the smoothed data curves. These differences were plotted for various stations against the tidal displacement relative to the mean lower low water level at the baseline site (site No. 1). This information was used to synthesize a general tidal displacement function in the marina.

IV.4 Tide Function Synthesis

Figure 8 illustrates typical data describing the relation of tidal differences between the baseline site (site 1) and the site examined, to the tide (relative to M. L. L. W.) at the baseline site. The difference in tidal levels is greater as the tide goes lower. The tidal differences plot for every site shows similar characteristics. Obviously the data is quite scattered, but it will serve to roughly approximate tidal characteristics in certain regions of the marina. The tides in regions in which there are no data gathering sites are estimated from the tides recorded at the nearest data gathering sites. The major point to be approximated is the entrance. The smoothed tide at the entrance is taken to be the same as that at site No. 1 (relative to M. L. L. W.). Examination of the plots of tidal differences shows why. All the sites except site No. 1 are in water -10 feet deep relative to the M. L. L. W. datum. If the tide height is greater than +5.0 feet above the M. L. L. W. datum (total depth 15.0 feet), there is less than a 0.2 foot difference in tide levels from site No. 1 to any other site. Since the bottom of the main channel between site No. 1 and the entrance is at -18 feet relative to M. L. L. W., the depth is always 15 feet or greater in this area. Therefore, any tidal differences in this region will be small and therefore neglected.

The tidal elevations used in simulating tidal flushing in Marina del Rey were calculated or estimated as follows:

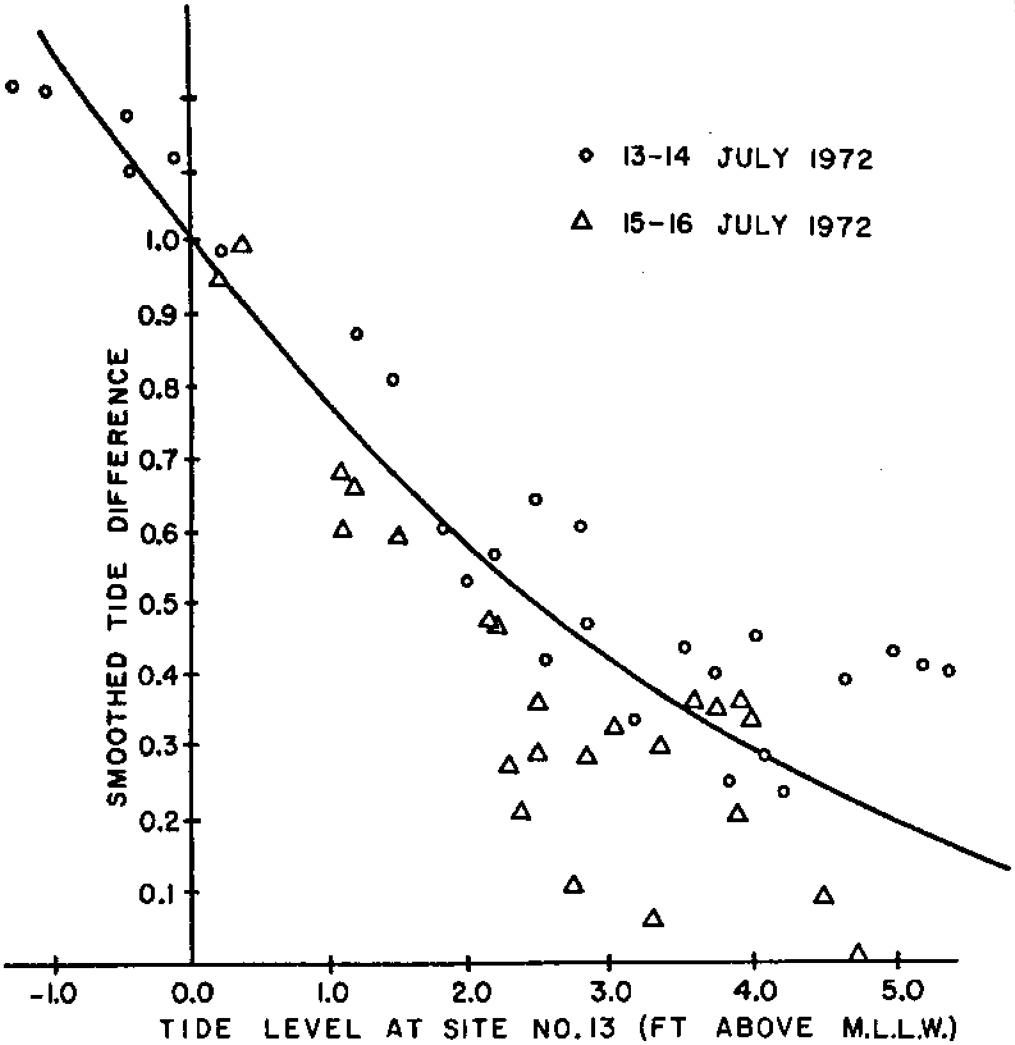


Figure 8. Smoothed tide differences between site No. 13 and site No. 1, plotted against smoothed tide at site No. 1.

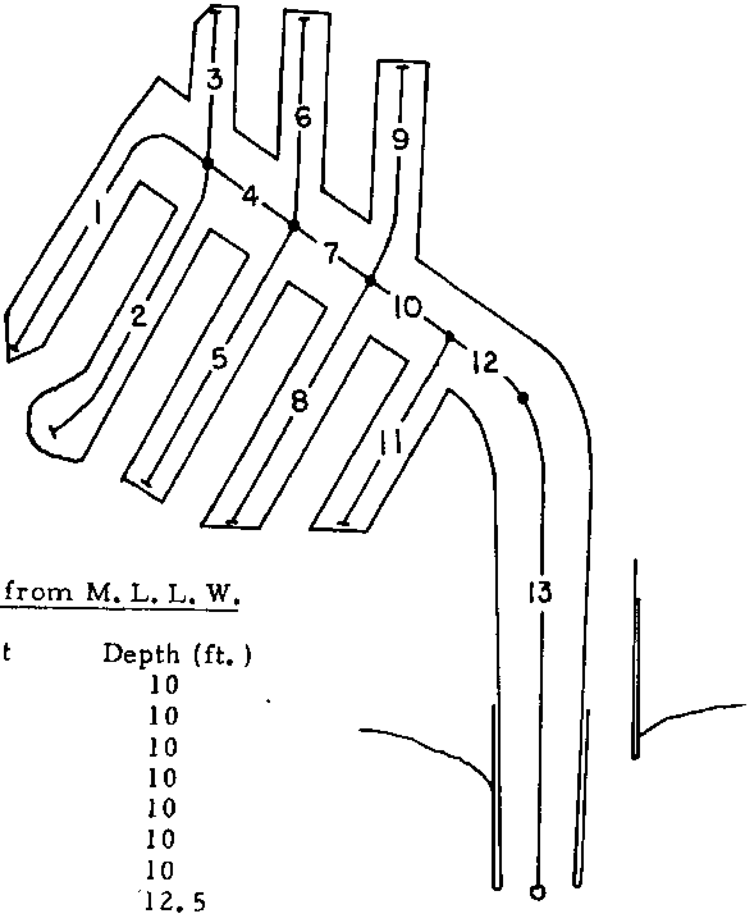
1. Specify a tide for site No. 1. This applies to segments lying between site No. 1 and the entrance. Use one of the recorded tides with the provision that the elevation at the beginning and end are at the same level (so there are no discontinuities when

the tide repeats in following cycles).

2. Using the differences at the known sites, calculate tides at these site relative to the site No. 1 tidal elevations.
3. For those segments where no tide data is available, interpolate or estimate using tidal elevations recorded in adjacent locations as a guide.

V. SIMULATION OF MARINA DEL REY

An examination of Figure 9 will show the division of Marina del Rey into obvious segments. The divisions occur at junction points between the basin and the main channel, or at points in the main channel where the bottom depth changes.



Depths from M. L. L. W.

Segment	Depth (ft.)
1	10
2	10
3	10
4	10
5	10
6	10
7	10
8	12.5
9	10
10	15
11	10
12	15
13	18

Figure 9. Marina del Rey as divided into segments.

Each segment is specified to the simulation program by its segment number, its width (assumed constant), its length, the initial number of volume elements into which it is divided, the segment numbers of the upstream connecting segments and the segment number of the downstream connecting segment. The bottom of each segment is assumed to lie on a horizontal plane.

The data requirements for the one-dimensional program have been mentioned previously, however they will be summarized here:

1. Alphameric prototype identification.
2. Number of tidal cycles to be simulated.
3. Concentrations in the ocean of parameters modeled.
4. Tidal cycles for which printed results are desired.
5. Tidal cycles for which plotted results are desired.
6. The number of hours in each tidal phase.
7. The number of water quality parameters modeled.
8. Parameter names and rate constants for first order decay (to base e).
9. Number of time steps per hour.
10. Printing control indicators
11. Listing of volume and concentrations of external flows (if any) into upstream end of each segment.
12. Specification of continuous inputs (if any), i.e. segment number, distance downstream, rate of pollutant discharge, and

concentrations.

13. Specification of a single instantaneous injection (if any).

14. Specification of continuous inputs of short duration (if any).

The remaining data cards contain tidal data which may be either theoretical or empirical data. For the present work, tidal data measured at Marina del Rey was used for the simulation. The tidal data used was organized into hourly groups. The data appears on 25 sets of 13 cards. Each card carries a depth and a width for one segment. Thirteen cards bearing depths and widths for each of

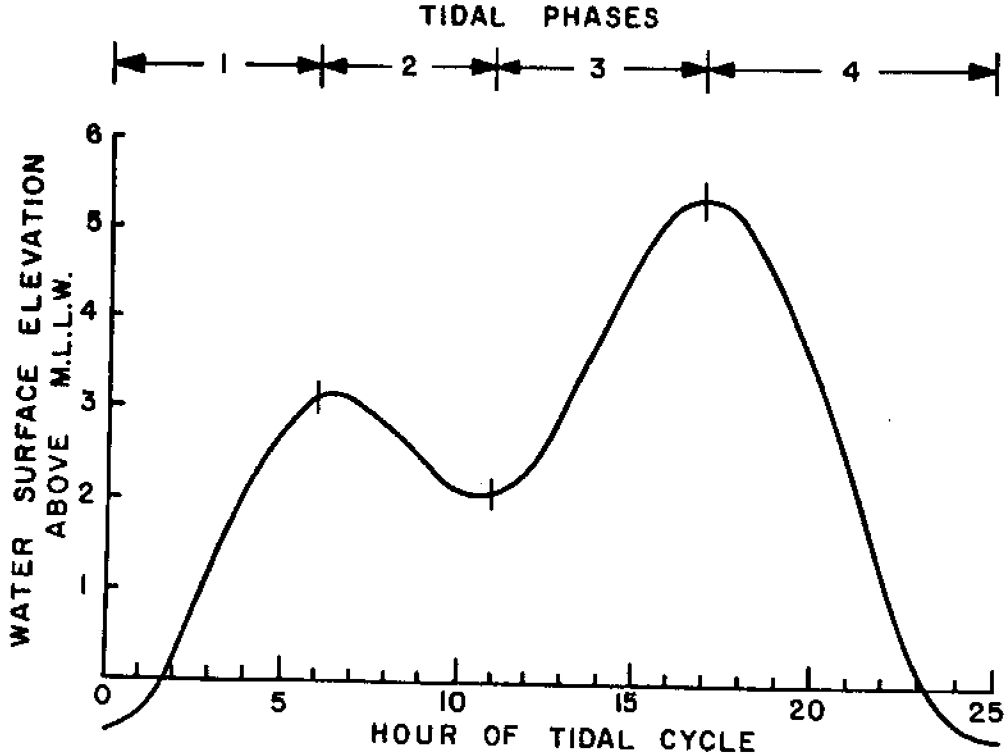


Figure 10. Recorded tide used as baseline data in simulation of Marina del Rey (recorded at site No. 1).

thirteen segments comprise one hours data. The tidal cycle is specified as lasting exactly 25 hours and repeating itself exactly each tidal day. Neither of these conditions holds in the prototype (the tidal period is approximately 24.8 hours, and the mixed tide changes diurnally with the motions of the sun and moon). The hourly data is linearly interpolated by the computer to yield data over shorter time increments.

The variables and the specific numerical values used in setting up the model of Marina del Rey are listed in the appendices.

As a consequence of the repetitive tides, it is expected that the centroid of a pollutant concentration curve will be moved to and fro in a similar repetitive action. Substantial flushing will not occur until the injected pollutant is dispersed enough to reach the entrance in significant concentrations at low tides. Then the centroid of the concentration distribution will show a net movement toward the entrance with each tidal cycle.

The model used in the present work is a "series" model. This means that in order to determine conditions during a tidal cycle N, the model must first carry out tidal cycles 1, 2, 3, and so on in series up to tidal cycle N. Time cannot be skipped in this model as it can be in the solution of a differential equation for a certain time.

The specification of the number of time steps per hour is restricted by the following criterion: the flow volume out of any segment during one time step may not exceed the water volume present in that segment at the start of that time step. Should this criterion not be met, negative water volumes are created which lead to program instability and eventual malfunction. The solution is to simply make sure that each time step is short enough to satisfy the criterion. In Marina del Rey, the short segments in the main channel are the most subject to instability. Time steps of 6 minutes (10 time steps per hour) have precluded any instability.

The dispersion coefficient calculations (discussed in Chapter 2) were made using a Manning roughness factor, n, of 0.031. This value was determined by criteria in Chow (1959).

Operational experience with the model showed that the dispersion of injected material in the marina was unrealistically slow. For this reason, the calculated dispersion coefficients were multiplied by a factor of 10 before use in the model. The resulting numerical values of the dispersion coefficient range from 44 sq. ft./sec. to 2.3 sq. ft./sec. These values seem realistic when compared to the higher values obtained in natural streams by various investigators as listed by Fischer (1958). Figure 11 shows the effect of this multiplication of the dispersion coefficient on the concentration history at a point in the landward end of basin E, following a single instantaneous injection at that point. The factor of 10 increase in the dispersion coefficient leads to an approximate factor of 2 decrease in the concentration from the upper to the lower curve over identical time periods.

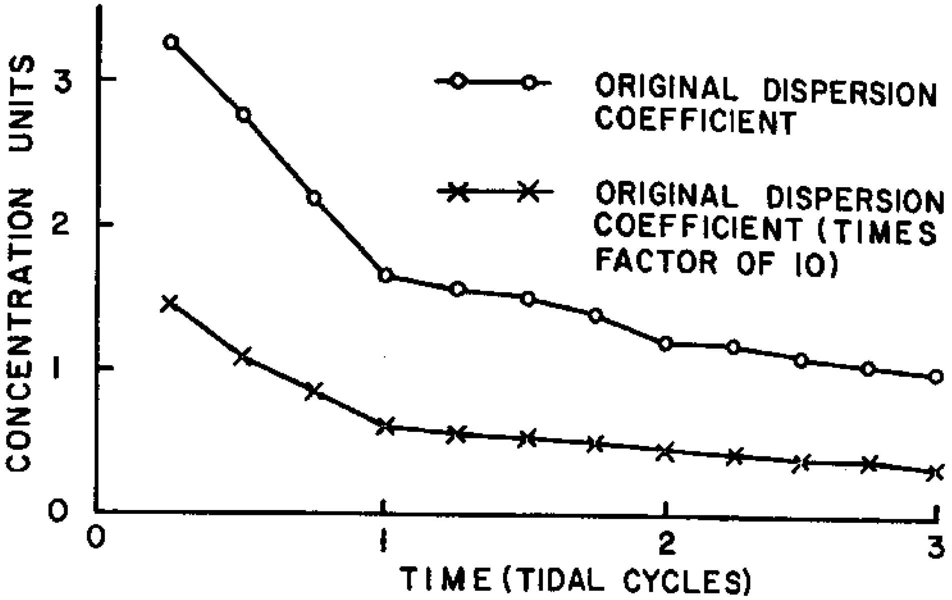


Figure 11. Comparative time history of concentrations at the landward end of basin E following a single instantaneous injection at that point. The comparison is of the effect of increasing originally derived dispersion coefficient by a factor of 10.

To investigate the flushing characteristics of Marina del Rey, a number of pollutant injections were hypothesized in separate simulations. To examine the effect of the timing of an injection relative to the tidal cycle, two cases were analyzed:

Case "A" A single instantaneous injection of 1000 cubic feet of a soluble and conservative substance during the last time step of the first hour of the first tidal cycle of the simulation. (This is at low tide.) The location is

5900 feet up the main channel from the entrance.

Case "B" Identical to case "A" except that the injection occurs in the last time step of hour 6 of the first tidal cycle (at the first high tide of the cycle).

To investigate the effects of the location of the injection upon flushing characteristics, three cases were analyzed:

Case "C" A continuous injection lasting for one tidal cycle (25 hours). The volume per hour is 8000 cubic feet of a solution containing 5000 PPM of a soluble and conservative material. The location of the injection is the landward end of basin E.

Case "D" Identical to case "C" except the location of the injection is at the landward end of basin H.

Case "E" Identical to case "C" except the location of the injection is in the main channel, 5900 feet from the marina entrance (same as cases "A" and "B").

The next chapter presents the results of these investigations.

The costs of computer runs simulating Marina del Rey vary according to the amount of processing time required, core memory allotted, and the amount of printing and plotting. For a run which simulates 7 tidal cycles, the cost ranges from $35.00 to $80.00.

VI. PRESENTATION AND DISCUSSION OF RESULTS

VI.1 Tidal Variations in Marina del Rey

The measured tidal history in Marina del Rey revealed two interesting features. The first and most striking is the presence, most of the time, of a tidal harmonic with a period of approximately 45 minutes, and an amplitude ranging, at a single site, from a few inches up to one foot. A gauge placed at the entrance detected no apparent harmonic component with this period, although it was strongly present at site No. 1, 5900 feet from the entrance. Although this harmonic component was not anticipated initially, a short, first order analysis indicates the harmonic period should be expected from the

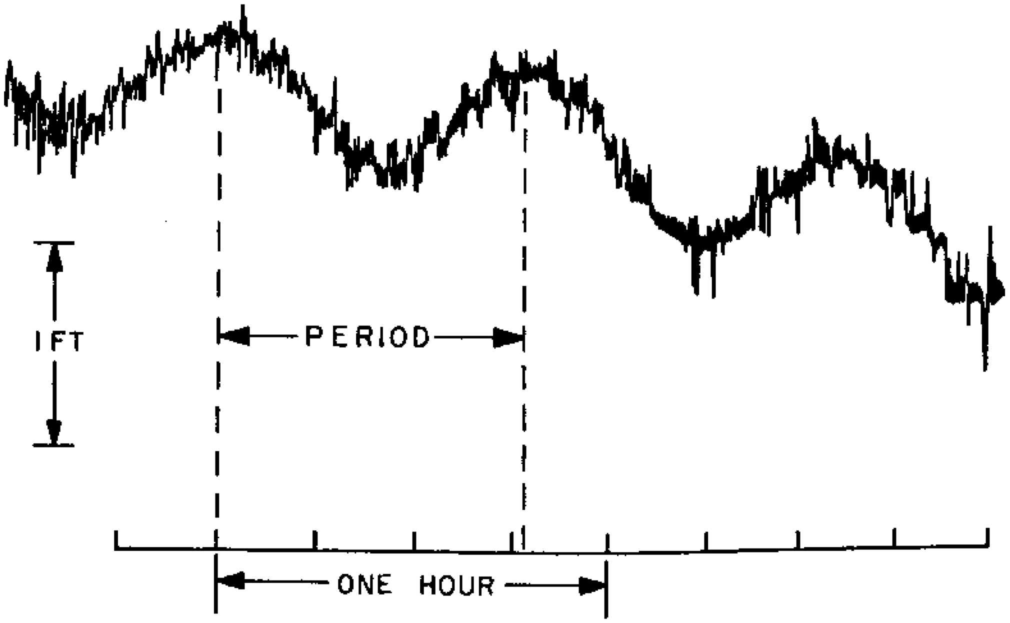


Figure 12. Typical tidal data as recorded at site No. 1, showing harmonic component.

geometry of the marina.

