COASTAL MARINA WATER QUALITY ASSESSMENT USING TIDAL PRISM ANALYSIS USER'S MANUAL

Prepared for:

U.S. Environmental Protection Agency
Region IV
Atlanta, Georgia

Prepared by:

Tetra Tech, Inc.
Fairfax, Virginia

EPA Contract #68-C9-0013
Work Assignment No. 1-62

February 28, 1992

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SUMMARY

Tetra Tech's *Marine Water Quality Models* report (1992) addressed the impacts of coastal marinas on water quality. Specifically, this report dealt with the selection and use of the best available computer models for analyzing the impact of a marina on water quality. Initially, all water quality models applicable to marinas were surveyed and divided into three categories: simple, mid-range, and complex. The impact assessment methods presented in Chapter 4 of the *Coastal Marina Assessment Handbook* (USEPA, 1985) was selected as the method of choice in the simple model category.

This document is the user's manual for a computer program based on the Tidal Prism Analysis (TPA) procedures for evaluation of coastal marina impact on water quality, presented in Chapter 4 of the *Coastal Marina Assessment Handbook* (USEPA, 1985). The purpose of this user's manual is to describe the features and the operation of the Tidal Prism Analysis computer program. This program is designed to perform simple water quality calculations including flushing time, pollutant concentration due to accidental spill, steady-state concentration of conservative and nonconservative pollutants, and dissolved oxygen levels. This manual includes descriptions of each method, equations used, sample input and output, and a program listing. Guidance is also provided for obtaining or estimating the input data and the decay rates.

Appendix A contains a microcomputer version of the NCDEM DO model and a user's guide (NCDEM, 1990). This version of the model assumes that the marina to be evaluated can be approximated by two segments. This program calculates the steady-state dissolved oxygen concentration inside the marina and the inlet channel. Appendix A describes input requirements to run the NCDEM DO model. In addition, it contains a listing of the program, as well as several input and output examples.

1. INTRODUCTION

The impact assessment methods presented in Chapter 4 of the *Coastal Marina Assessment Handbook* (USEPA, 1985) are appropriate screening tools. The methods presented in this user's manual, particularly some of the mathematical equations, are simplifications of more sophisticated techniques. Although simplified, however, these techniques as presented can provide reasonable approximations for the purpose of screening potential impact problems when site-specific data are not available.

The methods listed here include desktop screening methodologies that calculate seasonal or annual mean pollutant concentrations based on steady-state conditions and simplified flushing time estimates. These procedures are designed to examine and isolate water quality problems for more detailed analyses. The Tidal Prism Analysis is also used to highlight important data gaps in the early stage of a marina water quality assessment study.

The advantages of the Tidal Prism Analysis calculations are their comparatively low cost and ease of application. The disadvantages lie in their steady-state or tidally averaged temporal scale. When hydrodynamics and pollutant inputs vary rapidly, steady-state models are difficult to calibrate; consequently, these models are less satisfactory when waste load, river inflow, or tidal range vary appreciably with a period close to the flushing time of the water body.

2. GENERAL DESCRIPTION

The Tidal Prism Analysis, as presented, can provide reasonable approximations for screening potential impact problems when site-specific data are not available. This method is capable of addressing all marina water quality issues of concern (e.g., dissolved oxygen and fecal coliform). The primary strengths and advantages of the EPA screening procedures are as follows:

1. Excellent user documentation and guidance.
2. Relatively simple procedures with minimal data requirements that can be satisfied from existing and/or historic data when site-specific data are lacking.

Some of the equations of the Tidal Prism Analysis involve a large number of terms, and entering those parameters into a computer program is much more efficient and less likely to result in error than using a desktop calculator. This user's manual describes the PC version of the Tidal Prism Analysis methods.

Section 3 of this manual discusses the theoretical background for the Tidal Prism Analysis. In addition, Section 3 discusses the equations used to estimate the flushing characteristics of a coastal marina, pollutant concentrations for different time scales (accidental spill versus continuous discharge of pollutant), pollutant concentrations for different pollutant types (conservative versus nonconservative pollutants), and dissolved oxygen levels.

Section 4 presents several Tidal Prism Analysis example applications and provides the range and typical values of reaction rates used in this method. For each example, a table listing all the required input data is provided.

3. DETAILED DESCRIPTION

In general, data are required initially to define the marina system being modeled. Historical and other data sources should always be surveyed to obtain the required data for Tidal Prism Analysis application. The data required at the screening stage include system geometry, bathymetry, and tidal range. These input data are used to evaluate the flushing characteristics and to estimate typical dissolved oxygen level and fecal coliform concentration at a coastal marina site. Initial Tidal Prism Analysis calculations should be carried out to obtain an overall view of water quality conditions and to identify any potential water quality problems.