Consider a rectangular harbor 12,000 feet long (corresponding to the main channel and basin E of Marina del Rey). The characteristic length $\underline{a}$ is taken as 12,000 feet. The wavelength of a water wave in shallow water is:

$$L = C * T = \sqrt{gh} * T,$$

where g is the acceleration of gravity, h is the water depth and T is the wave period. Assume a water depth of 13 feet which is close to that at most points in the marina. The measured period of the tidal harmonic is approximately 45 minutes (it ranges from 40 to 50 minutes). Then the wavelength of the harmonic component is approximately given as:

$$L = \sqrt{32.2 * 13} * 2700 \text{ (ft/sec. sec)}$$
$$= 55,200 \text{ (feet)}.$$

The wave number ($k = 2\pi/L$) times the characteristic length is:

$$ka = \frac{2\pi}{L} * a = \frac{(2\pi)\,(12,000 \text{ ft.})}{55,200 \text{ ft.}} = 1.36.$$

This is very close to the $\underline{ka}$ value for the first mode of oscillation of a long rectangular harbor as predicted by J. J. Lee (1969). The period of the first mode of oscillation in Marina del Rey may then be logically expected to fall in the 40-50 minute range. The mode of oscillation at this 45 minute period is a pumping mode, causing the water surface to move upward and downward with fairly uniform amplitude everywhere within Marina del Rey except the entrance region.

The effect of the harmonic component is to supply additional energy for turbulent mixing to the marina. Mathematically, the influence of the harmonic would be felt mostly in the dispersion coefficient. The increase in accuracy which could be obtained by following these short period tidal oscillations were felt not to be worth the necessary additional programming complexity. Their effect may be included by increasing the dispersion coefficient by some small multiple. Therefore, the raw tidal data was smoothed as described in Chapter IV.

Examination of either raw or smoothed tidal data showed another feature of the tides in Marina del Rey. There are generally pronounced tidal elevation differences between tides at site No. 1 and tides recorded synoptically at interior points of the marina. These differences occur constantly and they are the greatest at low tide. The lower the tide, the greater the differences are. Figure 13 shows synoptic smoothed tidal curves as recorded in Marina del Rey. For the case illustrated, the elevation difference at low tide is almost 1 1/2 feet, however, at high tide the difference is reduced to about 0.2 feet.

It is difficult to draw firm correlations because of the diurnal tidal variations and equipment limitations which allowed examination of only two sites at a time. However, a possible explanation may be made. At low tide, the ratio of tidal rise to water depth is much greater than that at high tide, thus, the non-linear tidal response of the marina is more significant at low tide than at high tide. This non-linear effect may have a varying degree of influence at the interior points of the marina, and thus contribute to the observed differences in tidal elevation at low tide. The effect of these tidal elevation differences is to reduce the tidal flushing. This is because segment volume changes caused by the tides are reduced.

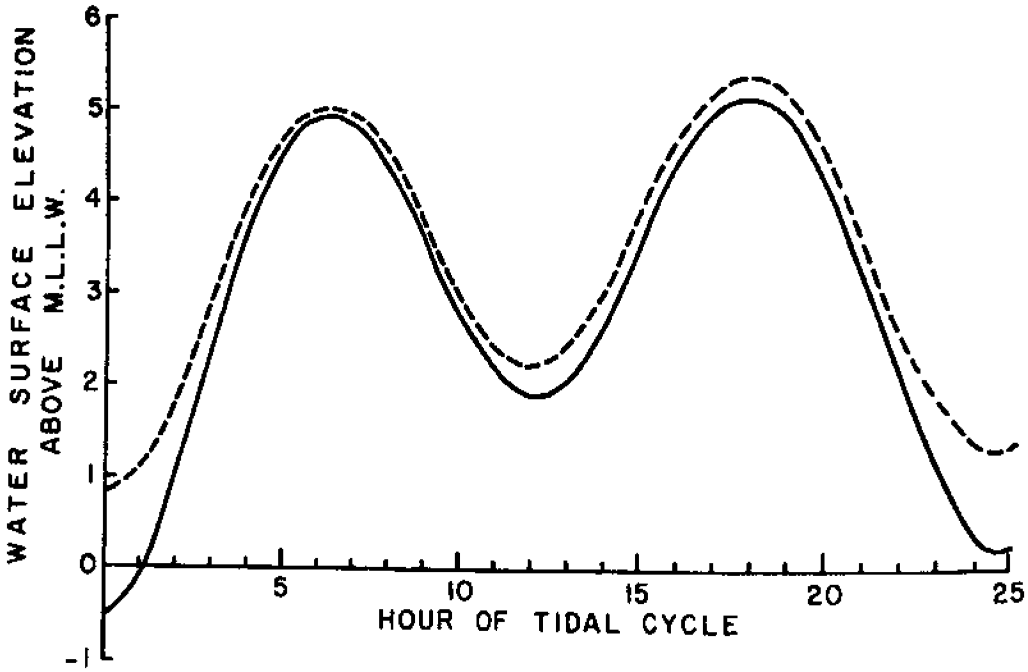


Figure 13. Typical synoptic tidal data. —— for site No. 1, 5900 feet from the entrance. - - - for site No. 4, 10,500 feet from the entrance.

VI. 2 Computer Modeling Results

The most interesting characteristic of the marina to be revealed by the computer model is its striking sensitivity to variations in the location and timing of pollutant injections. At the present time, the best use of the model is in making such comparisons of flushing characteristics as they vary in space and time in a particular estuary. This is because no dye studies have yet been conducted in the prototype to determine the efficacy of the model in predicting absolutely the amount of flushing action. The results presented below are from comparative studies.

The first comparison is between cases "A" and "B" (presented in Chapter V.), identical injections made at the same point in the main channel, but at different times in the tidal cycle. For the case "A", injection takes place instantaneously during the first low tide of the first tidal cycle of the simulation. After 7 tidal days, 25.9 percent of the material injected has been flushed out to sea. The case "B" injection takes place instantaneously during the first high tide of the first tidal cycle. After 7 tidal days, 57.9 percent of the material injected has been flushed out to sea. A small (6 hour) difference in the time of injection gives rise to a major difference in the percentage of material flushed out of the marina.

To demonstrate the behavior of the model in a qualitative way, the concentration distributions for the various cases were plotted by a digital incremental plotter. Figures 14 and 15 illustrate concentration distribution curves for case "A" for tidal cycles 1 and 2 following an instantaneous injection in the first hour of the first tidal cycle. The distance axis runs from zero at the entrance, up the main channel to the landward end of basin E (12,650 feet from the entrance).

It should be emphasized that Figure 14 and the following graphs show concentrations in the main channel and basin E only. Concentrations present in the adjoining basins are not represented, and discontinuities may be produced in the main channel concentration curves when such adjoining concentrations suddenly enter the main channel.

In Figure 14, the point of injection, 5900 feet from the entrance, is denoted by the arrow. At the end of the first flood phase (5 hours after injection), the centroid of the cloud of injected material has moved upstream approximately 1900 feet, and is spread over a 1500 foot length of the channel. The cloud moves downstream approximately 700 feet during the 5 hour ebb of the second phase. The cloud disperses only slightly. After the 6 hour flood of the third phase, a significant amount of material appears to have pushed into the adjoining basins, thus not appearing in the concentration curve. This is deduced because of the greatly decreased area under the concentration curve. Strong dispersive action is in evidence during the long 8 hour ebb tide of the fourth phase. Significant concentrations are now present over a 4000 foot length of the main channel. The increase in the area under the phase 4 curve over that of the phase 3 curve indicates that some of the dissolved material has returned to the main channel after being forced into the adjoining basins during phase 3. At the end of the fourth phase (24 hours after injection), the maximum concentration is only half that at the end of the first phase. Since no significant concentrations have yet reached the entrance, only traces of the injected material have been flushed out to sea.

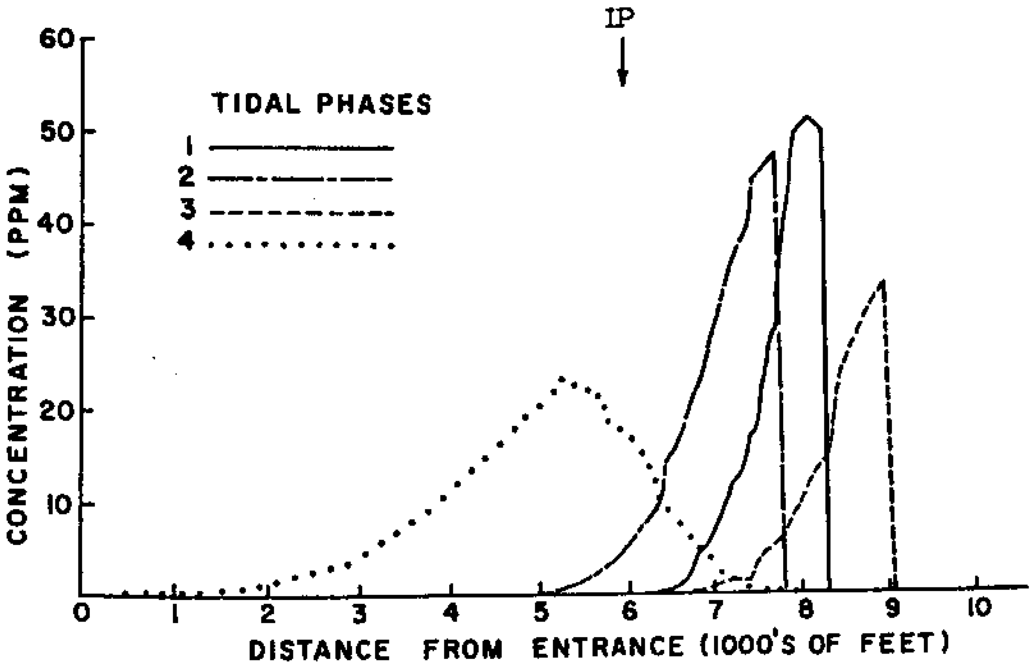


Figure 14. Case "A" concentration distributions in main channel and basin E during first tidal cycle. IP denotes point of injection.

Figure 15 illustrates concentration distribution curves during the second tidal day following the injection of case "A". The general behavior is the same as that of the first day. The maximum concentration during the second tidal day is only one third that during the first tidal day. The maxima do not decrease as rapidly from one phase to the next because the pollutant cloud has spread out and thus reduced concentration gradients. Significant flushing has not yet occurred; only 0.29 percent of the injected material has been flushed out to sea.

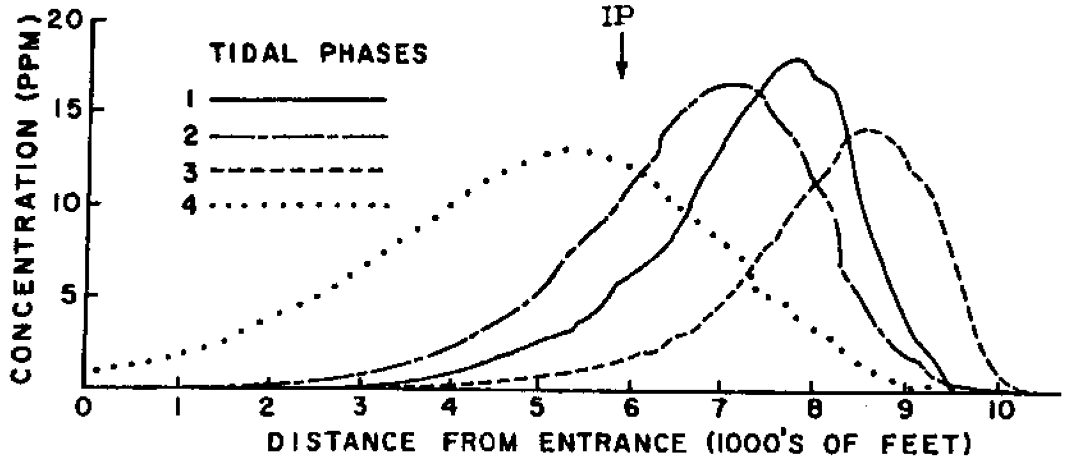


Figure 15. Concentration curves during second tidal cycle following injection of case "A". Note different vertical scale from that of Figure 14.

Figure 16 illustrates the concentration curves during the seventh tidal day following the case "A" injection. The dye cloud is well dispersed. The maximum concentration is 14 percent of what it was during the first tidal cycle. Significant flushing is occurring. After 7 tidal days, 25.9 percent of the injected material has been flushed out to sea. The remaining material is distributed over most of the main channel and basin areas.

Figures 17 and 18 illustrate the behavior of the pollutant cloud resulting from the injection of case "B". The injection occurs during the last time step of the phase 1 flood tide, thus the direction of initial movement of the pollutant cloud will be toward the entrance in response to the ebbing tide. It is expected that this will allow a greater amount of flushing than occurred in case "A".

The concentration distribution curves for the first tidal day are shown in Figure 17. The phase 1 curve shows the concentration distribution of the pollutant cloud before it has had a chance to disperse. The cloud has moved only a few feet upstream from the point of injection. The distribution curve is a sharp spike, with maximum value 343 PPM. After the 5 hour ebb of the second phase, the pollutant cloud has moved approximately 1100 feet toward the entrance, and its maximum concentration has been drastically reduced to 59 PPM by dispersive spreading. The 6 hour flood of the third phase moves the pollutant cloud back up the main channel,

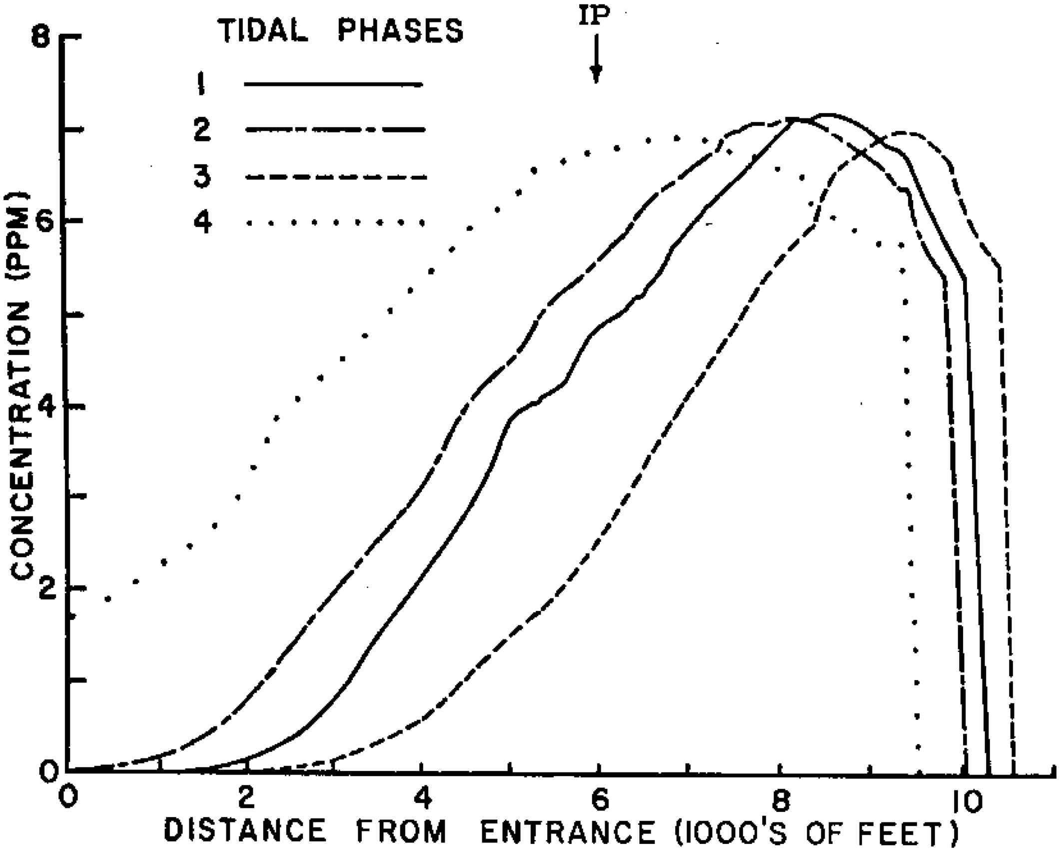


Figure 16. Concentration curves during the seventh tidal cycle following the injection of case "A". Note greatly increased vertical scale compared to Figure 15. The sharp concentration dropoffs on the right are due to finite difference character of the model and to limited dispersive action in basin E.

along which it extends approximately 2000 feet. After the 8 hour ebb of the fourth phase, the pollutant cloud is moved toward the entrance, and is spread along 4000 feet of the channel, and its

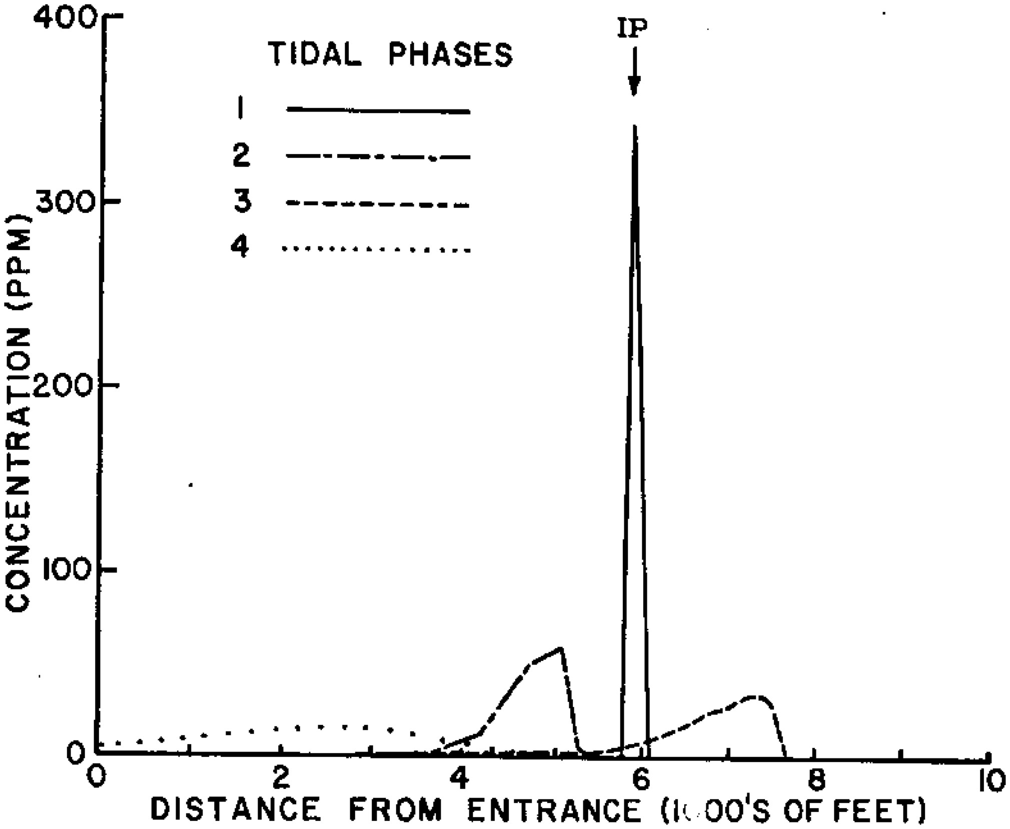


Figure 17. Case "B" concentration distributions in main channel and basin E during first tidal cycle. IP denotes point of injection.

maximum concentration is only 15.6 PPM. At the end of the first tidal day, 7.8 percent of the injected material has been flushed out of the marina; a significantly larger percentage than that of case "A" discussed previously.