A sensitivity analysis is also recommended when the simple model is used for a coastal marina application using historic or estimated conditions. In this case, the ranking (most to least effect on model results) can be used to determine which model coefficients should be measured and which model parameters can be estimated. For example, if the model is sensitive to sediment oxygen demand (SOD) rates, then SOD should be measured rather than estimated. On the other hand, if other parameters such as boat discharges and boat activities have little influence, then very little effort should be expended to estimate the exact values of such parameters.

3.1 Flushing Characteristics

Flushing and circulation are important physical characteristics of a marina site that should be considered in marina design. Methods such as the Tidal Prism Analysis can be used to provide preliminary estimates of expected flushing capability. This method is intended for use as a screening tool during the planning stages of a project. It should be recognized that more rigorous tools are available to estimate pollutant concentration fields.

The method chosen to estimate expected flushing from a marina site depends on the hydrographic characteristics of the site. The following parameters are required to estimate flushing characteristics for a semi-enclosed marina:

- Average marina depth at low tide and high tide;
- Volume of nontidal freshwater inflow into the marina;
- Surface area of the marina; and
- Percentage of discharged water returning to the basin on the following tidal cycle.

Flushing time for a marina within a semi-enclosed area can be estimated using simplified dilution calculations. For semi-enclosed marinas the flushing time can be approximated by the following equation:

$$T_F = \frac{[T_C \ x \ LOG(D)]}{LOG\left(\frac{(A \ x \ L)+(b \ x \ A \ x \ R)-(I \ x \ T_C)}{(A \ x \ H)}\right)} \quad (1)$$

If nontidal freshwater inflow from runoff or stream discharge into the marina basin can be ignored and the marina has relatively vertical sides, equation 1 becomes:

$$T_F = \frac{[T_C \ x \ LOG(D)]}{LOG\left(\frac{(A \ x \ L)+(b \ x \ A \ x \ R)}{(A \ x \ H)}\right)} \quad (2)$$

and for marinas with nonvertical sides, equation 2 becomes:

$$T_F = \frac{[T_C \ x \ LOG(D)]}{LOG\left(\frac{V_L+b \ x \ V_P}{V_H}\right)} \quad (3)$$

where:

T_F	=	Flushing time (hours)
T_C	=	Tidal cycle (hours)
A	=	Surface area of marina (m^2)
D	=	Desired dilution factor
R	=	Range of tide (m)
b	=	Return flow factor (dimensionless)
I	=	Nontidal freshwater inflow (m^3/hour)
L	=	Average depth at low tide (m)
H	=	Average depth at high tide (m)
V_L	=	Volume of marina at low tide (m^3)
V_H	=	Volume of marina at high tide (m^3)
V_P	=	Volume of marina tidal prism (V_H - V_L)

3.2 Accidental Spill

To assess the water quality impacts of marina-derived pollutants on the environment using the methods discussed in this manual, certain pollutant loading values must be available for use. If actual values for various loadings are not available, estimations can be made using methods described in the *Coastal Marina Assessment Handbook* (USEPA, 1985).

For a slug addition of pollutant in a semi-enclosed marina basin, estimates of pollutant concentrations can be made by using an expression such as the following (USEPA, 1985):

$$C_t = \left[\frac{A \ x \ L + b \ x \ A \ x \ R}{A \ x \ H}\right]^N x \left[\frac{M}{F_{11} \ x \ V_L}\right] e^{-kt} + C_A \ x \ e^{-kt} \qquad (4)$$

where:

C_t	=	Concentration of pollutant at time t (mg/L)
C_A	=	Ambient concentration of pollutant prior to addition of discharge (mg/L)
M	=	Mass of pollutant discharged into basin (mg)
k	=	Decay rate for nonconservative pollutants (day^{-1})
t	=	Time (days)
N	=	Number of tidal cycles ($24t/T_c$)
F_{11}	=	1000 (converts units to mg/L)

All other parameters are as defined previously in Equations 1 through 3.

3.3 Continuous Addition

3.3.1 Conservative Pollutant

For a continuous discharge of pollutant into a marina basin, an estimate of long-term concentrations (steady-state conditions) may be obtained by:

$$C = \frac{M_r \ x \ T_c \ x \ F_{12}}{(1 - b) \ x \ V_p} + C_A \qquad (5)$$

where:

C	=	Concentration of conservative pollutant (mg/L)
M_r	=	Total mass flow rate of pollutant into basin, including input by freshwater inflow (mg/day)
F_{12}	=	4.7×10^{-5} (converts units to mg/L)

All other parameters are as defined previously in Equations 1 through 4.

3.3.2 Nonconservative Pollutant

Equation 5 estimates steady-state concentrations for conservative pollutants. For cases where nonconservative pollutant concentrations versus time are of interest, Equation 6 may be used:

$$C_n = \left[\left(\frac{V_L + bxV_P}{V_H} \right)^n x\ e^{\frac{-kxT_c}{24}}\ x\ C_A \right] x\ e^{\frac{-kxT_c}{24}} + \left[\frac{T_c\ x\ M_r}{24000\ x\ V_H} + \frac{(1-b)\ x\ V_P\ x\ C_A}{V_H} \right] x \sum_{i=1}^{n} \left[\frac{V_L + bxV_P}{V_H}\ x\ e^{\frac{-kxT_c}{24}} \right]^{(i-1)} x\ e^{\frac{-kxT_c}{24}} \qquad (6)$$

Equation 6 approximates the continuous dilution of a pollutant discharged into the marina basin, resulting in a lower cumulative concentration over the flushing time than would be estimated using Equation 5. Therefore, if Equation 5 produces results that are acceptable, such as an indication that the pollutant concentration will be low, the more complex Equation 6 may be avoided.

Equations 1 through 6 represent desktop screening methodologies for estimating pollutant concentrations. The methodologies are intended to be used to identify trouble spots prior to more sophisticated analyses. The Water Quality Assessment: *A Screening Procedure for Toxic and Conventional Pollutants* (Mills et al., 1985) provides additional and more detailed descriptions of screening methodologies. When required, more sophisticated analyses of pollutant fate and transport can be performed through the use of estuarine water quality models, as described in *Marina Water Quality Models* (Tetra Tech, 1992).

3.4 Dissolved Oxygen

Low dissolved oxygen levels are indicators of serious water quality impacts that may result from poorly designed and maintained marinas (NCDEM, 1990). The assessment of DO impacts is complicated because the kinetics of dissolved oxygen are very complex. Dissolved oxygen concentrations can vary greatly over short periods of time (Thomann and Mueller, 1987).

The best way to assess marina impacts on water quality is to design a sampling strategy and physically measure dissolved oxygen values. During the sampling, sediment oxygen demand and other data can be collected, which may be used to estimate future dissolved oxygen levels using the mathematical modeling procedures described in *North Carolina Coastal Marinas Water Quality Assessment* (NCDEM, 1990) and the *Technical Guidance Manual for Performing Wasteload Allocations* (USEPA, 1989). Prior to data collection, screening procedures such as the equation below and those described in Thomann and Mueller (1987) and Mills et al. (1985) may be used to identify trouble spots. Equations 7a and 7b may be used to successively estimate dissolved oxygen concentrations at high tide and low tide in a semi-enclosed marina.

$$DO_L = \frac{1000\ x\ DO_H\ x\ V_L - 1000\ x\ V_L\ x\ C_B\ x\ (1 - e^{-K_1\ x\ \frac{T_C}{24}}) - \frac{B\ x\ A\ x\ T_C}{24}}{1000\ x\ V_L} \qquad (7b)$$

$$DO_H = (1000 \times DO_A \times V_P + 1000 \times V_P \times (DO_S - DO_A) \times (1 - e^{-k_a \times \frac{T_C}{24}}) - 1000 \times V_L \times C_B \times (1 - e^{-k_1 \times \frac{T_C}{24}}) - B \times A \times \frac{T_C}{24} + 1000 \times V_L \times DO_L + DO_I \times I \times T_C) \,/\, (1000 \times V_H) \tag{7a}$$

where:

DO_H	=	Approximate dissolved oxygen at high tide (mg/L)
DO_A	=	Ambient dissolved oxygen of water flushing into marina (mg/L)
DO_L	=	Approximate dissolved oxygen level in marina at low tide (mg/L)
DO_I	=	Dissolved oxygen in nontidal freshwater inflow (mg/L)
K_1	=	Oxidation coefficient (day^{-1})
DO_S	=	Saturated dissolved oxygen concentration (mg/L)
k_a	=	Reaeration coefficient (day^{-1})
B	=	Sediment oxygen demand (mg/m^2/day)
C_B	=	Biochemical oxygen demand (mg/L)

Equation 7a may be used to estimate dissolved oxygen levels for successive high tides by using the new value of DO_H in place of DO_L. Initially, the value of DO_L is set equal to DO_A, which is assumed constant over the period of analysis. Reaeration due to mixing, photosynthesis, or other sources is not considered, nor is loss of DO due to nitrification.

4. OPERATION

The Tidal Prism Analysis program is designed to be a user-friendly tool for performing simple water quality calculations. As such, the program is menu-driven, with the main features of the program broken into distinct sections. The program can be used to perform screening calculations and sensitivity analyses. This section describes the operation of the four components of the Tidal Prism Analysis program and explains of each option.

The input data required to carry out the Tidal Prism Analysis calculations for a semi-enclosed marina are listed in Tables 1 to 5 (at the end of this section) with Beacons Reach input parameters shown in parentheses. In addition, this section includes three interactive sample sessions using the Tidal Prism Analysis program. Data from the Beacons Reach marina are used in these examples. In these examples, the user-supplied input data are bold and underlined. The TPA output includes a listing of the input data entered into the program and the estimated pollutant concentration under these conditions. A sample output is provided for each model application.