Figure 18 illustrates concentration curves for each phase of the second tidal day. Here, the pollutant cloud, now fairly well spread out, moves up and down the main channel in response to the flood and

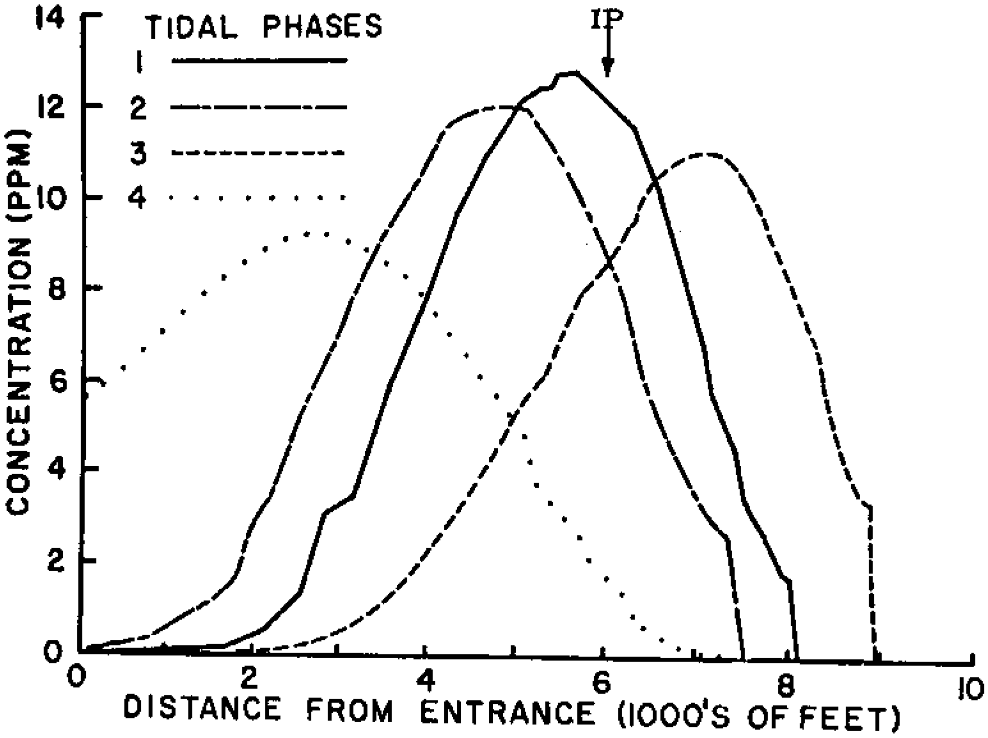


Figure 18. Concentration curves during second tidal cycle following injection of case "B". Note different vertical scale from that of Figure 18.

ebb of the tide. The maximum concentration at the end of the fourth phase is 9.1 PPM. At this time, 23.4 percent of the injected material has been flushed out. After 7 tidal days, 57.9 percent of the material injected has been flushed out of the marina.

Cases "C", "D", and "E" were intended to compare the flushing of continuous injections of one day's duration (simulating one day's storm drainage to the marina) made at different points. The injections are identical in all respects save one, their locations in the marina. The injections are continuous through the first tidal cycle.

In case "C", where injection takes place at the landward end of basin E (perhaps the quietest point in the marina), only 0.05 percent of the material injected has been flushed out to sea after 7 tidal days. In this case, the injected material slowly spread out through the marina, but did not reach the entrance in concentrations sufficient to allow significant flushing.

The injection of case "D" takes place at the landward end of basin H (much closer to the marina entrance). In this case, 0.38 percent of the injected material was flushed out after 7 days. After 14 days, 5.4 percent of the injected material was flushed out to sea. So there is more flushing activity in basin H than in basin E, however it is still very little.

The injection of case "E" takes place in the main channel, 5900 feet from the marina entrance. This is the same location as the injections of cases "A" and "B". After 7 days, 43.6 percent of the injected material has been flushed out to sea. Obviously there is a great deal more flushing capability in the main channel than there is in the basins.

Figures 19, 20, and 21 illustrate the response of the marina to case "C": a continuous injection of a pollutant lasting for one tidal day. This injection occurs at the landward end of basin E, 12,650 feet from the entrance. The extent of basin E on the horizontal axis is shown in the figures.

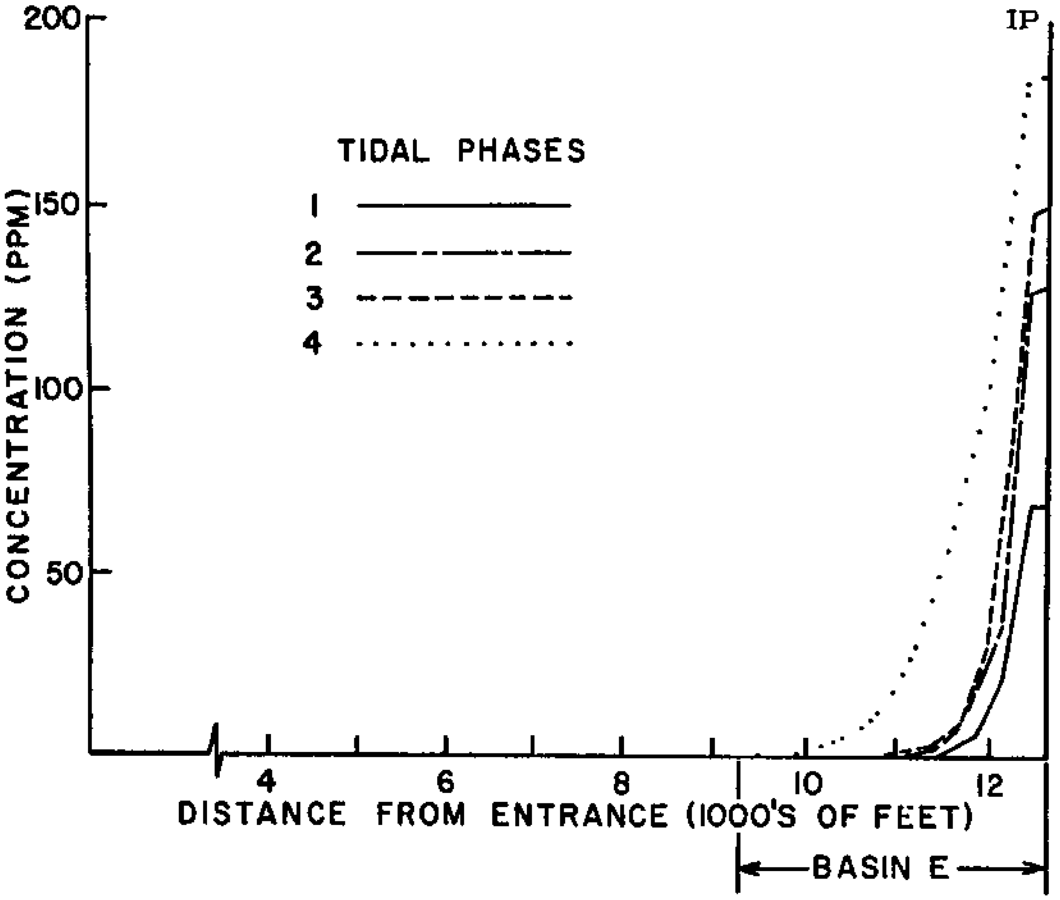


Figure 19. Case "C" concentration distributions in main channel and basin E during first tidal cycle. IP denotes the point of injection.

Figure 19 shows concentration distributions during the first tidal day (while the injection is occurring). The area under the concentration distribution curve increases during each phase. Any horizontal movement of the pollutant cloud is due mainly to the continuing injection. The presence of the solid boundaries of the sides and the end of the channel severely restricts fluid velocities and thus shear velocities, and hence convection and dispersion. The maximum concentration during this tidal day is 183 PPM.

Figure 20 shows the concentration distributions at the end of each phase of the second tidal day. The pollutant injection has ceased, and the concentration distributions are affected only by the flushing action of the marina. The limited flushing in the landward portion of basin E is illustrated by the close proximity of the concentration distribution curves of the first three phases. The fourth phase is quite long (8 hours) and so its distribution curve shows that the pollutant cloud has spread out somewhat. The maximum concentration is 104 PPM.

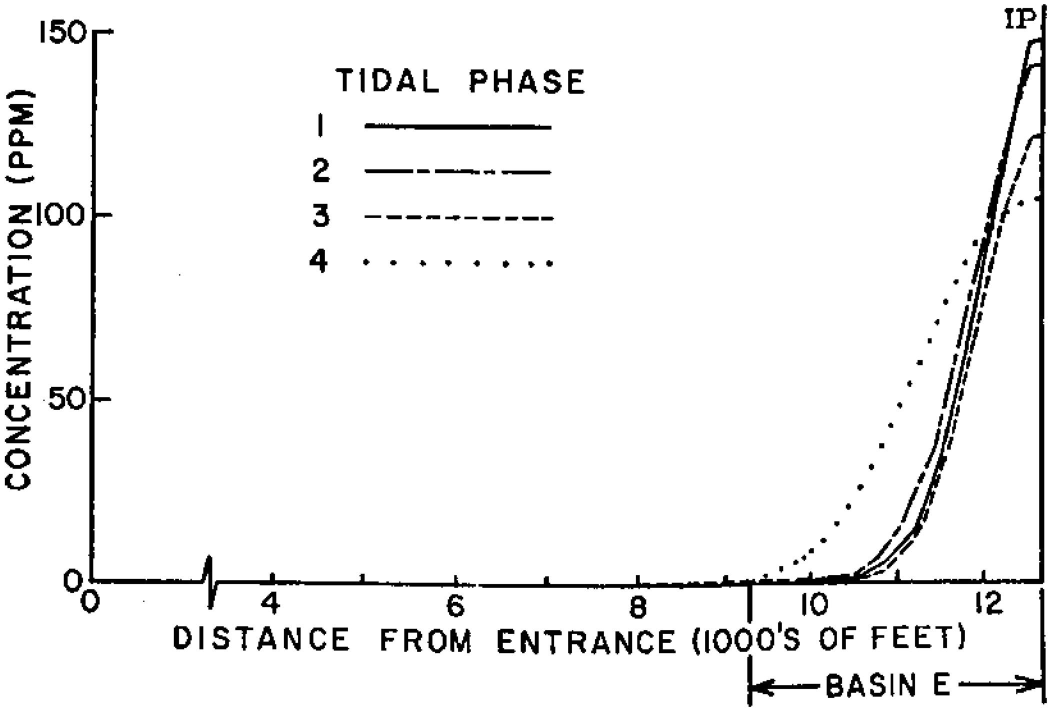


Figure 20. Concentration curves during second tidal cycle following injection of case "C".

Figure 21 shows the concentration distributions on the seventh tidal day following the injection. The pollutant cloud has dispersed downstream somewhat. There is still not much movement of the cloud from phase to phase. The maximum concentration during this tidal day is 56.9 PPM. No real flushing of material out of the marina has occurred as yet.

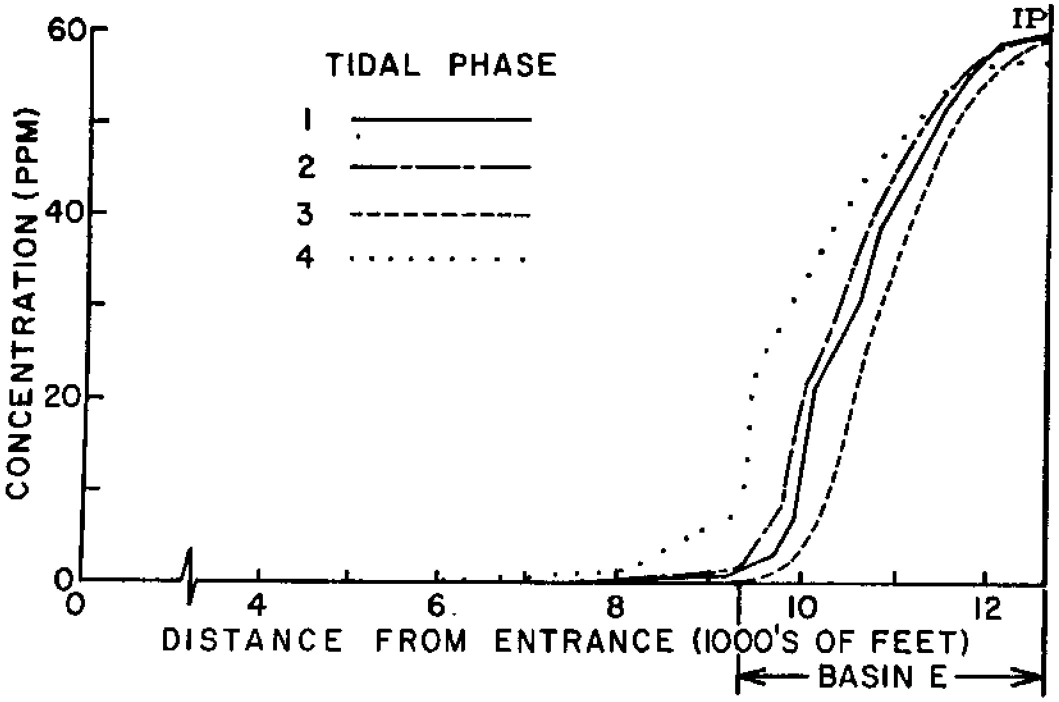


Figure 21. Concentration curves during seventh tidal cycle following injection of case "C". Note different vertical scale from that of Figures 19 and 20.

Table 1 on the following page summarizes the results for the various cases just discussed. The instantaneous injections of cases "A" and "B" demonstrated that the timing of pollutant discharges

TEST CASE NO.	TYPE	LOCATION	DISTANCE FROM ENTRANCE (FT)	AMOUNT	CONC. (PPM)	TIDAL CYCLE	HOUR	PERCENTAGE OF INJECTED MATERIAL FLUSHED OUT AFTER ___ DAYS				
								1	2	3	7	14
"A"	SINGLE INSTANTANEOUS	MAIN CHANNEL	5,900	1000 CUFT	PURE (10^6)	1	1	.06	2.16	6.49	25.98	—
"B"	SINGLE INSTANTANEOUS	MAIN CHANNEL	5,900	1000 CUFT	PURE (10^6)	1	6	7.85	23.36	34.78	57.93	—
"C"	CONTINUOUS, 1 DAY	BASIN E	12,630	8000 CUFT/HR	5000	1	CONT. 25 HRS	.005	.009	.014	.047	—
"D"	CONTINUOUS, 1 DAY	BASIN H	9,690	8000 CUFT/HR	5000	1	CONT. 25 HRS	.004	.008	.012	.38	5.38
"E"	CONTINUOUS, 1 DAY	MAIN CHANNEL	5,900	8000 CUFT/HR	5000	1	CONT. 25 HRS	3.92	13.57	21.96	43.62	—
"F"	SINGLE INSTANTANEOUS	MAIN CHANNEL	7,850	1000 CUFT	PURE (10^4)	1	6	.06	2.22	6.92	27.22	—

TABLE 1. Summary of test cases used in simulation of Marina del Rey.

relative to the tidal phase may greatly influence the amount of flushing activity available. The continuous discharges of cases "C", "D", and "E" have shown that the amount of flushing activity decreases with distance from the entrance of the marina.

VII. CONCLUSIONS

The following major conclusions can be drawn from this study:

1. The computer simulation model used for this study appears to work quite well as a comparative tool. Thus, the model can be used to compare the flushing characteristics of different injection time with relation to tidal phase for pollutants injected at the same point. The model can also be used for comparing the flushing characteristics of pollutants injected at different locations within the marina, thereby allowing the harbor designer to choose the best location for storm drainage outlet.

2. Flushing in Marina del Rey has been found to be very strongly influenced by the location of pollutant injection (such as the location of storm drainage outlet) regardless of the type of injection. It appears necessary to avoid placing pollutant injection points at constricted ends of the marina. The solid boundaries at such locations severely restrict convective and dispersive transport of pollutants. In other words, because of very limited flushing for pollutants injected at these locations a build up of pollutants to undesirable level could occur at such locations if the injections have a long duration. The model results indicate that the two locations where storm drain now discharging into the landward ends of Basin E and Basin F of Marina del Rey are among the poorest locations as far as

the capability for flushing is concerned.

3. Flushing may be markedly increased by moving pollutants injection points downstream (closer to the entrance). This is because in ebb tide phase the pollutant mass will be convected toward the entrance which after several phases of flushing action the injected mass will be flushed out of the marina.

4. Marina del Rey lacks continuous external inflows at its landward extremities to add the flushing. If sufficient discharge momentum from such external inflow exist the flushing may be significantly increased and not be so dependent on the location and time of pollutant injections.

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APPENDIX 1.

DERIVATION OF DIMENSIONLESS MASS TRANSFER COEFFICIENT

Consider volume elements N and N+1, and the dispersive mass transfer between them. Initially, concentrations are: C_1 (N) and C_1(N+1), and $C_1(N) < C_1(N+1)$. At the end of a time step, suppose we have two new concentrations: C_2(N) and C_2(N+1). Suppose an amount of material M was moved between these two elements by dispersion. The concentration changes would be as follows:

$$C_2(N) = C_1(N) + \frac{M}{V\ (N)} \qquad C_2(N+1) = C_1(N+1) - \frac{M}{V(N+1)}$$

The amount of material moved is the product of the mass transfer rate and the time increment over which it occurs, $M = M * \Delta t$. Diffusion theory tells us that the rate of mass transfer is the product of the diffusion coefficient, the cross-sectional area of the flow, and the concentration gradient. Between two volume elements whose centers are Δx apart, the concentration gradient is approximated by

$$\frac{C_1\ (N+1)\ -\ C_1\ (N)}{\Delta x},$$

and we have:

$$\dot{M} = E_L * A * \frac{C_1\ (N+1)\ -\ C_1 (N)}{\Delta x}$$

The amount of material transferred during a time step is

$$M = \frac{E_L * \Delta t * A}{\Delta x} (C_1(N+1) - C_1(N)) \qquad (1)$$

The change in concentration is found by dividing both sides of (1) by the volume of the element being considered:

$$C(N) = \frac{M}{V(N)} = \frac{E_L * \Delta t * A}{\Delta x * V(N)} (C_1(N+1) - C_1(N)). \qquad (2)$$

The dimensionless mass transfer coefficient for the N^{th} element is contained in the above expression. It is

$$EF(N) = \frac{E_L * \Delta t * A}{\Delta x * V(N)}.$$

In practice, this coefficient is computed for each element boundary for each time step. Then the dispersive mass transfer is computed using both the upstream and downstream values of EF.

APPENDIX 2.

List of Fortran Symbols

The following is a list of Fortran symbols that are not defined by comment cards in the program.

CHECK	Variable which stores summation of pollutant material remaining in marina.
CNODE	Array containing average concentration of all flows into nodes at the upstream end of segments.
CO	Array containing average concentration of elements in outflow from landward end of a segment.
CONC	One-dimensional array which stores concentrations to be plotted as ordinates.
CONPLT	Temporary storage for concentrations to be plotted.
CP	Temporary storage array for concentrations during dispersive step (subroutine DIFUSE).
CPASS	Array containing concentrations in flow between last one-dimensional segment and the open sea.
DES	One-dimensional array for temporary storage of 'PARAM', alphameric description of parameter.
DECAY	Array containing concentration decay factors for each parameter, equivalent to first order decay coefficient k in the quation $C = C_o e^{-kt}$, where t is in days.
DIEOFF	Rate of concentration decay of a parameter during pne time step.
DIFHI	Highest value of dimensionless mass transfer coefficient computed in one segment during one time step.

DIFLO	Lowest value of dimensionless mass transfer coefficient computed in one segment during one time step.
EF	Array containing values of dimensionless mass transfer coefficient for each element in a segment.
ENTDIS	One-dimensional array which stores distances to be plotted as abscissas.
FARPLT	Temporary storage array for distances from marina entrance (used for plotting concentration distributions).
FIRST	Logical variable indicating whether first section of subroutine RIVER is to be skipped. The first section is skipped during all except the first call to RIVER.
IDUM	Dummy time step index.
IPLOT	Array containing tidal cycle numbers for which concentration distribution plots are to be generated.
IPRINT	Array containing tidal cycle numbers for which concentration information is to be printed out.
IPTST	Array containing number of points to be plotted for each tidal phase of a plot frame.
IR	Number of hours in tidal phase being run, equivalent to a single value of ITREP.
IRNIT	IR * NIT
ITREP	Array containing the number of hours in each of the four tidal phases.
IFLOW	Indicator of the state of the tide.
IT	Time step index
ITM1	IT - 1
MINPUT	Segment number into which there is a continuous pollutant discharge.

MMAX1	The number of one-dimensional segments.
MMAXP1	MMAX1 + 1
MNEXT	Temporary storage of the number of the next main channel to be printed out in output.
MPLT	Array containing sequence of segments within which concentration distributions are to be plotted.
NCYCLE	Total number of tidal cycles to be run.
NEL	Dummy variable equated to values of NMAX in subroutine RIVER.
NIT	Number of time steps per hour.
NITM1	NIT - 1
NMAX	Array containing the number of elements in each segment.
NM	Temporary storage for single values of NMAX.
NPASS1 NPASS2	Printing control numbers. Zero value causes printout.
NQ	Index of pollutant or pollution parameter.
NQM	Number of pollutants or parameters. Dimensions allow maximum of three.
NSTEPS	Number of time steps in one tidal cycle
NT	Temporary storage of number of elements in segment.
PERCNT	Percentage of injected material (NQ = 1) flushed out.
PLOTIT	Logical variable indicating whether plot is desired.
PRT	Logical variable indicating whether printout is desired.
QI	Volume of flow through seaward end of a segment during one time step.

QO	Volume of flow through landward end of a segment during one time step.
STORE	Logical variable in main program indicating whether or not plot data is to be stored.
SUMQ	Total volume of flow out of entrance during one ebb tide.
SUMQC	Total amount of pollutant carried out through entrance during one ebb tide.
SUMSEG	Summation of lengths of segments used in plot routine.
TOTSLG	Total amount of pollutant injected.
TR	Array containing distances travelled by the midpoint of an element during one time step.
TRANS	Mass exchange between fluid elements during one time step. Computed by subroutine DIFUSE for each element boundary.
V	Volume of fluid elements
VEL	Average longitudinal flow velocity along a segment.
VOL	Initial segment volume, computed in first section of subroutine RIVER.
X	Distance in longitudinal direction.
XE	Length of an element
XL	Length of a segment
XPLOT	Distance coordinate of fluid element from upstream end of its segment.
YMOST	Maximum concentration (ordinate) of a given plot.
YSCALE	Vertical scale for plot

A number of library subprograms are used to instruct the University Computing Co., Inc. digital incremental plotter at USC's computing facility. The names of these are listed below for clarity:

PINIT	Writes user identifier on plot.
CHAR	Writes alphameric character strings.
NUMPLT	Writes numeric characters.
AXIS	Draws, annotates and labels axes.
PLTLN	Plots straight lines between two specified points.
SCALF	Sets scale factors.
VECTOR	Plots series of points contained in two one-dimensional arrays, linking with straight line segments.
RESET	Resets offsets and scale factors to zero.
ENPLT	Ends plot.

APPENDIX 3.