4.1 Program Access

The Tidal Prism Analysis program is designed to run on an IBM-PC microcomputer or compatible with at least 70 K of random access memory (RAM). Use of a math coprocessor is optional. This program is written in FORTRAN 77 and requires MS DOS 2.1 or higher. Use of this program does not require a hard disk.

To run the program, the user enters the program name (i.e., TPA). Once the program has begun, the user will be presented with a menu of the following choices (Figure 1).

Enter Procedure Number You Wish to Execute:

(1) Flushing Characteristics.
(2) Accidental Pollutant Spill.
(3) Conservative/Non-conservative Pollutant.
(4) Dissolved Oxygen Concentration.
(5) Exit the program.

Make a Selection and then Hit Return

Option==>

Figure 1. TPA Main Menu

The desired option is selected by entering 1, 2, 3, 4, or 5. The first choice is used to calculate flushing time for a coastal marina (i.e., Equation 3). The second option is used to calculate conservative pollutant concentration due to accidental spill after several tidal cycles (i.e., Equation 4). The third option is used to calculate the steady-state concentration for conservative pollutant (i.e., Equation 5) or a nonconservative pollutant (i.e., Equation 6) for a coastal marina. The fourth option is used to compute dissolved oxygen concentration at high and low tide consecutively (i.e., Equation 7). The fifth and last option is used to terminate the program and return the user to the operating system.

When the program is finished calculating pollutant concentration according to user-specified procedures, the final menu appears on the user's terminal (Figure 2). This menu has two options. The first option allows the user to go back to the main menu, and the second option permits the user to terminate the current session. By selecting the first option from this menu, the user can perform several calculations during the same session.

Make a Selection and then Hit Return **(1) Go Back to Main Menu.** **(2) Exit the program.**

Figure 2. TPA Final Menu

Typical ranges of reaction rates used in the Tidal Prism Analysis program are listed in Table 6. Additional information pertaining to reaction rates can be obtained from Bowie et al. (1985). The remainder of this section briefly describes the features and operation of the four TPA program options.

4.2 Option 1

This option allows the user to enter descriptive information on the system being modeled. The program calculates the flushing time of a coastal marina according to Equation 3. This option requires a total of six responses (Table 1). The first three responses are the average marina depth at low tide and high tide (L and H) and the marina surface area (A). The next response is the return flow factor (b) the percentage of tidal prism that was previously flushed from the marina on the outgoing tide, which is expressed as a decimal fraction. The fifth response is the desired dilution factor (D). This parameter should be selected according to the amount of flushing desired; if a complete flushing is desired, a very low value can be selected. The last input is the tidal period (T_C), which is 12.5 hours for semi-diurnal tide and 25 hours for diurnal tide. Table 1 lists input data required to estimate the flushing time of a coastal marina.

4.3 Option 2

This option permits the user to calculate the pollutant concentration in a coastal marina due to an accidental spill. Pollutant concentration is estimated according to Equation 4. This option requires a total of nine responses (Table 2). The first five responses were previously discussed under the flushing characteristics option (option 1) and will not be repeated. The sixth response is the desired time in days (i.e., concentration is estimated after X number of days). The next response is mass of pollutant (M) discharged into the marina basin. The eighth response is the ambient concentration of pollutant prior to the accidental spill (C_A). The last response is the decay rate for the discharged pollutant (K). If the discharged pollutant is conservative, then this parameter is set to zero. Decay rates vary depending on the pollutant type, and therefore users are encouraged to consult other references such as *Rates, Constants and Kinetics Formulations in Surface Water Quality Modeling* (Bowie et al., 1985).

4.4 Option 3

This option calculates long-term pollutant concentration in a coastal marina and presents the user with two choices. The first choice (3.1) is used to estimate conservative pollutant concentration and the second choice (3.2) is used to calculate nonconservative pollutant concentration. Equation 4 is used to calculate conservative pollutant concentration, while Equation 5 is used to calculate nonconservative pollutant concentration. All responses are discussed under previous options and will not be repeated. Option 3.1 requires a total of seven responses (Table 3); Option 3.2 requires nine responses (Table 4). In Option 3.2 the user is given the choice to estimate either fecal coliform or another nonconservative pollutant. The typical range of the fecal coliform die-off coefficient is presented in Table 6. These values may be used when site-specific data are not available.

4.5 Option 4

This option allows the user to calculate the dissolved oxygen concentration inside a coastal marina. Equation 7 is used to calculate the dissolved oxygen concentration at high tide and low tide. This option requires a total of 12 responses (Table 5). The first three responses are the average dissolved oxygen level in the ambient water (DO_A), the saturated dissolved oxygen (DO_S), and the dissolved oxygen concentration at low tide (DO_L). When site-specific data are not available, DO_L may be set equal to DO_A. DO_S can be estimated using methods discussed in Bowie et al. (1985) if the average temperature and salinity for ambient water are available. Table 6 lists the typical range of the reaction rate used in this option to estimate dissolved oxygen levels. More information pertaining to reaction rates can be found in Bowie et al. (1985).