LISTING OF FORTRAN PROGRAM AND TYPICAL OUTPUT

```
C-----------------------------------------------------------------------------
C
C      NUMERICAL STUDY OF POLLUTANT TRANSPORT PROCESSES IN ESTUARIES WHICH
C      MAY BE APPROXIMATED BY A ONE-DIMENSIONAL GEOMETRY.
C
C-----------------------------------------------------------------------------
C      MANAGEMENT PROGRAM
C
C        THIS PROGRAM IS ADAPTED FROM THAT OF H. FISCHER (MARCH,1970)
C        HIS RIVQUAL SUBROUTINE IS COUPLED DIRECTLY TO THE  OCEAN
C        THE NECESSARY ASSUMPTION IS THAT THE CONCENTRATIONS OF PARAMETERS
C        IN THE OCEAN REMAIN CONSTANT
C
C      REQUIRED INPUT INFORMATION IS GIVEN BELOW.....
C
C      --MAIN PROGRAM--
C
C      CARD    VARIABLE    UNITS     FORMAT     --------DEFINITION--------
C
C        1      IDFLOW       -        20A4      ALPHAMERIC SITE IDENTIFICATION
C        2      NCYCLE       -         I3       NUMBER OF TIDAL CYCLES TO BE RUN
C              CGIVEN(NQM)  LB/CUFT   4F10.0    CONC. IN THE OCEAN (CONSTANT)
C        3     IPRINT        -        20I4      CYCLES TO PRINT RESULTS
C        4     IPLOT         -        20I4      CYCLES TO PLOT RESULTS
C        5     ITREP(4)     HRS        4I5      HOURS IN EACH TIDAL PHASE
C        6     NQM           -         I3       NUMBER OF QUALITY PARAMETERS
C        7     PARAM(4)      -     4(A10.F5.0)      PARAMETER NAME
C              DECAY(4)    (1/DAYS)             DECAY FACTOR TO BASE E
C
C      --SUBROUTINE RIVER--
C
C      CARD    VARIABLE    UNITS     FORMAT       --------DEFINITION--------
C
C        8     NIT           -          I5        NO. OF TIME STEPS/HOUR
C              NPASS1        -          I2        PRINTING CONTROL
C              NPASS2        -          I2        PRINTING CONTROL
C
C        9     QMEAS(M)  CU.FT/       10F8.0      EXTERNAL FLOW INTO UPSTREAM
C       10     QMEAS(M)    TIME STEP  10F8.0      END  OF SEGMENT M.
C
C       11     CMEAS(M,NQ)    PPM     10F8.0      CONC. OF EXTERNAL FLOW
C       12     CMEAS(M)               10F8.0      (SEPARATE SET FOR EACH NQ)
C
C       13     MINPUT(M)       -        I5        CONTINUOUS DISCHARGE INFO
C              XADD(I)        FT.     F10.0       DISTANCE DOWNSTREAM
C              ADD(I)   CU.FT./IT STEP F10.0      VOLUME OF DISCHARGE
C              CADD(I,NQ)    PPM      3F10.0      CONCENTRATIONS, PPM
C      ( THERE MAY BE UP TO 5 POINTS OF CONTINUOUS DISCHARGE)
C
C       18     NCSLUG          -        I5        CYCLE OF SLUG INJECTION
C              IHRSLG          -        I5        HOUR OF INJECTION
C              MSLUG           -        I5      SEGMENT WHERE SLUG IS INJECTED
C              XSLUG          FT.     F10.0     LOCATION IN THAT SEGMENT
C              NQSLUG          -        I3      INDICATOR OF THE PARAMETER INJECTED
C              VSLUG        CU.FT.    F15.5     VOLUME OF SOLUTION INJECTED
C              CONSLG         PPM     F15.5     CONCENTRATION IN PPM
C
C       19     INFO FOR SHORT CONTINUOUS INPUTS, 3 CARDS.   EACH CARD IS BLANK.
C              OR CONTAINS FOLLOWING INFO...........
C              JSTART(I)       -        I5        STARTING CYCLE NUMBER
C              JEND(I)         -        I5        ENDING CYCLE NUMBER
C              JM(I)           -        I5        SEGMENT NUMBER
C              XINT(I)        FT.      F10.0      DISTANCE DOWNSTREAM
C              JNQ(I)          -        I3        SOLUTION INDEX, NQ
C              VINT(I)     CU.FT./IT STEP F10.0 VOLUME OF  DISCHARGE PER TIME STEP
C
C     - - -CARDS DESCRIBING ONE-DIMENSIONAL GEOMETRY FOLLOW- - -
C       22     NMAX(M)         -        I2        NO. OF ELEMENTS IN SEGMENT M
C              XL(M)          FT.     F10.0       LENGTH OF SEGMENT M
C              MA(M)           -        I3        FIRST UPSTREAM SEGMENT
C              MB(M)           -        I3        SECOND UPSTREAM SEGMENT
C              MC(M)           -        I3        THIRD UPSTREAM SEGMENT
C              MD(M)           -        I3        THE DOWNSTREAM SEGMENT
C     -------------PLUS AN ADDITIONAL CARD FOR EACH SEGMENT
C
C     THE UPSTREAM SEGMENT NUMBERS (MA, MB, MC) SHOULD BE PUNCHED IN THE
C     LEFTMOST AVAILABLE POSITION.  (MD) MUST BE PUNCHED IN THE LAST POSITION.
C
C            REMAINING DATA CARDS CONTAIN TIDAL DATA.  EACH CARD LISTS TWO NOS...
C            HA(M,IT)       FT.       F10.0      WATER DEPTHS (COMPUTED)
C            BON(M,IT)      FT.       F10.0      SEGMENT WIDTHS (COMPUTED)
C     (THERE SHOULD BE ONE CARD WITH A DEPTH AND A WIDTH ON IT FOR EACH
C     SEGMENT FOR EACH HOUR OF THE 25 HOUR TIDAL CYCLE.)
C
C
```

```
------------------------------------------------------------------------

    THE SEGMENTS MUST BE NUMBERED SO THAT THE HIGHEST NUMBERED SEGMENT
    IS THE FURTHEST DOWNSTREAM .  ELEMENTS ARE ASSIGNED NUMBERS STARTING
    FROM THE UPSTREAM END OF THE SEGMENT, AND INCREASING DOWNSTREAM.

------------------------------------------------------------------------


    PARAMETERS SPECIFIED IN 'BLOCK DATA' .........

    INITIALIZE FOLLOWING ARRAYS TO ZERO; C,QI,QO,CI,CO,V,DIFHI,DIFLO,
    XPLOT,FARPLT,CONPLT, MPLT, IPTST,ENTDIS,CONC.

    INITIALIZE LOGICAL VARIABLES 'PLOTIT', AND 'STORE' TO .FALSE.

    INITIALIZE LOGICAL VARIABLE 'FIRST' TO .TRUE.

    INITIALIZE FOLLOWING VARIABLES TO THE REQUIREMENTS OF THE ESTUARY
    BEING MODELED.....
    MMAX1 -  NUMBER OF ONE-DIMENSIONAL SEGMENTS IN THE GEOMETRY MODELED
    IFLOW -  STARTING TIDE STATE  (USUALLY = 1, INDICATING FLOOD TIDE)

    DIMENSION ITREP(4),IDFLOW(20)     ,IPRINT(20),CGIVEN(4)
    'ITREP' IS THE NUMBER OF HOURS IN EACH OF THE FOUR TIDAL PHASES PER CYCLE
    'IDFLOW' IS ALPHAMERIC IDENTIFICATION OF SITE
    'IPRINT' UP TO 20 TIDAL CYCLE VALUE (HOURS) AT WHICH PRINTOUT IS DESIRED

    COMMON/ALL/MMAX1,IR,MAJOR,ICYCLE,PRT,CPASS(9,4),IFLOW,FIRST
    'MMAX1'   -THE NUMBER OF ONE-DIMENSIONAL SEGMENTS
    'IR'      -THE NUMBER OF HOURS IN TIDAL PHASE CURRENTLY BEING RUN
    'MAJOR'   -THE INDEX FOR THE TIDAL PHASE CURRENTLY BEING RUN
    'ICYCLE'  -THE NUMBER OF THE TIDAL CYCLE BEING RUN
    'PRT'     -LOGICAL VARIABLE. VALUE .TRUE. ENABLES PRINTING OF OUTPUT
    'CPASS'   -CONCENTRATION OF FLOW ACROSS RIVER-OCEAN INTERFACE
               DIMENSIONED(MAX. HOURS IN ONE PHASE, PARAMETER)

    COMMON/CONSTI /NQM, PARAM(4,3), DECAY(4)
    'NQM'     -THE NUMBER OF QUALITY PARAMETERS TO BE RUN (MAXIMUM NO. = 3)
    'PARAM'   - 10 LETTER ALPHAMERIC PARAMETER NAME
    'DECAY'   -CONCENTRATION DECAY FACTOR, TO BASE E

    COMMON/PLTC/XPLOT(20,30), FARPLT(270,4), CONPLT(270,4, 3),
   1 MPLT(20), IPTST(4),     ENTDIS(270), CONC(270), SUMXL, IPLOT(20),
   2 PLOTIT, STORE, DES(4), YSCALE(3)
    COMMON/RIV1/ B(20,250),H(20,250),BH(20,250),NMAX(20),XL(28),
   1    C(20,30,4),QI(22),QO(22),CI(22,4),NO(20),NI(20),IT,ITM1,
   2 IDUM,IPNIT,CO(20,4),CNODE(20,4),QMEAS(20),CMEAS(20,4),VEL(20),
   3  V(20,30)

------------------------------------------------------------------------

    THE DATA STATEMENT APPEARING IN THE BLOCK DATA SUBPROGRAM MUST BE WRITTEN
    TO SUIT THE SPECIFIC GEOMETRY

------------------------------------------------------------------------
      LOGICAL FIRST, PRT, PLOTIT, STORE
      READ (5,2) (IDFLOW(I), I=1,20)
    2 FORMAT(20A4)
      READ(5,5)NCYCLE,CGIVEN(1),CGIVEN(2),CGIVEN(3),CGIVEN(4)
    5 FORMAT(I3,4F10.0)
      READ(5,25) (IPRINT(INDPRT),INDPRT=1,20)
   25 FORMAT(20I4)
      READ(5,27)(IPLOT(INDPLT),  INDPLT = 1, 20)
   27 FORMAT(20I4)
      READ(5,45) ITREP(1),ITREP(2),ITREP(3),ITREP(4)
   45 FORMAT(4I5)
      READ(5,55) NQM
   55 FORMAT(I3)
      READ(5,65)((PARAM(NQ,I),I=1,3), DECAY(NQ),NQ=1,NQM)
   65 FORMAT(3(3A4,F5.0))
      WRITE(6,75)(IDFLOW(I),I=1,20)
   75 FORMAT(1H1,' PROGRAM TO COMPUTE POLLUTANT TRANSPORT IN ESTUARIES
     1WHICH ARE APPROXIMATED BY ONE-DIMENSIONAL SEGMENTS.',///,
     2' LOCATION OF THIS RUN IS ',20A4)
      WRITE(6,85)
   85 FORMAT(///,5X,'PARAMETER',15X,'DECAY RATE CONSTANT',/)
      DO 90 NQ = 1,NQM
   90 WRITE(6,95) (PARAM(NQ,I),I=1,3), DECAY(NQ)
   95 FORMAT(5X,3A4,10X,F10.3)
      DO 96 INDPLT = 1,20
   96 IF(IPLOT(INDPLT) .NE. 0)STORE = .TRUE.
      IF( .NOT. STORE) GO TO 98
      CALL PINIT
      CALL CHAR(0.0,1.3,1.5706,0.5,'MARINA DEL REY',14)
```

```
      CALL FACTOR(.60)
      XORIG = 2.0
      YORIG = 1.0
   98 INDPRT = 1
      INDPLT = 1
   10 CONTINUE
      PRT = .FALSE.
      IF(ICYCLE .NE. IPRINT(INDPRT)) GO TO 15
      PRT = .TRUE.
      INDPRT = INDPRT + 1
   15 CONTINUE
      PLOTIT = .FALSE.
      IF(ICYCLE .NE. IPLOT(INDPLT)) GO TO 20
      PLOTIT = .TRUE.
      INDPLT = INDPLT + 1
   20 CONTINUE
      DO 50 MAJOR = 1,4
      IR = ITREP(MAJOR)
      GO TO (30,40),IFLOW
C-----------------------------------------------------------------------
C     IFLOW INDICATES THE STATE OF THE TIDE. '1' = FLOOD, '2' = EBB
C
C     IF TIDE IS FLOODING, PARAMETER CONCENTRATIONS AT RIVER ENTRANCE ARE
C     GIVEN (OCEAN CONCENTRATION ASSUMMED CONSTANT), AND THE RIVER SUBROUTINE
C     IS CALLED.
C
C     IF THE TIDE IS EBBING, THE RIVER SUBROUTINE IS CALLED WITHOUT ANY
C     PRELIMINARY STEPS.
C
C-----------------------------------------------------------------------
   30 DO 31 NO = 1, NOM
      DO 31 I = 1,IR
   31 CPASS(I,NO) = CGIVEN(NO)
      CALL RIVER
      IFLOW = 2
      GO TO 50
   40 CALL RIVER
      IFLOW = 1
   50 CONTINUE
C-----------------------------------------------------------------------
C
C     PLOT RESULTS FOR THIS CYCLE IF REQUESTED
C
C-----------------------------------------------------------------------
      IF (.NOT. PLOTIT) GO TO 190
      DO 190 NO = 1, NOM
      CALL RESET
C
C     FIND MAXIMUM CONCENTRATION FOR THIS CYCLE.
      YMOST = CONPLT(1,1,NO)
      DO 100 MAJOR = 1,4
      ISTOP = IPTST(MAJOR)
      DO 100 I = 1,ISTOP
      IF(CONPLT(I,MAJOR,NO) .GT. YMOST) YMOST = CONPLT(I,MAJOR,NO)
  100 CONTINUE
C     YMOST ASSUMED .GT. 0.1
      DIV = 1.0
      DIVSAV = 1.0
  101 YMOST = YMOST/DIV
      IYMOST = YMOST
      IF(IYMOST .EQ. 0) GO TO 102
      DIV = 10.0
      DIVSAV = DIVSAV*10.0
      GO TO 101
  102 ICHAR = YMOST*10.0 + 1
      YAXIS = ICHAR * DIVSAV/10.0
C     COMPUTE SCALE FACTOR
      YSCALE(NO) = 10.0/YAXIS
  105 CONTINUE
C
      CALL ORIGIN(XORIG,YORIG, -1)
      CALL CHAR(2.0, 11.0, 0.0, 0.2, 'CONCENTRATION OF ', 17)
      DO 110 I = 1,3
  110 DES(I) = PARAM(NO,I)
      CALL CHAR(5.4,11.0,0.0,0.2, DES,12)
      CALL CHAR(8.0, 11.0, 0.0, 0.2, ' IN MAIN CHANNEL FROM ENTRANCE TO
     1END OF BASIN E AT THE', 55)
      CALL CHAR(2.0, 10.6, 0.0, 0.2, 'END OF EACH PHASE OF TIDAL CYCLE N
     1UMBER ', 40)
      XICYCL = ICYCLE
      CALL NUMPLT(10.2,10.6,0.0,0.2,XICYCL,-1)
      CALL CHAR( 10.5, 10.5, 0.0, 0.2,'. NUMBERS ON CURVES REFER TO TID
     1AL PHASE NUMBERS.', 60)
      CALL AXIS(0.0,0.0,'CONCENTRATION (PPM)', 19,10.0, 0.0,1.5708)
```

```
      DO 115 N = 1, ICHAR
      YTIC = N * 10.0/ICHAR
      YNUM = N*DIVSAV/10.0
      CALL NUMPLT(0.4,YTIC,0.0,-0.1,YNUM,1)
  115 CALL PLTLN(0.0,YTIC,-0.1,YTIC)
      CALL AXIS( 0.0, 0.0, 'DISTANCE FROM ENTRANCE (FT.)', -28, 26.0,-27
     1,1,0.0)
      DO 120 N = 2,14,2
      XTIC = 2.0*(N-2)
      XNUM = 1000.0*(N-2)
  120 CALL NUMPLT(XTIC,-0.2,0.0,-0.1, XNUM,0)
C     AT THIS POINT THE PLOT FRAME IS SET UP.  NOW SET SCALE FACTORS AND
C     PLOT A CURVE FOR EACH PHASE.
      YSC = YSCALE(NQ)
      CALL SCALF(0.002,YSC,1)
C     TRANSFER FOR IMMEDIATE PLOTTING.
      MAJOR = 1
      ISTOP = IPTST(MAJOR)
      DO 122 I = 1, ISTOP
      ENTDIS(I) = FARPLT(I,MAJOR)
  122 CONC(I) = CONPLT(I,MAJOR,NQ)
      CALL VECTOR (ENTDIS,CONC,ISTOP,1,4,'1')
      MAJOR = 2
      ISTOP = IPTST(MAJOR)
      DO 124 I = 1, ISTOP
      ENTDIS(I) = FARPLT(I,MAJOR)
  124 CONC(I) = CONPLT(I,MAJOR,NQ)
      CALL VECTOR (ENTDIS,CONC,ISTOP,1,4,'2')
      MAJOR = 3
      ISTOP = IPTST(MAJOR)
      DO 126 I = 1, ISTOP
      ENTDIS(I) = FARPLT(I,MAJOR)
  126 CONC(I) = CONPLT(I,MAJOR,NQ)
      CALL VECTOR (ENTDIS,CONC,ISTOP,1,4,'3')
      MAJOR = 4
      ISTOP = IPTST(MAJOR)
      DO 128 I = 1, ISTOP
      ENTDIS(I) = FARPLT(I,MAJOR)
  128 CONC(I) = CONPLT(I,MAJOR,NQ)
      CALL VECTOR (ENTDIS,CONC,ISTOP,1,4,'4')
      CALL RESET
      XORIG = XORIG + 20.0
  190 CONTINUE
      IF(ICYCLE .EQ. NCYCLE) GO TO 60
      ICYCLE = ICYCLE + 1
      GO TO 10
   60 IF(.NOT. STORE) GO TO 200
      XEND = XORIG + 10.0
      CALL ENPLT(XEND,0.0)
      WRITE(6,195)
  195 FORMAT(' PLOT GENERATED. END OF RUN.')
      STOP
  200 WRITE(6,210)
  210 FORMAT(' END OF RUN.')
      STOP
      END
```

```
      BLOCK DATA
      COMMON/ALL/MMAX1,IR,MAJOR,ICYCLE,PRT,CPASS(9,4),IFLOW,FIRST
      LOGICAL FIRST, PRT, PLOTIT, STORE
      DATA MMAX1,ICYCLE, IFLOW/13,1,1/,FIRST/.TRUE./
      COMMON/RIV1/ H(20,250),HI(20,250),FH(20,250),NMAX(20),XL(20),
     1    C(20,30,4),QI(22),QO(22),CI(22,4),NI(20),NI(20),IT,ITM1,
     2 IDUM,IRNIT,CO(20,4),CNODE(20,4),QMEAS(20),CMEAS(20,4),VEL(20),
     3  V(20,30)
      DATA C,QI/2400*0.0,22*0.0/
      DATA CI, CO /88*0.0,80*0.0/,V/600*0.0/
      COMMON/D/DIFHI(20),DIFLO(20)
      DATA DIFHI,DIFLO/20*0.0,20*0.0/
      COMMON/RIV3/ NCSLUG, IHRSLG,MSLUG,NSLUG,XSLUG,NIT,SUMOUT,PERCNT
      DATA SUMOUT/0.0/, PERCNT/0.0/
      COMMON/PLTC/XPLOT(20,30), FARPLT(270,4), CONPLT(270,4, 3),
     1 MPLT(20), IPTST(4),     ENTDIS(270), CONC(270), SUMXL, IPLOT(20),
     2 PLOTIT, STORE, DES(4), YSCALE(3)
      DATA XPLOT/600*0.0/, FARPLT/1080*0.0/, CONPLT/3240*0.0/,
     1 MPLT/20*0/, IPTST/4*0/,  ENTDIS, CONC/270*0.0,270*0.0/,
     2 PLOTIT,STORE/.FALSE., .FALSE./
      END
```

```
      SUBROUTINE RIVER
      DIMENSION MA(20),MB(20),MC(20),MD(20),DIFOFF(4),SUMOC(4)
      COMMON/ALL/MMAX1,IR,MAJOR,ICYCLE,PET,CPASS(9,4),IFLOW,FIRST
      COMMON/RIV1/ B(20,250),H(20,250),BH(20,250),NMAX(20),XL(28),
     1   C(20,30,4),QI(22),QO(22),CI(22,4),NC(20),NI(20),IT,ITM1,
     2 IDUM,IRNIT,CR(20,4),CNODE(20,4),QMEAS(20),CMEAS(20,4),VEL(20),
     3  V(20,30)
C
C     'B' - WIDTH OF 1-D SEGMENT AT WATER SURFACE. DIMENSIONED (M1,NSTEPS)
C     'H' - MEAN DEPTH OF 1-D SEGMENT. DIM (M1,NSTEPS)
C     'BH'- VALUES OF B*H  DIM(M1,NSTEPS))
C     'NMAX'  -NUMBER OF ELEMENTS IN SEGMENT.DIM(M1)
C     'XL'    -LENGTH OF A SEGMENT
C     'V'     -VOLUME CONTAINED IN AN ELEMENT
C     'C'     -CONCENTRATION IN ELEMENTS. DIM(M1,30,NQM)
C     'QI'    -VOLUME OF INFLOW INTO SEAWARD END OF SEGMENT
C     'QO'    -VOLUME OF OUTFLOW FROM LANDWARD END OF SEGMENT
C     'CI'    -CONCENTRATION OF OUTFLOW FROM SEAWARD END OF A SEGMENT
C     'IT'    -TIME STEP INDEX
C     'CNODE' -AVERAGE CONCENTRATION OF ALL INFLOWS INTO THE NODE AT THE
C               UPSTREAM END OF A SEGMENT
C     'QMEAS' -VOLUME OF (POSSIBLE) EXTERNAL FLOW INTO UPSTREAM END OF A
C               SEGMENT.(PER TIME STEP)
C     'CMEAS' -CONCENTRATION OF THIS EXTERNAL FLOW.
C
C
      COMMON/RIV2/ NADD(5), MINPUT (5), XADD(5), ADD(5), CADD(5,3)
C     THIS BLOCK CONTAINS THE INFORMATION FOR CONTINUOUS DISCHARGE OF
C     SOLUTIONS  AT UP TO FIVE DIFFERENT LOCATIONS
C
C     'NADD'    -THE NUMBER OF THE ELEMENT PRESENTLY LOCATED AT THE POINT
C                OF CONTINUOUS DISCHARGE.
C     'MINPUT' - THE SEGMENT IN WHICH SITE OF CONTINUOUS DISCHARGE IS
C                LOCATED.
C     'XADD'    -DISTANCE DOWNSTREAM FROM THE LANDWARD END OF A SEGMENT
C                TO THE POINT OF CONTINUOUS DISCHARGE.
C     'ADD'     -VOLUME OF SOLUTION PER TIME STEP ADDED AS CONTINUOUS
C                SOURCE.
C
C     'CADD'    -CONCENTRATION OF SOLUTION IN PPM
C
      COMMON/RIV3/ NCSLUG, IHRSLG,MSLUG,NSLUG,XSLUG,NIT,SUMOUT,PERCNT
C     THIS BLOCK CONTAINS SLUG INPUT INFORMATION
C     VARIABLES DEFINED IN 'MAIN'
C
      COMMON/RIV4/JSTART(3),JEND(3),JM(3),JN(3),XINT(3),JNQ(3),VINT(3),
     1 CINT(3)
C     THIS BLOCK CONTAINS SHORT CONTINUOUS INPUT INFORMATION
C
      COMMON/CONSTI /NQM, PARAM(4,3), DECAY(4)
      COMMON/D/DIFHI(20),DIFLO(20)
      COMMON/ /HA(20,25),BDN(20,25)
C     'HA'    - MEAN DEPTH IN A SEGMENT, AT HOURLY INTERVALS (COMPUTED BY
C               HYDRODYNAMIC PROGRAM).
C     'BDN'   - MEAN WIDTH OF A SEGMENT (COMPUTED BY HYDRO. PROGRAM).
C
      COMMON/PLTC/XPLOT(20,20), FARPLT(270,4), CONPLT(270,4, 3),
     1 MPLT(20), IPTST(4),      ENTDIS(270), CONC(270), SUMXL, IPLOT(20),
     2 PLOTIT, STORE, DES(4), YSCALE(3)
C