4.6 TPA Sample Sessions

This section provides three TPA sample sessions (Figures 3, 4, and 5). These examples list the program inquiries under each option. In these figures, the user responses are underlined. Figure 1 lists the required input data to calculate flushing time for a coastal marina. Input data for the Beacons Reach Marina are used for these examples.

AVERAGE DEPTH AT LOW TIDE L (m):	1.8
AVERAGE DEPTH AT HIGH TIDE H (m):	2.4
SURFACE AREA OF MARINA A (m^2):	9448
RETURN FLOW FACTOR B (dimensionless):	0.0
DESIRED DILUTION D (dimensionless):	0.1
Enter Tidal Information.	
(1) Semi-diurnal Tide (12.5 hours).	
(2) Diurnal Tide (25.0 hours).	
Make a Selection and then Hit Return	1

Figure 3. Flushing Time Sample Session

Non-conservative Pollutant	
AVERAGE DEPTH AT LOW TIDE L (m)	: 1.8
AVERAGE DEPTH AT HIGH TIDE H (m)	: 2.4
SURFACE AREA OF MARINA A (m^2)	: 9448
RETURN FLOW FACTOR B (dimensionless)	: 0.0
DESIRED DILUTION D (dimensionless)	: 0.1
FECAL COLIFORM DIE-OFF RATE Kx (day^{-1})	: 0.5
Enter Tidal Information.	
(1) Semi-diurnal Tide (12.5 hours).	
(2) Diurnal Tide (25.0 hours).	
Make a Selection and then Hit Return	: 1
AMBIENT FECAL COLIFORM CONCENTRATION Ca (mpn/100 mL)	: 0.
MASS OF POLLUTANT DISCHARGED INTO BASIN (mpn/day)	: 11000000000
DO YOU WANT TO CHANGE THE FLUSHING TIME ?	N
IS THIS FECAL COLIFORM ?	Y

Figure 4. Fecal Coliform Sample Session

AMBIENT DISSOLVED OXYGEN DOA (mg/L)	: 6.3
SATURATED DISSOLVED OXYGEN CONCEN. DOS (mg/L)	: 6.9
DISSOLVED OXYGEN IN MARINA AT LOW TIDE DOL (mg/L)	: 6.3
DISSOLVED OXYGEN IN NON-TIDAL FRESHWATER MARINA INFLOW DOI (m^3/hour)	: 0.0
NON-TIDAL FRESHWATER INFLOW /hour	: 0.0
REAERATION COEFFICIENT Ka (day^{-1})	: 0.3
OXIDATION COEFFICIENT K1 (day^{-1})	: 0.1
SEDIMENT OXYGEN DEMAND B (g O_2/m^2-day)	: 2.68
BIOCHEMICAL OXYGEN DEMAND Cb (mg/L)	: 7.23
AVERAGE DEPTH AT LOW TIDE L (m)	: 1.8
AVERAGE DEPTH AT HIGH TIDE H (m)	: 2.4
SURFACE AREA OF MARINA A (m^2)	: 9448
HOW MANY TIDAL CYCLES DO YOU NEED TO RUN THIS MODEL?	10

Enter Tidal Information.
(1) Semi-diurnal Tide (12.5 hours).
(2) Diurnal Tide (25.0 hours).

Make a Selection and then Hit Return : 1

Figure 5. Dissolved Oxygen Sample Session

TABLE 1. Summary of Input Data Required to Calculate Flushing Characteristics.

Variable	Beacons Reach Marina	Description
L	(1.8)	Average depth at low tide (m)
H	(2.4)	Average depth at high tide (m)
A	(9448)	Surface area of marina (m^2)
b	(0.0)	Return flow factor (dimensionless)
D	(0.1)	Desired dilution factor (dimensionless)
T_C	(12.5)	Tidal cycle (hours)

TABLE 2. Input Data Requirements for Accidental Pollutant Spill Calculations.

Variable	Description
L	Average depth at low tide (m)
H	Average depth at high tide (m)
A	Surface area of marina (m^2)
b	Return flow factor (dimensionless)
T_C	Tidal cycle (hours)
t	Time (days)
M	Mass of pollutant discharged into basin (mg)
C_A	Ambient concentration of pollutant prior to addition of discharge (mg/L)
K	Decay rate for nonconservative pollutants (day^{-1})

TABLE 3. Input Data Requirements for Conservative Pollutant Calculations.

Variable	Description
L	Average depth at low tide (m)
H	Average depth at high tide (m)
A	Surface area of marina (m^2)
b	Return flow factor (dimensionless)
M_r	Total mass flow rate of pollutant into basin, including input by freshwater inflow (mg/day)
T_C	Tidal cycle (hours)
C_A	Ambient concentration of pollutant prior to addition of discharge (mg/L)

TABLE 4. Input Data Requirement for Nonconservative Pollutant Calculations.

Variable	Beacons Reach Marina	Description
L	(1.8)	Average depth at low tide (m)
H	(2.4)	Average depth at high tide (m)
A	(9448)	Surface area of marina (m^2)
b	(0.0)	Return flow factor (dimensionless)
D	(0.1)	Desired dilution factor (dimensionless)
K_x	(1.2)	Fecal coliform dye off rate (0.3-1.2 day^{-1})
T_C	(12.5)	Tidal cycle (hours)
C_a	(0.0)	Ambient fecal coliform concentration (mpn/100mL)
M_r		Mass of pollutant discharged into basin (mg)

TABLE 5. Input Data Requirements for Dissolved Oxygen Calculations.

Variable	Beacons Reach Marina	Description
DO_A	(6.3)	Ambient dissolved oxygen of water flushing into marina (mg/L)
DO_S	(6.9)	Saturated dissolved oxygen concentration (mg/L)
DO_L	(6.3)	Dissolved oxygen level in marina at low tide (mg/L)
DO_I	(0.0)	Dissolved oxygen in nontidal freshwater inflow (mg/L)
k_a	(0.3)	Reaeration coefficient (day^{-1})
K_1	(0.1)	Oxidation coefficient (day^{-1})
B	(2.68)	Sediment oxygen demand ($mg/m^2/day$)
C_B	(7.23)	Biochemical oxygen demand (mg/L)
L	(1.8)	Average depth at low tide (mL)
H	(2.4)	Average depth at high tide (m)
A	(9448)	Surface area of marina (m^2)
T_C	(12.5)	Tidal cycle (hours)

TABLE 6. Typical Ranges of Reaction Rates Used in TPA.

k_a	Reaeration coefficient (day^{-1})	0.25 - 3.0
K_1	Oxidation coefficient (day^{-1})	0.05 - 3.0
B	Sediment oxygen demand ($mg/m^2/day$)	0.0 - 5.0
C_B	Biochemical oxygen demand (mg/L)	0.1 - 0.3
K_x	Fecal coliform die-off rate (day^{-1})	0.3 - 1.2