      LOGICAL FIRST, PET, PLOTIT, STORE
      IF(.NOT. FIRST) GO TO 200
      FIRST = .FALSE.
      TOTSLG = 0.0
      READ(5,100) NIT,NPASS1,NPASS2
  100 FORMAT(3I5)
C     'NIT'     NUMBER OF TIME STEPS PER HOUR.  MINIMUM IS 2.  DIMENSIONS
C               ALLOW A MAXIMUM OF 10.
C     'NPASS1','NPASS2'  -PRINTING CONTROL NUMBERS. ZERO VALUE CAUSES PRINTOUT
C
      READ(5,101)(QMEAS(M),M=1,MMAX1)
  101 FORMAT(10F8.0)
      WRITE(6,102)
  102 FORMAT(//,' GIVEN DISCHARGE INTO UPSTREAM END OF SEGMENTS, CU.FT./
     1TIME STEP',/)
      WRITE(6,101)(QMEAS(M), M=1,MMAX1)
      DO 103 NQ=1,NQM
  103 READ(5,101)(CMEAS(M,NQ),M=1,MMAX1)
      DO 104 I=1,5
  104 READ(5,105) MINPUT(I),XADD(I), ADD(I), (CADD(I,NQ), NQ=1,3)
  105 FORMAT(I5,2F10.0,3F11.2)
      WRITE(6,106)
  106 FORMAT(///,' CONTINUOUS CONCENTRATION INPUT TO THE FOLLOWING POINT
     1S',//,'     SEGMENT          LOCATION         DISCHARGE VOLUME/TIME STEP
     2 CONCENTRATIONS(NQ) - - -',/)
      IF(MINPUT(1) .EQ.    0 .AND. MINPUT(2) .EQ. 0   ) GO TO 142
```

```
      DO 107 I=1,5
  107 WRITE(6,108) MINPUT(I),XADD(I), AFD(I), (CADD(I,NO), NO=1,3)
  108 FORMAT(I5,2F15.0,4F15.5)
      GO TO 145
  142 WRITE(6,143)
  143 FORMAT(//,' NONE')
  145 READ(5,110) NCSLUG,IHRSLG,MSLUG,XSLUG,NQSLUG,VSLUG,CONSLG
  110 FORMAT(3I5,F10.0,I3,2F15.5)
      WRITE(6,112)
  112 FORMAT(//,'  SLUG CONCENTRATION INPUT')
      IF(NCSLUG .EQ. 0) WRITE(6,113)
  113 FORMAT(//,'   NONE')
      IF(NCSLUG .NE. 0) WRITE(6,114) VSLUG,(PARAM(NQSLUG,I),I=1,3),
     1 NCSLUG,IHRSLG,XSLUG,MSLUG
  114 FORMAT(//,' THERE IS A SINGLE SLUG INJECTION OF',F15.5,' CUBIC FT.
     1 OF',3A4,' IN TIDAL CYCLE ',I3,' DURING THE LAST',/,' TIME STEP OF
     2 HOUR ',I3,' OF THE 25 HOUR CYCLE.  THE LOCATION OF THE INJECTION
     3IS',F10.0,' FT. DOWNSTREAM OF THE',/,' LANDWARD END OF SEGMENT',
     4 I3,' .')
C     READ SHORT CONTINUOUS INPUT INFORMATION HERE
      DO 118 I = 1,3
  118 READ(5,119) JSTART(I),JEND(I),JM(I),XINT(I),JNQ(I),VINT(I),CINT(I)
  119 FORMAT(3I5,F10.0,I3,2F10.0)
      WRITE(6,120)
  120 FORMAT(///,' CONTINUOUS CONCENTRATION INPUTS SUSTAINED FOR ONE OR
     1MORE TIDAL CYCLES . . . . ')
      DO 125 I = 1,3
      IF(JSTART(I) .EQ. 0) GO TO 125
      NQ=JNQ(I)
      WRITE(6,122)(PARAM(NQ,J),J=1,3),XINT(I),JM(I),JSTART(I),JEND(I),
     1 VINT(I), CINT(I)
  122 FORMAT(//,' THERE IS A CONTINUOUS INPUT OF ',3A4,', ',F10.0,' FT.
     1DOWNSTREAM OF THE LANDWARD END OF SEGMENT',I3,',',/,' BEGINNING IN
     2 TIDAL CYCLE',I5,' ENDING IN CYCLE',I5,' .  THE VOLUME PER HOUR IS
     3',F10.0,' CU.FT.',/,' OF CONCENTRATION',F15.5,'PPM.')
  125 CONTINUE
      IF(JSTART(1) .EQ. 0 .AND. JSTART(2) .EQ. 0 .AND. JSTART(3) .EQ. 0)
     1 WRITE(6,126)
  126 FORMAT(//,'    NONE')
      READ(5,132)(NMAX(M),XL(M),MA(M),MB(M),MC(M),MD(M),M=1,MMAX1)
  132 FORMAT(I2,F10.0,4I3)
C
C     DETERMINATION OF SEGMENT SEQUENCE FOR PLOT ROUTINE.
      M = 1
      DO 71 I = 1,6
      MPLT(I) = M
      M = MD(M)
   71 CONTINUE
   72 CONTINUE
C
      DO 133 NQ=1,NQM
  133 DIEOFF(NQ) = EXP(-DECAY(NQ)/( NIT*24.0))
      WRITE(6,134)(DIEOFF(NQ), NQ=1,NQM)
  134 FORMAT(//,' DECAY CONSTANTS ARE',//, 4(1X,F8.6,5X),/)
      WRITE(6,135) NIT
  135 FORMAT(//,' NUMBER OF TIME STEPS PER HOUR IS',I3)
C       READ THE WIDTHS AND DEPTHS OF THE ONE-DIMENSIONAL SEGMENTS FOR
C       EACH HOUR OF THE 25 HR. CYCLE.  THIS INFO COMPUTED BY HYDRO. PROG.
      DO 137 IT=1,25
      DO 137 M=1,MMAX1
  137 READ(5,138) HA(M,IT), BDN(M,IT)
  138 FORMAT(2F10.0)
C
C     THE STATEMENTS FROM HERE DOWN TO LABEL '150' INTERPOLATE BETWEEN HOURLY
C     DATA ON THE SEGMENT WIDTHS AND DEPTHS.  THIS PROVIDES H(M,IT) AND B(M,IT)
C     AT EVERY TIME STEP, IT.
C
      NSTEPS = NIT*25
      DO 150 M=1,MMAX1
      ITEMP = 0
      DO 139 IT = NIT, NSTEPS, NIT
      ITEMP = ITEMP + 1
      H(M,IT) = HA(M, ITEMP)
      B(M,IT) = BDN(M,ITEMP)
  139 BH(M,IT) = B(M,IT) * H(M,IT)
      NITM1 = NIT - 1
      DO 140 IT = 1, NITM1
      B(M,IT) = B(M,NSTEPS) + IT*(B(M,NIT) - B(M,NSTEPS))/NIT
      BH(M,IT) = BH(M,NSTEPS) + IT*(BH(M,NIT) - BH(M,NSTEPS))/NIT
  140 H(M,IT) = BH(M,IT)/B(M,IT)
      DO 150 I = 1, 24
      IP1 = I*NIT + 1
      IEND = I*NIT + NITM1
      DO 150 IT = IP1, IEND
      B(M,IT)=B(M,I*NIT) +(IT-I*NIT)*(B(M,I*NIT+NIT)-B(M,I*NIT))/NIT
      BH(M,IT)=BH(M,I*NIT)+(IT-I*NIT)*(BH(M,I*NIT+NIT)-BH(M,I*NIT))/NIT
  150 H(M,IT) = BH(M,IT)/B(M,IT)
```

```
C       IF REQUESTED (NPASS1 =0), A DESCRIPTION OF THE FLOW SYSTEM (BY NUMBER)
C       WILL BE PRINTED NOW.
C
        IF(NPASS1 .NE. 0) GO TO 158
        DO 156 M = 1,MMAX1
        WRITE(6,152) M, XL(M), MA(M), MB(M), MC(M), MD(M),NMAX(M)
  152 FORMAT(////,' BRANCH ',I2,', LENGTH',F10.2,', LANDWARD BRANCHES ',
     *3(I2,', '),' SEAWARD BRANCH ',I2,', NO. OF ELEMENTS = ',I2 ,/)
        WRITE(6,153)
  153 FORMAT(5X,'DEPTH AND WIDTH OF THIS BRANCH AT EACH HOUR ARE')
        WRITE(6,154)(H(M,IT),B(M,IT), IT= NIT,NSTEPS,NIT)
  154 FORMAT(6(2X,F6.2,F10.1,4X))
  156 CONTINUE
  158 CONTINUE
        WRITE(6,159)
  159 FORMAT(1H1)
C
C       THE STATEMENTS DOWN TO LABEL 170 COMPUTE THE VOLUME OF EACH SEGMENT
C       AND DIVIDE IT INTO STARTING ELEMENTS.
        DO 170 M=1, MMAX1
        VOL = BH(M,NSTEPS) * XL(M)
        V(M,1)= VOL/NMAX(M)
        NT = NMAX(M)
        DO 165 N=2, NT
  165 V(M,N)=V(M,1)
  170 CONTINUE
C
        MMAXP1 = MMAX1 + 1
        QI(MMAXP1) =0.0
        IT = 0
  200 CONTINUE
        IRNIT= IR*NIT
C-----------------------------------------------------------------------
C
C       BEGIN TIME STEP ITERATION. MAIN LOOP EXTENDS DOWN TO LABEL 500.
C
C-----------------------------------------------------------------------
        DO 500 IDUM=1,IRNIT
        ITEMP=(IDUM-1)/NIT +1
        MMAXP1 = MMAX1 + 1
        DO 202 NQ=1,NQM
  202 CNODE(MMAXP1,NQ)= CPASS(ITEMP,NQ)
        IT = IT+1
        IF(IT .GT. NSTEPS) IT=1
        ITM1 = IT - 1
        IF(IT .EQ. 1) ITM1 = NSTEPS
C
C       FOR EACH SEGMENT, CALL SUBROUTINE MAP. RETURN WITH FLOW AND CONCENTRATIO
C       INFORMATION, CNODE, QO, AND QI FOR SEGMENT M.
        DO 205 M=1, MMAX1
  205 CALL MAP (M,MA(M), MB(M), MC(M))
C
        NT = NMAX(MMAX1)
        DO 211 M=1,MMAX1
  211 VEL(M) =.5*(QO(M)+QI(M))/BH(M,IT   )
C
C       IF TIDE IS EBBING, AND FLOW IS OUT OF SEAWARD END OF LAST SEGMENT, THEN
C       CONCENTRATION AT ENTRANCE NODE EQUATED TO CONCENTRATION OF LAST ELEMENT
C       OF LAST SEGMENT, FOR EACH PARAMETER.
        IF(IFLOW .NE. 2 .AND. QI(MMAX1) .GT. 0.0) GO TO 209
  207 DO 208 NQ=1,NQM
  208 CNODE(MMAXP1,NQ) = C(MMAX1,NT,NQ)
C
C       IF THIS IS THE FIRST TIDAL CYCLE, AND IF NPASS2=0, AND IF THE TIME
C       VALUE IS AN HOUR MULTIPLE, FLOW INFORMATION WILL BE PRINTED.
  209 IF(ICYCLE.EQ.1.AND.NPASS2.EQ.0.AND.IT/NIT*NIT.EQ.IT) GO TO 210
        GO TO 218
  210 CONTINUE
        WRITE (6,212)IT
  212 FORMAT(/////,2(5X,'BRANCH       INFLOW       OUTFLOW      TRAVEL',7
     1X),'IT = ', I4,/)
        WRITE(6,214) (M,QI(M),QO(M), VEL(M),M=1,MMAX1)
  214 FORMAT(    2(5X,I4,1X,F15.0,1X,F14.0,1X,F11.2,7X))
        WRITE(6,215)(DIFHI(M),DIFLO(M),M=1,MMAX1)
  215 FORMAT(/,' HIGH AND LOW VALUES OF THE ADJUSTED DIMENSIONLESS DIFFU
     1SION COEFFICIENT FOR EACH SEGMENT, IN PAIRS . . .',/,
     2 4(4(G12.5,',',G12.5,';',5X),/))
        DO 216 M=1,MMAX1
        DIFLO(M) = 0.0
  216 DIFHI(M) = 0.0
  218 CONTINUE
C
C       FOR EACH SEGMENT, CALL SUBROUTINE BRANCH. THIS ROUTINE MOVES VOLUME
C       ELEMENTS TO ACOUNT FOR THE FLOWS DETERMINED IN SUBROUTINE MAP.  THE
C       NUMBER OF VOLUME ELEMENTS IN THE SEGMENT M (NMAX(M) ) MAY INCREASE
```

```
C       OR DECREASE HERE.
C
        DO 220 M=1,MMAX1
        CALL BRANCH(M,MD(M))
  220   CONTINUE
C
C       FOR EACH SEGMENT, CALL SUBROUTINE DIFUSE. THIS ROUTINE ADJUSTS ELEMENT
C       CONCENTRATIONS TO ACCOMPLISH DIFFUSIVE STEP. RETURNS WITH THE ADJUSTED
C       ELEMENT CONCENTRATIONS. INCLUDES PROVISION FOR COMBINING VERY SMALL
C       ELEMENTS
        DO 250 M=1,MMAX1
        CALL DIFUSE(M)
  250   CONTINUE
C
C       ADD INPUT OF WATER QUALITY PARAMETERS AT (UP TO 5) DESIGNATED POINTS
C
        DO 255 I=1,5
        MTEMP = MINPUT(I)
        IF(MTEMP .EQ. 0) GO TO 255
        NTEMP =NADD(I)
        DO 253 NQ=1,NOM
  253   C(MTEMP,NTEMP,NQ) = C(MTEMP,NTEMP,NQ) + ADD(I)    *CADD(I,NQ)/
       1(V(MTEMP,NTEMP) + ADD(I))
        V(MTEMP,NTEMP) = V(MTEMP,NTEMP) + ADD(I)
        TOTSLG = TOTSLG + ADD(I)*CADD(I,NQ)/1000000.
  255   CONTINUE
C
C       ADD SLUG INJECTION IF SPECIFIED BY NCSLUG NOT EQUAL TO ZERO.
C       SINGLE SLUG INJECTIONS USED TO DETERMINE THE FLUSHING TIME CONSTANT.
C
        IF(NCSLUG .NE. ICYCLE)GO TO 270
        IF(IT/NIT .NE. IHRSLG .OR. IT/NIT*NIT .NE. IT) GO TO 270
  261   C(MSLUG,NSLUG,NQSLUG) = (C(MSLUG,NSLUG,NQSLUG)*V(MSLUG,NSLUG) +
       1  CONSLG*VSLUG)/(V(MSLUG,NSLUG) + VSLUG)
        TOTSLG = TOTSLG + CONSLG*VSLUG/1000000.
  270   CONTINUE
C       END OF SLUG INJECTION STEP
C
C-----------------------------------------------------------------------------
C
C       SHORT CONTINUOUS INPUTS ADDED HERE
C
C-----------------------------------------------------------------------------
        DO 290 I=1,3
        IF(JSTART(I) .EQ.0 .OR. ICYCLE .LT. JSTART(I) .OR. ICYCLE .GT.
       1 JEND(I)) GO TO 290
        M = JM(I)
        N=JN(I)
        NQ=JNQ(I)
        C(M,N,NQ) =(C(M,N,NQ)*V(M,N) + VINT(I)*CINT(I))/(V(M,N) +VINT(I))
        V(M,N) = V(M,N) + VINT(I)
        TOTSLG = TOTSLG + VINT(I)*CINT(I)/1000000.
  290   CONTINUE
C       END OF CONTINUOUS INPUT STEP
C
  300   DO 360 M=1,MMAX1
        NT =NMAX(M)
        DO 360 N=1,NT
        DO 358 NQ=1,NOM
  358   C(M,N,NQ) = DIEOFF(NQ) *C(M,N,NQ)
C
C       AT THIS POINT, SPECIAL INSTRUCTIONS MAY BE INSERTED TO REPRESENT CHEMICAL
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C       REACTIONS BETWEEN PARAMETERS. IE..C(M,N,4)=C(M,N,4)+(1-DIEOFF(2))*C(M,N,2)
C
  360   CONTINUE
C
C       IF THE TIDE IS FLOOD, SKIP DOWN TO LABEL 500.  IF THE TIDE IS EBB,
C       FIND THE CONCENTRATION OF FLOW FROM THE RIVER TO THE OCEAN.
        IF(IFLOW .NE. 2)  GO TO 500
        IF ((IDUM/NIT)*NIT+1 .NE. IDUM) GO TO 410
        SUMQ =0.0
        DO 405 NQ=1,NOM
  405   SUMQC(NQ) = 0.
  410   SUMQ = SUMQ + QI(MMAX1)
        DO 415 NQ=1,NOM
  415   SUMQC(NQ) = SUMQC(NQ) + QI(MMAX1) * CI(MMAX1,NQ)
        IF((IDUM/NIT)*NIT .NE. IDUM) GO TO 500
        DO 425 NQ=1,NOM
  425   CPASS(ITEMP,NQ) = SUMQC(NQ)/SUMQ
C       CALCULATE TOTAL AMOUNT OF INJECTED MATERIAL REMAINING IN THE SYSTEM.
        CHECK = 0.0
        DO 51  M = 1,MMAX1
        NEL = NMAX(M)
        DO 51  N = 1, NEL
   51   CHECK = CHECK +(V(M,N)*C(M,N,1))/1000000.0
```

```
      PERCNT = 100.0 - 100.0*CHECK/TOTSLG
  500 CONTINUE
C-----------------------------------------------------------------------
C
C     PRINT AND/OR PLOT OUTPUT IF SO REQUESTED. OTHERWISE, RETURN.
C
C-----------------------------------------------------------------------
      IF(.NOT.PRT)GO TO 700
      WRITE(6,502) MAJOR,ICYCLE
  502 FORMAT(1H1,' CONCENTRATIONS IN THE RIVER, AT THE END OF PHASE ',
     *I2,' OF CYCLE ',I3,' IN PARTS PER MILLION',/)
      M1=1
  505 M2=0
      M3 = 0
      MNEXT = MD(M1)
      IF(MNEXT.EQ.0) GO TO 509
      M2 = MC(MNEXT)
      M3 = MB(MNEXT)
  509 CALL XPPNT(M1,M2,M3)
      IF(MNEXT .EQ. 0) GO TO 600
      M1=MNEXT
      IF(M1 .LT. MMAXP1) GO TO 505
  600 IF (IFLOW .EQ. 2) WRITE(6,510) (CPASS(I,1),I=1,IR)
  510 FORMAT(///,' AVERAGE CONCENTRATION OF PARAM(1) IN FLOW INTO OCEAN,
     1 EACH HOUR',//,8G15.4)
      IF(MAJOR .EQ. 4)WRITE(6,520)PERCNT,TOTSLG
  520 FORMAT(//,' PERCENTAGE OF SLUG INPUT FLUSHED OUT SO FAR IS',
     1 G12.4,', TOTAL INPUT SO FAR IS',G12.4,' CU.FT.')
  700 IF(.NOT. PLOTIT) RETURN
C
C     PLOT DATA STORAGE OCCURS HERE.
      SUMSEG = 0.0
      I = 0
      DO 740 K = 1,6
      KINV = 7 - K
      M = MPLT(KINV)
      NM = NMAX(M)
      DO 730 J = 1,NM
      I = I + 1
      IPTST(MAJOR) = I
      JINV = NMAX(M) + 1 - J
      FARPLT(I,MAJOR) = SUMSEG + XL(M) - XPLOT(M,JINV)
      DO 730 NQ=1,NQM
  730 CONPLT(I,MAJOR,NQ) = C(M,JINV,NQ)
  740 SUMSEG = SUMSEG + XL(M)
C     DATA STORAGE COMPLETED FOR THIS PHASE
      RETURN
      END
```

```
      SUBROUTINE MAF(M,M1,M2,M3)
      COMMON/RIV1/ R(20,250),H(20,250),RH(20,250),NMAX(20),XL(20),
     1    C(20,30,4),QI(22),QO(22),CI(20,4),ND(20),NI(20),IT,ITM1,
     2 ICUM,IRNIT,CR(20,4),CNODE(20,4),QMEAS(20),CMEAS(20,4),VEL(20),
     3  V(20,30)
      COMMON/ALL/MMAX1,IR,MAJOR,ICYCLE,HFT,CPASS(9,4),IFLOW,FIRST
      COMMON/CONSTI /NQM, PARAM(4,2), DECAY(4)
      NT = NMAX(M)
      IF(M1.NE.0 .OR. M2.NE.0 .OR. M3.NE.0) GO TO 20
   10 QI(M) = (RH(M,IT) - RH(M,ITM1))*XL(M) - QMEAS(M)
      QO(M) = 0.0
      DO 15 NQ=1,NQM
   15 CNODE(M,NQ) = C(M,1,NQ)
```

```
      IF(QI(M) .LT. 0.0) GO TO 200
      RETURN
C
C     THE ABSENCE OF UPSTREAM SEGMENTS IS DENOTED BY SEGMENTS NUMBERED
C     ZERO (0).  SINCE  ZERO SUBSCRIPTS ARE NOT ALLOWED. ZERO IS REPLACED
C     BY 22 HERE.  ANY SEGMENT NO. 22 IS TREATED AS IF IT WASN'T THERE.
C     AT THE END OF THIS ROUTINE, 22 IS SET BACK TO ZERO.
C
   20 IF(M2 .EQ. 0) M2=22
      IF(M3 .EQ. 0) M3=22
      QI(22) = 0.0
      DO 40 NO=1,NOM
   40 CI(22,NO) = 0.0
      QO(M) = QI(M1) + QI(M2) + QI(M3)
      QI(M) = (BH(M,IT) - BH(M,ITM1))*XL(M) + QO(M) - QMEAS(M)
      VOLEL = BH(M,ITM1) * XL(M)
      IF(QO(M) .GE. VOLEL) GO TO 380
      IF( -QI(M) .GE. VOLEL) GO TO 390
   90 CONTINUE
C-----------------------------------------------------------------------
C
C     COMPUTE CONCENTRATION OF OUTFLOW FROM LANDWARD END OF SEGMENT
C
C-----------------------------------------------------------------------
      IF(QO(M)) 200, 200, 100
  100 CONTINUE
      VOL = 0.0
      DO 110 I = 1, NT
      N = I
      VOL = VOL + V(M,N)
      IF(QO(M) .LT. VOL) GO TO 120
  110 CONTINUE
  120 DO 140 NO = 1, NOM
      SUM = 0.0
      IF(N .EQ. 1) GO TO 135
      DO 130 NTEMP = 2, N
  130 SUM = SUM + C(M,NTEMP-1,NO) * V(M,NTEMP-1)
  135 CO(M,NO) = (SUM + C(M,N,NO)*(V(M,N) + QO(M) - VOL))/QO(M)
      IF(CO(M,NO) .LT. 0.0) WRITE(6,137) CO(M,NO),M,IT
  137 FORMAT(' NEGATIVE CONCENTRATION CO =',G15.4,'M = ',I4,'IT  = ',I4)
  140 CONTINUE
C-----------------------------------------------------------------------
C
C     COMPUTE  CONCENTRATION OF OUTFLOW FROM SEAWARD END OF SEGMENT
C
C-----------------------------------------------------------------------
  200 IF(QI(M)) 210, 300, 300
  210 CONTINUE
      VOL = 0.0
      DO 220 I     = 1, NT
      NINV = I
      N = NT + 1 - NINV
      VOL = VOL + V(M,N)
      IF(-QI(M) .LT. VOL) GO TO 230
  220 CONTINUE
  230 DO 250 NO = 1,NOM
      SUM = 0.0
      IF(NINV .EQ. 1) GO TO 245
      DO 240 NTEMP = 2,NINV
  240 SUM = SUM + C(M,NT+2-NTEMP,NO) * V(M,NT+2-NTEMP)
  245 CI(M,NO) = (SUM+C(M,N,NO) *(V(M,N)-QI(M)-VOL))/(-QI(M))
  250 CONTINUE
      IF(M1 .EQ. 0) RETURN
  300 CONTINUE
      Q1 = QI(M1)
      Q2 = QI(M2)
      Q3 = QI(M3)
      Q4 = QO(M)
      IF(Q1 .GT. 0.0) Q1=0.0
      IF(Q2 .GT. 0.0) Q2=0.
      IF(Q3 .GT. 0.0) Q3=0.
      IF(Q4 .LT. 0.0)Q4=0.0
      DO 310 NO=1,NOM
  310 CNODE(M,NO)=(-Q1*CI(M1,NO)-Q2*CI(M2,NO)-Q3*CI(M3,NO)+Q4*CO(M,NO)
     1   +QMEAS(M)*CMEAS(M,NO))/(Q4+QMEAS(M)-Q1-Q2-Q3)
      IF(M2 .EQ. 22) M2 = 0
      IF(M3 .EQ. 22) M3=0
  370 RETURN
  380 CONTINUE
  390 CONTINUE
      WRITE(6,410) M, QI(M),QO(M),IT
  410 FORMAT(/,' TRANSFER EXCEEDS ELEMENT VOLUME,BRANCH ',I2,
     1', INFLOW =',F13.0,', OUTFLOW =',F13.0,', TIME STEP ' , I2)
      STOP
      END
```

```
      SUBROUTINE BRANCH (M,M4)
      COMMON/ALL/MMAX1,IR,MAJOR,ICYCLE,PPT,CPASS(9,4),IFLOW,FIRST
      COMMON/CIV1/ F(20,250),H(20,250),BH(20,250),NMAK(20),XL(28),
     1   C(20,30,4),QI(22),QO(22),CI(22,4),NO(20),NI(20),IT,ITM1,
     2 IDUM,IENIT,CO(20,4),CNODE(20,4),QMEAS(20),CMEAS(20,4),VEL(20),
     3  V(20,30)
      COMMON/CONSTI /NOM, PARAM(4,3), DECAY(4)
      NT = NMAX(M)
      IF(QO(M)) 100,300,200
C     MOVE AN ELEMENT INTO UPSTREAM END OF SEGMENT M.
  100 CONTINUE
      DO 110 N=1,NT
      NINV=NT+1-N
      V(M,NINV+1)=V(M,NINV)
      DO 110 NQ=1,NOM
  110 C(M,NINV+1,NQ)= C(M,NINV,NQ)
      NT = NT + 1
      V(M,1) = - QO(M)
      DO 120 NQ=1,NOM
  120 C(M,1,NQ)=CNODE(M,NQ)
      GO TO 300
C     MOVE ELEMENTS OUT OF UPSTREAM END.
  200 CONTINUE
      VOL = 0.0
      DO 210 I=1,NT
      N = I
      VOL = VOL + V(M,N)