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APPENDIX A: TPA MODEL LISTING

```
C      PROGRAM Tidal Prism Analysis

C     AUTHOR : M. ZAKI MOUSTAFA, Tetra Tech, Inc.
c
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)

c...   Define file name character strings.
       character*40  filein, fileout
       character*1 ans
       logical       filexist
c
       CALL SYSTEM ('CLS')

      write(*,*) '  Welcome to The Tidal Prism Analysis Program (TPA) '
      write(*,*) '    This program is based on the Tidal Prism '
      write(*,*) '      Analysis Procedures presented in '
      write(*,*) '             in Chapter 4 of the'
      write(*,*) '  Coastal Marina Assessment Handbook (USEPA, 1985) '
      WRITE(*,*)
      write(*,*) '              Developed By '
      write(*,*) '             Tetra Tech, Inc. '
      WRITE(*,*)
      write(*,*) '              Developed For '
      write(*,*) '        EPA Region IV, Atlanta, GA  '
      WRITE(*,*)

c
c...   Format statements.
110    format(1X,' Enter OUTPUT file name ')
120    format(A)

c...   Get the output file name.
25      write(*,*)
        write(*,110)
        write(*,*)
          read(*,120,err=25) fileout
c
c...    Check if fileout already exists.
        inquire(file=fileout, exist=filexist)
        if ( filexist )  then
           write(*,*) 'File Already Exists.'
           write(*,*) 'Choose Another Name.'
           goto 25
        endif
c
c...   Open output file.
      open(6,file=fileout,status = 'NEW')

700   CONTINUE

    5 CALL SYSTEM ('CLS')

      WRITE(*,*)' Enter Procedure Number You Wish to Execute:'
      WRITE(*,*)
      WRITE(*,*)'(1)  Flushing Characteristics.'
      WRITE(*,*)'(2)  Accidental Pollutant Spill. '
      WRITE(*,*)'(3)  Conservative/Non-conservative Pollutant.'
      WRITE(*,*)'(4)  Dissolved Oxygen Concentration.'
      WRITE(*,*)'(5)  Exit program.'
      WRITE(*,*)
```

```
      WRITE(*,201)
201   FORMAT(1X,'Make a Selection and then Hit Return',//)
      WRITE(*,*)'Option ==> '
      WRITE(*,*)

      READ (*,*,ERR=5) ITYPE
      IF (( ITYPE .LT. 1 ) .OR. ( ITYPE .GT. 5 )) GO TO 5
      IF ( ITYPE .EQ. 1 ) THEN
         CALL FLUSHING
         GO TO 800
      ENDIF

      IF ( ITYPE .EQ. 2 ) THEN
         CALL ACCIDENT
         GO TO 800
      ENDIF

      IF ( ITYPE .EQ. 3 ) THEN

    7 CALL SYSTEM ('CLS')

      WRITE(*,*)' Enter Procedure Number You Wish to Execute:'
      WRITE(*,*)
      WRITE(*,*)'(1)  Conservative Pollutant (Option 3.1). '
      WRITE(*,*)'(2)  Nonconservative Pollutant (Option 3.2).'
      WRITE(*,*)'(3)  Exit program.'
      WRITE(*,*)
      WRITE(*,201)
      WRITE(*,*)'Option ==> '
      WRITE(*,*)
      READ (*,*,ERR=7) IPOLTANT

      IF (( IPOLTANT .LT. 1 ) .OR. ( IPOLTANT .GT. 3 )) GO TO 7

          IF ( IPOLTANT .EQ. 1 ) THEN
             CALL CONSERVAT
             GO TO 800
          ENDIF

          IF ( IPOLTANT .EQ. 2 ) THEN
             CALL NONCONSER
             GO TO 800
          ENDIF

          IF ( IPOLTANT .EQ. 3 ) GO TO 900

      ENDIF

      IF ( ITYPE .EQ. 4 ) THEN
         CALL OXYGEN
         GO TO 800
      ENDIF

      IF ( ITYPE .EQ. 5 ) GO TO 900

800   CONTINUE

C800   CALL SYSTEM ('CLS')

      WRITE(*,*)
      WRITE(*,*) ' Make a Selection and then Hit Return'
      WRITE(*,*)
```

```
      WRITE(*,*)'(1)  Go Back to Main Menu.'
      WRITE(*,*)'(2)  Exit the Program.'
      WRITE(*,*)
      READ (*,*) IEND
      IF ( IEND .EQ. 2 )  THEN
         CLOSE (6)
         GO TO 900
      ENDIF

      IF ( IEND .EQ. 1 ) THEN
         GO TO 700
      ELSE
         GO TO 800
      ENDIF

900    STOP
       END

      SUBROUTINE FLUSHING

C     AUTHOR : M. ZAKI MOUSTAFA, Tetra Tech, Inc.
c
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)

C      This subroutine solves Equation # 3 in the User's manual.
      REAL L, Ka, k1, Mr, Kx
      character*1 ans

      write(*,*) ' the following parameters are needed to calculate'
      write(*,*) ' marina flushing time'

      WRITE(6,101)
  101 FORMAT(//,'Flushing characteristics:',//)

      WRITE(*,*) 'AVERAGE DEPTH AT LOW TIDE  L (m) : '
       WRITE(*,*)
      READ (*,*) L
      WRITE(6,1) L

       WRITE(*,*) 'AVERAGE DEPTH AT HIGH TIDE  H (m) : '
       WRITE(*,*)

       READ (*,*) H
       WRITE(6,2) H

       WRITE(*,*) 'SURFACE AREA OF MARINA  A (m2) : '
       WRITE(*,*)
       READ (*,*) A
       WRITE(6,3) A

       WRITE(*,*) ' RETURN FLOW FACTOR  B (dimensionless) : '
       WRITE(*,*) '  range = 0.0 to 1.0  '
       WRITE(*,*)
       READ (*,*) B
       WRITE(6,4) B

       WRITE(*,*) ' DESIRED DILUTION FACTOR  D : '
       WRITE(*,*) ' range = 0.0 to 1.0  '
       WRITE(*,*)
       READ (*,*) D
       WRITE(6,5) D
```

```
6     CALL SYSTEM ('CLS')

      WRITE(*,*) ' Enter Tidal Information.'
      WRITE(*,*) '(1)  Semi-diurnal Tide (12.5 hours).'
      WRITE(*,*) '(2)  Diurnal Tide (25.0 hours). '
      WRITE(*,*)
      WRITE(*,200)
200   FORMAT(1X,'Make a Selection and then Hit Return',//)

      READ (*,*,ERR=6) ITC

      IF ( ITC .EQ. 2 ) THEN
         TC = 25.0
         WRITE(6,9)
          GO TO 999
      ENDIF
      IF ( ITC .EQ. 1 ) THEN
         TC = 12.5
         WRITE(6,10)
         GO TO 999
      ELSE
      GO TO 6
      ENDIF

  999 CONTINUE
          VL   =  L * A
          VH   =  H * A
          VP   =  VH - VL

C   CALCULATE SOME CONSTANTS
        TT    = TC / 24.0

      TOP_Tf = TC * ALOG10 (D)
      BOT_Tf = ALOG10 ( (VL + ( B * VP )) / VH)

      Tf  =  TOP_Tf / BOT_Tf

      WRITE(*,7) TF
      WRITE(*,8)  (TF/TC)

      WRITE(6,7) TF
      WRITE(6,8)  (TF/TC)


    1 FORMAT(' AVERAGE DEPTH AT LOW TIDE (m)   L  = ', F14.2)
    2 FORMAT(' AVERAGE DEPTH AT HIGH TIDE (m)  H  = ', F14.2)
    3 FORMAT(' SURFACE AREA OF MARINA (m2)     A  = ', F14.2)
    4 FORMAT(' RETURN FLOW FACTOR (dimensionless) B = ', F14.2)
    5 FORMAT(' DESIRED DILUTION                D  = ', F14.2)
    7 FORMAT(' FLUSHING TIME (in hours)        TF =  ',F14.2)
    8 FORMAT(' FLUSHING TIME (in tidal cycles) TF = ' ,F14.2)
    9 FORMAT(' Diurnal Tide                    TC =      25.0 hours ')
   10 FORMAT(' Semi-diurnal Tide               TC =      12.5 hours ')

      RETURN
      END


      SUBROUTINE ACCIDENT

C     AUTHOR : M. ZAKI MOUSTAFA, Tetra Tech, Inc.