      IF(QO(M) .LT. VOL) GO TO 220
  210 CONTINUE
      WRITE(6,215)M,IT
  215 FORMAT(' ALL ELEMENTS USED FOR QO(M) UPSTREAM, SUB. BRANCH, M = ',
     1  I2,'TIME STEP = ',I4)
  220 V(M,N) = VOL - QO(M)
      DO 230 NTEMP = N,NT
      V(M,NTEMP-N+1) = V(M,NTEMP)
      DO 230 NQ=1,NOM
  230 C(M,NTEMP-N+1,NQ) = C(M,NTEMP,NQ)
      NT = NT-N+1
  300 IF(QI(M)) 400,600,500
C     MOVE ELEMENTS OUT OF DOWNSTREAM END OF SEGMENT M.
  400 CONTINUE
      VOL= 0.0
      DO 410 NINV=1,NT
      N= NT+1-NINV
      VOL = VOL + V(M,N)
      IF((-QI(M)) .LT. VOL) GO TO 420
  410 CONTINUE
      WRITE(6,415)M, IT
  415 FORMAT(' ALL ELEMENTS USED IN MAKING UP QI(M) DOWNSTREAM, SUB. BRA
     1NCH.  M = ',I2,' TIME STEP = ',I4)
  420 V(M,N) = VOL + QI(M)
      NT = N
      GO TO 600
C     MOVE AN ELEMENT INTO THE DOWNSTREAM END OF SEGMENT M.
  500 V(M,NT+1)=QI(M)
      MMAXP1 = MMAX1 + 1
      IF(M4 .EQ. 0) M4 = MMAXP1
      DO 510 NQ=1,NOM
      IF(M4 .EQ. MMAXP1 .AND. IFLOW .EQ. 1 .AND. CNODE(MMAXP1,NQ) .NE.
     1  0.0) WRITE(6,520) MAJOR, ICYCLE
  520 FORMAT(' NODE CONCENTRATION AT MARINA ENTRANCE IS NOT ZERO ON FLOO
     1D TIDE, PHASE = ', I3, ', CYCLE = ', I3)
  510 C(M,NT+1,NQ)=CNODE(M4,NQ)
      NT=NT+1
  600 CONTINUE
      NMAX(M)=NT
      IF(M4 .EQ. MMAXP1) M4 = 0
  750 RETURN
      END
```

```
      SUBROUTINE DIFUSE(M)
      COMMON/ /XPRINT(20,30),XE(30),TR(30),EF(30),TRANS(30,4),CP(30)
      COMMON/ALL/MMAX1,IR,MAJOR,ICYCLE,PPT,CPASS(9,4),IFLOW,FIRST
      COMMON/RIV1/ B(20,250),H(20,250),BH(20,250),NMAX(20),XL(28),
     1    C(20,30,4),QI(22),QO(22),CI(22,4),NO(20),NI(20),IT,ITM1,
     2 IDUM,IRNIT,CO(20,4),CNODE(20,4),QMEAS(20),CMEAS(2C,4),VEL(20),
     3  V(20,30)
      COMMON/RIV2/ NADD(5), MINPUT (5), XADD(5), ADD(5), CADD(5,3)
      COMMON/RIV3/ NCSLUG, IHRSLG,MSLUG,NSLUG,XSLUG,NIT,SUMOUT,PERCNT
      COMMON/RIV4/JSTART(3),JEND(3),JM(3),JN(3),XINT(3),JNQ(3),VINT(3),
     1 CINT(3)
      COMMON/CONSTI /NOM, PARAM(4,3), DECAY(4)
      COMMON/D/DIFHI(20),DIFLO(20)
      COMMON/PLTC/XPLOT(20,30), FAPPLT(270,4), CONPLT(270,4, 3),
     1 MPLT(20), IPTST(4),     ENTDIS(270), CONC(270), SUMXL, IPLOT(20),
     2 PLOTIT, STORE, DES(4), YSCALE(3)
      DIMENSION X(30),EFOR(30)
   90 CONTINUE
      NT = NMAX(M)
      IF (NT .EQ. 0) GO TO 500
      NTM1=NT-1
      NT2=NT*2
C-----------------------------------------------------------------------
C
C     COMPUTE LENGTHS OF ELEMENTS (XE) AND POSITION OF MIDPOINTS(X)
C
C-----------------------------------------------------------------------
      DO 100 N=1,NT
      XE(N)=V(M,N)/BH(M,IT   )
  100 IF(XE(N) .EQ. 0.0) XE(N)=XL(M)/10C000.C
      X(1)=.5*XE(1)
      IF(NT .EQ. 1) GO TO 115
      DO 110 N=2,NT
  110 X(N)=.5*(XE(N-1)+XE(N)) + X(N-1)
      IF(NT.GT.10..AND.(XL(M)/NT).LT.(B(M,IT   )*.333)) GO TO 700
      IF((XL(M)/(X(2)-X(1))).GT.NT2) GO TO 300
      IF((XL(M)/(X(NT)-X(NT-1))).GT. NT2) GO TO 400
      IF(NT .GE. 29) GO TO 700
C
  115 CONTINUE
C-----------------------------------------------------------------------
C
C     COMPUTE ADJUSTED MASS TRANSFER COEFFICIENT, EF(NTEMP).
C
C-----------------------------------------------------------------------
C
C
      DO 160 N = 1,NTM1
C     TR IS DISTANCE TRAVELED BY MIDPOINT OF AN ELEMENT DURING ONE TIME STEP.
C     IT IS COMPUTED AS THE ABSOLUTE VALUE OF . . . . (VELOCITY AT UPSTREAM
C     END OF SEGMENT)*(DIST. OF ELEMENT FROM THIS END AS FRACTION OF XL)
C     + (VEL. AT DOWNSTREAM END)*(DIST. OF ELEMENT FROM DOWNSTREAM END AS
C     FRACTION OF SEGMENT LENGTH) . . . .
      TR(N)=ABS(2.0*(QO(M)*X(N) + QI(M)*(XL(M)-X(N)))
     1   /((BH(M,IT) + BH(M,ITM1))*XL(M)))
C
C     THE DIMENSIONLESS MASS TRANSFER COEFFICIENT, EF(N) IS COMPUTED AS
C     FOLLOWS.  THE DIFFUSION COEFFICIENT IS DERIVED FROM ELDER'S FORMULA
C     FOR A WIDE, OPEN-CHANNEL (ELDER,J.W., 'DISPERSION OF MARKED FLUID IN
C     TURBULENT SHEAR FLOW', J. FLUID MECH., VOL. 5, 1959, PP. 544-560).
C
C     EL = 5.9 * WATER DEPTH * SHEAR VELOCITY
C
C     USING THE CHEZY EQUATION, THIS BECOMES...
C     EL = 45.0 * N * D**(5.0/6.0) * U
C
C              N = MANNING FRICTION FACTOR = .030
C              D = WATER DEPTH
C              U = TIDAL VELOCITY
C
C     THE DIMENSIONLESS MASS TRANSFER COEFFICIENT IS.......
C
C     EF(N) = EL*TIME INCREMENT*CHANNEL CROSS-SECTIONAL AREA/
C             (DISTANCE BETWEEN ELEMENTS*ELEMENT VOLUME)
C
C
C
C***********************************************************************
C     COMPUTED EF(N) INCREASED BY FACTOR OF 10.0
      EF(N) = 13.5*H(M,IT)**(5.0/6.0)*TR(N)/((X(N+1) - X(N))*XE(N))
C
C     THE FOLLOWING INSTRUCTION NOTES THAT THE MAXIMUM POSSIBLE MASS
C     EXCHANGE IS THAT WHICH MAKES ADJACENT CONCENTRATIONS EQUAL.......
C     I.E. ... 1/2 THE INITIAL CONCENTRATION DIFFERENCE
      IF( EF(N) .GT. 0.5) EF(N) = 0.5
C     DATA ON EF(N)
```

```
C
C
C
      IF(ICYCLE .GE. 2) GO TO 148
      EFSTOR = EF(N)
      IF(N      .EQ. 1 .AND. DIFLO(M) .EQ. 0) DIFLO(M) = EFSTOR
      IF(EFSTOR .GT. DIFHI(M)) DIFHI(M) = EFSTOR
      IF(EFSTOR .LT. DIFLO(M)) DIFLO(M) = EFSTOR
  148 DO 150 NO=1,NOM
C     TRANS(N     ,NO) IS THE MASS FLUX TO (OR FROM) ELEMENT N+1
C     DURING ONE TIME STEP.
      IF(C(M,N       ,NO) .GE. 1.0E+60    .OR. C(M,N     ,NO) .GE. 1.0E+60
     1  .OR. EF(N     ) .GE. 1.0E+30) GO TO 151
  149 IF(      C(M,N        ,NO) + C(M,N     ,NO)   .LT. 1.0E-60)GO TO 155
      TRANS(N,NO) = EF(N) * (C(M,N+1,NO) - C(M,N,NO))
      GO TO 150
  151 WRITE(6,152) IT,M,N,N,EF(N),C(M,N,NO), C(M,N+1,NO), NO
  152 FORMAT(//,1X,'EXCESSIVE CONCENTRATION OR OVERSIZE DIFFUSION COEFFI
     1CIENT. IT = ',I3,', SEGMENT NO. = ' ,I3,', ELEMENT NO. = ',I3,/,'
     2 EF(',I3,') = ',G12.4,'C(M,N,N0) = ',G12.4,'C(M,N+1,NO) = ',G12.4,
     3', SOLUTION',I3)
      GO TO 149
  155 TRANS(N     ,NO) = 0.0
  150 CONTINUE
  160 CONTINUE
C-----------------------------------------------------------------------
C
C     ADJUST ELEMENT CONCENTRATIONS TO ACCOMPLISH DIFFUSIVE STEP
C     CP(N) IS TEMPORARY STORAGE FOR NEWLY COMPUTED CONCENTRATIONS
C
C-----------------------------------------------------------------------
      DO 240 NO=1,NOM
      DO 190 N=1,NTM1
C
      IF(XE(N+1) - XE(N)) 170,180,180
C     IF ELEMENT N CONTAINS MORE VOLUME THAN DOWNSTREAM ELEMENT, REDUCE THE
C     OUTGOING CONCENTRATION CHANGE OF ELEMENT N BY THE RATIO OF THE
C     VOLUMES.......
  170 CP(N) = C(M,N,NO) + TRANS(N,NO)*XE(N+1)/XE(N)
      GO TO 190
C
C     IF ELEMENT N CONTAINS LESS VOLUME THAN DOWNSTREAM ELEMENT, USE THE
C     FULL CHANGE OF CONCENTRATION IN ELEMENT N .......
  180 CP(N) = C(M,N,NO) + TRANS(N,NO)
  190 CONTINUE
      CP(NT)=C(M,NT,NO)
C
      DO 230 N=2,NT
      IF(XE(N-1) - XE(N))210,220,220
C
C     IF ELEMENT N CONTAINS MORE VOLUME THAN UPSTREAM ELEMENT, REDUCE THE
C     INCOMING CONCENTRATION CHANGE BY THE RATIO OF THE VOLUMES .....
  210 C(M,N,NO)=CP(N)-TRANS(N-1,NO)*XE(N-1)/XE(N)
      GO TO 230
C
C     IF ELEMENT N CONTAINS LESS VOLUME THAN THE UPSTREAM ELEMENT,
C     THEN USE FULL CHANGE OF CONCENTRATION .......
  220 C(M,N,NO)=CP(N)-TRANS(N-1,NO)
  230 CONTINUE
      C(M,1,NO) = CP(1)
  240 CONTINUE
      IF(IDUM .NE. IRNIT) GO TO 275
      DO 260 N=1,NT
      XPLOT(M,N) = X(N)
  260 XPRINT(M,N)=X(N)
  275 CONTINUE
C-----------------------------------------------------------------------
C
C     IDENTIFY ELEMENTS FOR INPUT OF MASS FROM CONTINUOUS SOURCES
C
C-----------------------------------------------------------------------
      DO 280 I=1,5
      IF(M .NE. MINPUT(I)) GO TO 280
      DO 277 N=1,NT
      NTEMP = N
      IF(X(N) .GE. XADD(I)) GO TO 278
  277 CONTINUE
  278 NADD(I) = NTEMP
      IF(NTEMP .EQ. 1) GO TO 280
      IF((XADD(I) -X(NTEMP-1)) .LT. (X(NTEMP)-XADD(I)))NADD(I)=NTEMP-1
  280 CONTINUE
C-----------------------------------------------------------------------
C
C     IDENTIFY ELEMENTS FOR SHORT CONTINUOUS INPUTS
C
C-----------------------------------------------------------------------
```

```
      DO 291 I=1,[illegible]
      IF(JSTART(I) .EQ. 0 .OR. ICYCLE .LT. JSTART(I) .OR.
     1 ICYCLE .GT. JEND(I)) GO TO 291
      IF(M .NE. JN(I)) GO TO 291
      DO 283 N=1,NT
      NTEMP = N
      IF(X(N) - .5*XE(N) .LE. XINT(I) .AND. X(N) + .5*XE(N) .GT.
     1 XINT(I)) GO TO 284
  283 CONTINUE
  284 JN(I)=NTEMP
  291 CONTINUE
C-----------------------------------------------------------------------
C
C       IDENTIFY ELEMENT FOR SLUG INJECTION
C
C-----------------------------------------------------------------------
      IF(NCSLUG .NE. ICYCLE .OR. IT/NIT .NE. IHRSLG .OR.
     1 IT/NIT*NIT .NE. IT) GO TO 299
      IF (M .NE. MSLUG) GO TO 299
      DO 293 N = 1,NT
      NTEMP = N
      IF(X(N) - .5*XE(N) .LT. XSLUG .AND. X(N) + .5*XE(N) .GT. XSLUG)
     1 GO TO 294
  293 CONTINUE
  294 NSLUG = NTEMP
  299 RETURN
C-----------------------------------------------------------------------
C
C       RETURN TO MAIN PROGRAM.  SUBSEQUENT STEPS ACCOMPLISH REDUCTION
C       OF NUMBER OF ELEMENTS IN SEGMENT WHENEVER TWO SMALL ELEMENTS
C       ACCUMULATE AT EITHER END OF SEGMENT, OR WHEN NUMBER OF ELEMENTS
C       IN SEGMENT WILL EXCEED ALLOWABLE STORAGE.
C
C-----------------------------------------------------------------------
  300 VT=V(M,1) + V(M,2)
      DO 305 NQ=1,NOM
  305 C(M,1,NQ) = (C(M,1,NQ) * V(M,1) + C(M,2,NQ) * V(M,2))/VT
      V(M,1)= VT
      DO 310 N=3,NT
      V(M,N-1)=V(M,N)
      DO 310 NQ=1,NOM
  310 C(M,N-1,NQ)=C(M,N,NQ)
      GO TO 500
  400 VT=V(M,NTM1) + V(M,NT)
      DO 410 NQ=1,NOM
  410 C(M,NTM1,NQ)=(V(M,NT)*C(M,NT,NQ)+V(M,NTM1)*C(M,NTM1,NQ))/VT
      V(M,NTM1)=VT
  500 NMAX(M) = NT-1
      IF(NT .LE. 1) GO TO 520
      GO TO 90
  520 WRITE(6,530)M
  530 FORMAT(/,' ELEMENT REDUCTION STOP, M = ',I3)
      STOP
C
C       SUBROUTINE FOR COMBINING ELEMENTS, CALLED WHEN AVG. ELEMENT LENGTH
C       IS LESS THAN 1/3 OF SEGMENT WIDTH.
C
  700 CONTINUE
      NWANT = 1
      XEMIN=XE(1)
      DO 720 N=2,NT
      IF(XE(N) .LT. XEMIN) GO TO 710
      GO TO 720
  710 NWANT=N
      XEMIN=XE(N)
  720 CONTINUE
      IF(NWANT .EQ. 1) GO TO 300
      IF(NWANT .EQ. NT) GO TO 400
      IF(XE(NWANT+1)-XE(NWANT-1))760,760,740
  740 LL=NWANT-1
      LU=NWANT
      GO TO 770
  760 LL=NWANT
      LU=NWANT+1
  770 CONTINUE
      VT=V(M,LL)+V(M,LU)
      DO 775 NQ=1,NOM
  775 C(M,LL,NQ)=(V(M,LL)*C(M,LL,NQ)+V(M,LU)*C(M,LU,NQ))/VT
      V(M,LL)=VT
      DO 780 N=LU,NTM1
      V(M,N)=V(M,N+1)
      DO 780 NQ=1,NOM
  780 C(M,N,NQ) = C(M,N+1,NQ)
      GO TO 500
      END
```

```
      SUBROUTINE XPRNT(M1,M2,M3)
      DIMENSION NT(3)
      LOGICAL P(3)
      COMMON/DIV1/ D(20,250),H(20,250),HH(20,250),NMAX(20),XL(20),
     1     C(20,30,4),QI(22),QO(22),CI(22,4),NC(20),NI(20),IT,ITM,
     2 IDUM,IPNIT,CC(20,4),CNCDE(20,4),QMEAS(20),CMEAS(20,4),VEL(20),
     3  V(20,30)
      COMMON/ /XPRINT(20,30),XE(30),TR(30),EF(30),TRANS(30,4),CP(30)
      DO 5 I = 1,3
    5 P(I) = .TRUE.
      NT(1)= NMAX(M1)
      NT(2) = 0
      NT(3) = 0
      IF(M2 .NE. 0) NT(2) = NMAX(M2)
      IF(M3 .NE. 0) NT(3) = NMAX(M3)
  140 IF(M2.EQ.0 .AND. M3.EQ.0) GO TO 111
      IF(M3 .EQ. 0) GO TO 112
  110 WRITE(6,10)M3,M1,M2
   10 FORMAT(/,3(17X,'SEGMENT',I3,17X),/,7X,2('DIST.',4X,'CONC.(NQ) - -
     1- - - - -',15X),'DIST.',4X,'CONC.(NQ) - - - - - -',/)
      GO TO 14
  111 IF(M2.EQ.0) GO TO 151
  112 WRITE(6,11) M1,M2
   11 FORMAT(/,44X,2(17X,'SEGMENT',I3,17X),/,56X,1('DIST.',4X,'CONC.(NQ)
     1- - - - -',15X),'DIST.',4X,'CONC.(NQ) - - - - - -',/)
      GO TO 14
  151 WRITE(6,12)M1
   12 FORMAT(/,63X,'SEGMENT',I3,/,52X,'DIST.     CONC.(NQ) - - - - - -',
     1/)
   14 N = 0
   15 N=N+1
      DO 20 I=1,3
   20 IF(N .GT. NT(I)) P(I)= .FALSE.
      IF (N .GE. 31) STOP
      IF(.NOT.P(1).AND. .NOT. P(2).AND..NOT.P(3)) RETURN
      IF(P(3)) GO TO 210
      IF(P(1)) GO TO 220
      GO TO 230
  210 IF(P(1)) GO TO 240
      IF(P(2)) GO TO 250
      WRITE(6,211) XPRINT(M3,N),(C(M3,N,NQ),NQ=1,3  )
      GO TO 15
  220 IF(P(2)) GO TO 260
      WRITE(6,221) XPRINT(M1,N),(C(M1,N,NQ),NQ=1,3  )
      GO TO 15
  230 WRITE(6,231) XPRINT(M2,N),(C(M2,N,NQ),NQ=1,3  )
      GO TO 15
  240 IF(P(2)) GO TO 270
      WRITE(6,241) XPRINT(M3,N),(C(M3,N,NQ),NQ=1,3  ), XPRINT(M1,N),
     1    (C(M1,N,NQ),NQ=1,3  )
      GO TO 15
  250 WRITE(6,251) XPRINT(M3,N),(C(M3,N,NQ),NQ=1,3  ),XPRINT(M2,N),
     1    (C(M2,N,NQ),NQ=1,3  )
      GO TO 15
  260 WRITE(6,261) XPRINT(M1,N),(C(M1,N,NQ),NQ=1,3  ),XPRINT(M2,N),
     1    (C(M2,N,NQ),NQ=1,3  )
      GO TO 15
  270 WRITE(6,271) XPRINT(M3,N),(C(M3,N,NQ),NQ=1,3  ),XPRINT(M1,N),
     1    (C(M1,N,NQ),NQ=1,3  ),XPRINT(M2,N),(C(M2,N,NQ),NQ=1,3  )
      GO TO 15
  211 FORMAT(F7.0,1X,3G12.4)
  221 FORMAT(44X,F7.0,1X,3G12.4)
  231 FORMAT(88X,F7.0,1X,3G12.4)
  241 FORMAT(F7.0,1X,3G12.4,F7.0,1X,3G12.4)
  251 FORMAT(F7.0,1X,3G12.4,44X,F7.0,1X,3G12.4)
  261 FORMAT(44X,F7.0,1X,3G12.4, F7.0,1X,3G12.4)
  271 FORMAT(3(F7.0,1X,3G12.4))
      END
```

```
PROGRAM TO COMPUTE POLLUTANT TRANSPORT IN ESTUARIES  WHICH APE APPROXIMATED BY ONE-DIMENSIONAL SEGMENTS.

LOCATION OF THIS RUN IS     MARINA DEL REY, CALIFCRNIA.  TIDAL DATA INTERPOLATED FROM SURVEY DATA.

   PARAMETER              DECAY RATE CONSTANT

   SOLUTION 1                0.0

GIVEN DISCHARGE INTO UPSTREAM END CF SEGMENTS, CU.FT./TIME STEP

     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.

CONTINUOUS CONCENTRATION INPUT TO THE FOLLOWING PCINTS
  SEGMENT       LOCATION      DISCHARGE VOLUME/TIME STEP   CONCENTRATIONS(NQ) - - -


NONE

 SLUG CONCENTRATION INPUT

 NONE


CONTINUOUS CONCENTRATION INPUTS SUSTAINED FOR ONE OR MORE TIDAL CYCLES . . . .

THERE IS A CONTINUOUS INPUT OF SOLUTION 1  .      500. FT. DOWNSTREAM OF THE LANDWARD END OF SEGMENT   12.
BEGINNING IN TIDAL CYCLE    1 ENDING IN CYCLE    1 .  THE VOLUME PER HOUR IS       800. CU.FT.
OF CONCENTRATION     5000.00000PPM.

DECAY CONSTANTS APE

1.000000

NUMBER OF TIME STEPS PER HOUR IS 10


BRANCH  1. LENGTH   3350.00. LANDWARD BRANCHES  0.  0.  0.  SEAWARD BRANCH  4. NO. OF ELEMENTS =  9

    DEPTH AND WIDTH OF THIS BRANCH AT EACH HOUR ARE
  10.30     600.0        10.88     600.0        11.70     600.0        12.51     600.0        12.55     600.0        13.43     600.0
  13.40     600.0        13.14     600.0        12.48     600.0        12.51     600.0        12.45     600.0        12.73     600.0
  13.29     600.0        13.96     600.0        14.70     600.0        15.25     600.0        15.45     600.0        15.27     600.0
  14.67     600.0        13.77     600.0        12.70     600.0        11.54     600.0        10.70     600.0        10.24     600.0
  10.15     600.0
```

```
BRANCH  2. LENGTH   3150.00. LANDWARD BRANCHES  0.  0.  0.  SEAWARD BRANCH  4. NO. OF ELEMENTS =  6

   DEPTH AND WIDTH OF THIS BRANCH AT EACH HOUR ARE
  10.10     600.0        10.13    600.0       11.57     600.0       12.41    600.0       12.43    600.0       13.39    600.0
  13.35     600.0        13.08    600.0       12.71     600.0       12.41    600.0       12.34    600.0       12.64    600.0
  13.24     600.0        13.96    600.0       14.75     600.0       15.33    600.0       15.55    600.0       15.36    600.0
  14.72     600.0        13.76    600.0       12.61     600.0       11.39    600.0       10.51    600.0       10.03    600.0
   9.94     600.0

BRANCH  3. LENGTH   1650.00. LANDWARD BRANCHES  0.  0.  0.  SEAWARD BRANCH  4. NO. OF ELEMENTS =  3

   DEPTH AND WIDTH OF THIS BRANCH AT EACH HOUR ARE
  10.36     450.0        10.84    450.0       11.63     450.0       12.44    450.0       12.48    450.0       13.40    450.0
  13.37     450.0        13.09    450.0       12.73     450.0       12.44    450.0       12.38    450.0       12.67    450.0
  13.24     450.0        13.95    450.0       14.72     450.0       15.30    450.0       15.52    450.0       15.33    450.0
  14.69     450.0        13.75    450.0       12.64     450.0       11.46    450.0       10.63    450.0       10.30    450.0
  10.23     450.0

BRANCH  4. LENGTH   1000.00. LANDWARD BRANCHES  1.  2.  3.  SEAWARD BRANCH  7. NO. OF ELEMENTS =  3

   DEPTH AND WIDTH OF THIS BRANCH AT EACH HOUR ARE
   9.94    1050.0        10.57   1050.0       11.45    1050.0       12.31   1050.0       12.36   1050.0       13.27   1050.0
  13.24    1050.0        12.97   1050.0       12.60    1050.0       12.31   1050.0       12.24   1050.0       12.54   1050.0
  13.12    1050.0        13.82   1050.0       14.59    1050.0       15.17   1050.0       15.38   1050.0       15.19   1050.0
  14.55    1050.0        13.63   1050.0       12.51    1050.0       11.28   1050.0       10.37   1050.0        9.87   1050.0
   9.77    1050.0

BRANCH  5. LENGTH   3050.00. LANDWARD BRANCHES  0.  0.  0.  SEAWARD BRANCH  7. NO. OF ELEMENTS =  6

   DEPTH AND WIDTH OF THIS BRANCH AT EACH HOUR ARE
  10.89     600.0        10.75    600.0       11.99     600.0       12.65    600.0       12.63    600.0       13.48    600.0
  13.45     600.0        13.21    600.0       12.90     600.0       12.65    600.0       12.60    600.0       12.84    600.0
  13.35     600.0        13.99    600.0       14.69     600.0       15.23    600.0       15.43    600.0       15.25    600.0
  14.67     600.0        13.80    600.0       12.82     600.0       11.85    600.0       11.18    600.0       10.82    600.0
  10.75     600.0

BRANCH  6. LENGTH   2350.00. LANDWARD BRANCHES  0.  0.  0.  SEAWARD BRANCH  7. NO. OF ELEMENTS =  5

   DEPTH AND WIDTH OF THIS BRANCH AT EACH HOUR ARE
  10.93     600.0        11.34    600.0       11.96     600.0       12.60    600.0       12.63    600.0       13.44    600.0
  13.42     600.0        13.16    600.0       12.84     600.0       12.59    600.0       12.54    600.0       12.78    600.0
  13.30     600.0        13.96    600.0       14.69     600.0       15.24    600.0       15.45    600.0       15.27    600.0
  14.66     600.0        13.77    600.0       12.76     600.0       11.83    600.0       11.20    600.0       10.98    600.0
  10.91     600.0
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```
CONCENTRATIONS IN THE RIVER, AT THE END OF PHASE  1 OF CYCLE   1 IN PARTS PER MILLION

              SEGMENT  2                                SEGMENT  1                               SEGMENT  3
     DIST.    CONC.(NO) - - - - - - -           DIST.    CONC.(NO) - - - - - - -           DIST.    CONC.(NO) - - - - - -

  195.   0.0        0.0        0.0         158.   0.0        0.0        0.0          210.   0.0        0.0        0.0
  585.   0.0        0.0        0.0         475.   0.0        0.0        0.0          630.   0.0        0.0        0.0
  974.   0.0        0.0        0.0         791.   0.0        0.0        0.0         1050.   0.0        0.0        0.0
 1364.   0.0        0.0        0.0        1108.   0.0        0.0        0.0         1415.   0.0        0.0        0.0
 1754.   0.0        0.0        0.0        1424.   0.0        0.0        0.0         1610.   0.0        0.0        0.0
 2144.   0.0        0.0        0.0        1741.   0.0        0.0        0.0
 2496.   0.0        0.0        0.0        2057.   0.0        0.0        0.0
 2814.   0.0        0.0        0.0        2374.   0.0        0.0        0.0
 3062.   0.0        0.0        0.0        2664.   0.0        0.0        0.0
                                          2928.   0.0        0.0        0.0
                                          3194.   0.0        0.0        0.0
                                          3339.   0.0        0.0        0.0

              SEGMENT  5                                SEGMENT  4                               SEGMENT  6
     DIST.    CONC.(NO) - - - - - - -           DIST.    CONC.(NO) - - - - - - -           DIST.    CONC.(NO) - - - - - -

  203.   0.0        0.0        0.0          52.   0.0        0.0        0.0          189.   0.0        0.0        0.0
  608.   0.0        0.0        0.0         145.   0.0        0.0        0.0          567.   0.0        0.0        0.0
 1013.   0.0        0.0        0.0         230.   0.0        0.0        0.0          945.   0.0        0.0        0.0
 1419.   0.0        0.0        0.0         306.   0.0        0.0        0.0         1323.   0.0        0.0        0.0
 1824.   0.0        0.0        0.0         374.   0.0        0.0        0.0         1701.   0.0        0.0        0.0
 2230.   0.0        0.0        0.0         441.   0.0        0.0        0.0         2047.   0.0        0.0        0.0
 2602.   0.0        0.0        0.0         571.   0.0        0.0        0.0         2277.    1.883     0.0        0.0
 2911.    1.261     0.0        0.0         741.    1.643     0.0        0.0
                                           889.    2.357     0.0        0.0
                                           951.    3.320     0.0        0.0

              SEGMENT  8                                SEGMENT  7                               SEGMENT  9
     DIST.    CONC.(NO) - - - - - - -           DIST.    CONC.(NO) - - - - - - -           DIST.    CONC.(NO) - - - - - -

  189.   0.0        0.0        0.0         106.    3.684     0.0        0.0          174.   0.0        0.0        0.0
  567.   0.0        0.0        0.0         259.    3.772     0.0        0.0          521.   0.0        0.0        0.0
  945.   0.0        0.0        0.0         391.    3.787     0.0        0.0          868.   0.0        0.0        0.0
 1323.   0.0        0.0        0.0         529.    3.726     0.0        0.0         1215.   0.0        0.0        0.0
 1701.   0.0        0.0        0.0         608.    3.634     0.0        0.0         1563.   0.0        0.0        0.0
 2079.   0.0        0.0        0.0         687.    3.549     0.0        0.0         1876.   0.4843     0.0        0.0
 2427.   0.9011     0.0        0.0         766.    3.481     0.0        0.0         2159.    3.644     0.0        0.0
 2743.    3.682     0.0        0.0         818.    3.449     0.0        0.0         2326.    3.384     0.0        0.0
                                           871.    3.393     0.0        0.0
                                           924.    3.387     0.0        0.0

              SEGMENT 11                                SEGMENT 10                               SEGMENT  0
     DIST.    CONC.(NO) - - - - - - -           DIST.    CONC.(NO) - - - - - - -           DIST.    CONC.(NO) - - - - - -

  177.   0.0        0.0        0.0          55.    3.391     0.0        0.0
  532.   0.0        0.0        0.0         167.    3.436     0.0        0.0
  887.   0.0        0.0        0.0         295.    3.578     0.0        0.0
 1241.   0.0        0.0        0.0         430.    4.025     0.0        0.0
 1596.   0.0        0.0        0.0         557.    4.290     0.0        0.0
 1916.    3.611     0.0        0.0         652.    5.075     0.0        0.0
 2205.    3.849     0.0        0.0         747.    5.423     0.0        0.0
 2375.    5.152     0.0        0.0         842.    5.518     0.0        0.0
                                           905.    5.018     0.0        0.0
                                           968.    5.052     0.0        0.0
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                          SEGMENT 12
                 DIST.    CONC.(NO) - - - - - -

          106.    4.302         0.0          0.0
          299.    3.816         0.0          0.0
          463.    4.235         0.0          0.0
          578.    1.972         0.0          0.0
          655.   0.4827         0.0          0.0
          731.   0.1213         0.0          0.0
          846.   0.7846E-02     0.0          0.0
          961.   0.3002E-03     0.0          0.0
         1038.   0.3753E-04     0.0          0.0
         1114.   0.1408E-05     0.0          0.0
                          SEGMENT 13
                 DIST.    CONC.(NO) - - - - - -

          222.   0.0            0.0          0.0
          802.   0.0            0.0          0.0
         1516.   0.0            0.0          0.0
         2150.   0.0            0.0          0.0
         2707.   0.0            0.0          0.0
         3220.   0.0            0.0          0.0
         3696.   0.0            0.0          0.0
         4167.   0.0            0.0          0.0
         4619.   0.0            0.0          0.0
         5021.   0.0            0.0          0.0


 BRANCH     INFLOW      OUTFLOW    TRAVEL        BRANCH     INFLOW      OUTFLOW    TRAVEL      IT =   70

   1        -6020.          0.      -0.37           2        -5660.          0.      -0.35
   3        -2224.          0.      -0.18           4       -17052.     -13903.      -1.11
   5        -3658.          0.      -0.23           6        -2818.          0.      -0.17
   7       -26519.     -23528.      -1.52           8        -5211.          0.      -0.32
   9        -3167.          0.      -0.26          10       -38045.     -34896.      -1.91
  11        -4313.          0.      -0.27          12       -45978.     -42357.      -2.32
  13       -62350.     -45978.      -2.44
HIGH AND LOW VALUES OF THE ADJUSTED DIMENSIONLESS DIFFUSION COEFFICIENT FOR EACH SEGMENT, IN PAIRS . . .
0.24357E-01, 0.10291E-03;      0.16079E-01, 0.11094E-03;      0.66054E-02, 0.10080E-03;      0.50000    , 0.39159E-02;
0.12166E-01, 0.74204E-04;      0.10757E-01, 0.72860E-04;      0.50000    , 0.60418E-02;      0.13645E-01, 0.12300E-03;
0.14606E-01, 0.10413E-03;      0.50000    , 0.15222E-01;      0.14702E-01, 0.10203E-03;      0.50000    , 0.76539E-02;
0.65452E-01, 0.90309E-03;


 BRANCH     INFLOW      OUTFLOW    TRAVEL        BRANCH     INFLOW      OUTFLOW    TRAVEL      IT =   80

   1       -52252.          0.      -3.31           2       -52910.          0.      -3.37
   3       -20786.          0.      -1.76           4      -154296.    -125948.     -10.29
   5       -45750.          0.      -2.89           6       -36654.          0.      -2.32
   7      -264629.    -236700.     -15.48           8       -43500.          0.      -2.73
   9       -29604.          0.      -2.52          10      -368183.    -337733.     -18.81
  11       -40313.          0.      -2.57          12      -443512.    -408495.     -22.78
  13      -601848.    -443512.     -23.92
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CONCENTRATIONS IN THE RIVER, AT THE END OF PHASE  4 OF CYCLE   3 IN PARTS PER MILLION

             SEGMENT  2                                          SEGMENT  1                                     SEGMENT  3
   DIST.     CONC.(NO) - - - - - - -                  DIST.     CONC.(NO) - - - - - - -                 DIST.     CONC.(NO) - - - - - -

  262.   0.0        0.0        0.0           209.   0.0        0.0        0.0              275.   0.0        0.0        0.0
  787.   0.0        0.0        0.0           628.   0.0        0.0        0.0              825.   0.0        0.0        0.0
 1312.   0.0        0.0        0.0          1047.   0.0        0.0        0.0             1375.   0.0        0.0        0.0
 1837.   0.0        0.0        0.0          1466.   0.0        0.0        0.0
 2362.   0.0        0.0        0.0          1884.   0.0        0.0        0.0
 2887.   0.0        0.0        0.0          2303.   0.0        0.0        0.0
                                            2722.   0.0        0.0        0.0
                                            3141.   0.0        0.0        0.0

             SEGMENT  5                                          SEGMENT  4                                     SEGMENT  6
   DIST.     CONC.(NO) - - - - - - -                  DIST.     CONC.(NO) - - - - - - -                 DIST.     CONC.(NO) - - - - - -

  254.   0.0        0.0        0.0            40.   0.7632     0.0        0.0              235.   0.0        0.0        0.0
  762.   0.0        0.0        0.0           122.   0.7862     0.0        0.0              705.   0.0        0.0        0.0
 1271.   0.0        0.0        0.0           262.   0.8389     0.0        0.0             1175.   0.0        0.0        0.0
 1779.   0.0        0.0        0.0           418.    1.013     0.0        0.0             1645.   0.0        0.0        0.0
 2287.   0.0        0.0        0.0           514.    1.148     0.0        0.0             2115.   0.0        0.0        0.0
 2796.   0.0        0.0        0.0           590.    1.233     0.0        0.0
                                             682.    1.349     0.0        0.0
                                             790.    1.497     0.0        0.0
                                             897.    1.634     0.0        0.0
                                             975.    1.731     0.0        0.0

             SEGMENT  8                                          SEGMENT  7                                     SEGMENT  9
   DIST.     CONC.(NO) - - - - - - -                  DIST.     CONC.(NO) - - - - - - -                 DIST.     CONC.(NO) - - - - - -

  242.   0.0        0.0        0.0            17.    2.373     0.0        0.0              235.   0.0        0.0        0.0
  725.   0.0        0.0        0.0            90.    2.424     0.0        0.0              705.   0.0        0.0        0.0
 1208.   0.0        0.0        0.0           204.    2.528     0.0        0.0             1175.   0.0        0.0        0.0
 1692.   0.0        0.0        0.0           307.    2.655     0.0        0.0             1645.   0.0        0.0        0.0
 2175.   0.0        0.0        0.0           433.    2.775     0.0        0.0             2115.   0.0        0.0        0.0
 2658.   0.0        0.0        0.0           543.    3.138     0.0        0.0
                                             598.    3.206     0.0        0.0
                                             680.    3.315     0.0        0.0
                                             790.    3.440     0.0        0.0
                                             897.    3.530     0.0        0.0

             SEGMENT 11                                          SEGMENT 10                                     SEGMENT  0
   DIST.     CONC.(NO) - - - - - - -                  DIST.     CONC.(NO) - - - - - - -                 DIST.     CONC.(NO) - - - - - -

  240.   0.0        0.0        0.0           106.    4.219     0.0        0.0
  720.   0.0        0.0        0.0           267.    4.420     0.0        0.0
 1200.   0.0        0.0        0.0           356.    4.549     0.0        0.0
 1680.   0.0        0.0        0.0           443.    4.649     0.0        0.0
 2160.   0.0        0.0        0.0           527.    4.826     0.0        0.0
                                             594.    4.921     0.0        0.0
                                             660.    5.017     0.0        0.0
                                             760.    5.152     0.0        0.0
                                             893.    5.269     0.0        0.0
                                             980.    5.336     0.0        0.0

                                                      SEGMENT 12
                                               DIST.   CONC.(NO) - - - - - -

                                              65.    5.723     0.0        0.0
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     175.      5.976        0.0          0.0
     331.      5.991        0.0          0.0
     529.      6.185        0.0          0.0
     655.      6.402        0.0          0.0
     738.      6.477        0.0          0.0
     820.      6.556        0.0          0.0
     907.      6.630        0.0          0.0
    1025.      6.723        0.0          0.0
    1135.      6.793        0.0          0.0
                        SEGMENT 13
            DIST.     CONC.(NO) - - - - - -

      16.      6.975        0.0          0.0
     217.      7.066        0.0          0.0
     592.      7.247        0.0          0.0
     957.      7.288        0.0          0.0
    1346.      7.206        0.0          0.0
    1745.      7.002        0.0          0.0
    2156.      6.694        0.0          0.0
    2555.      6.291        0.0          0.0
    3076.      5.741        0.0          0.0
    3609.      4.766        0.0          0.0
    4051.      4.274        0.0          0.0
    4502.      3.710        0.0          0.0
    4959.      3.235        0.0          0.0

AVERAGE CONCENTRATION OF PARAM(1) IN FLOW INTO OCEAN, EACH HOUR
   0.3637E-04   0.8529E-03   0.1360E-01   0.1272      0.6624      1.693      2.464      2.737

PERCENTAGE OF SLUG INPUT FLUSHED OUT SO FAR IS   21.96    . TOTAL INPUT SO FAR IS   1000.    CU.FT.
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