```

```
c
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)

C      This subroutine solves Equation # 4 in the User's manual.
      REAL L, Ka, k1, M, K
      character*1 ans

      write(*,*) ' the following parameters are needed to calculate'
      write(*,*) ' pollutant concentration due to Accidental Spill '

       WRITE(6,101)
  101  FORMAT(//,'Accidental Spill',//)

       WRITE(*,*) 'AVERAGE DEPTH AT LOW TIDE  L (m) : '
       WRITE(*,*)
       READ (*,*) L
       WRITE(6,1) L

       WRITE(*,*) 'AVERAGE DEPTH AT HIGH TIDE  H (m) : '
       WRITE(*,*)
       READ (*,*) H
       WRITE(6,2) H

       WRITE(*,*) 'SURFACE AREA OF MARINA  A (m2) : '
       WRITE(*,*)
       READ (*,*) A
       WRITE(6,3) A

       WRITE(*,*) ' RETURN FLOW FACTOR  B (dimensionless) :'
       WRITE(*,*) ' range = 0.0 to 1.0 '
       WRITE(*,*)
       READ (*,*) B
       WRITE(6,4) B

5     CALL SYSTEM ('CLS')
      WRITE(*,*) ' Enter Tidal Information.'
      WRITE(*,*) '(1)  Semi-diurnal Tide (12.5 hours).'
      WRITE(*,*) '(2)  Diurnal Tide (25.0 hours). '
      WRITE(*,*)
      WRITE(*,200)
200   FORMAT(1X,'Make a Selection and then Hit Return',//)

      READ (*,*,ERR=5) ITC
      IF ( ITC .EQ. 2 ) THEN
         TC = 25.0
         WRITE(6,8)
         GO TO 50
      ENDIF
      IF ( ITC .EQ. 1 ) THEN
         TC = 12.5
         WRITE(6,9)
         GO TO 50
      ELSE
      GO TO 5
      ENDIF

   50 CONTINUE

      R    = H - L
      WRITE(6,6) R

```

```
            WRITE(*,*) 'ENTER TIME (days) AFTER OCCURRENCE OF SPILL
            WRITE(*,*)
            READ (*,*) TIME
            WRITE(6,7) TIME

            WRITE(*,*) ' MASS OF POLLUTANT DISCHARGED INTO BASIN (mg)'
            WRITE(*,*)
            READ (*,*)  M
            WRITE(6,10)
            WRITE(6,11) M

            WRITE(*,*) ' Ambient Concentration of Pollutant Prior'
            WRITE(*,*) ' to Discharge (mg/L) '
            WRITE(*,*)
            READ (*,*)  CA
            WRITE(6,12)
            WRITE(6,13) CA

            WRITE(*,*) ' DECAY RATE FOR POLLUTANT  K (per day): '
            WRITE(*,*) ' IF CONSERVATIVE POLLUTANT ENTER ZERO'
            WRITE(*,*)
            READ (*,*)  K
            WRITE(6,14) K

            VL    =  L * A
            FIRST_T = ( ( (VL) + (B*A*R)  ) / (A*H))
            N       = ANINT (24.0*TIME/TC)
            FIRST_T = ((FIRST_T)**N)

            T1    = -1.0 * K * TIME
            SS    =  EXP(T1)

            SECOND_T = ( M / (1000.0 * VL) ) * SS
            THIRD_T  = CA * SS

            CT = ( FIRST_T * SECOND_T ) + THIRD_T
            WRITE(6,15)
            WRITE(6,16) CT
            WRITE(*,15)
            WRITE(*,16) CT

          1 FORMAT(' AVERAGE DEPTH AT LOW TIDE  (m)       L  = ', F14.2)
          2 FORMAT(' AVERAGE DEPTH AT HIGH TIDE (m)       H  = ', F14.2)
          3 FORMAT(' SURFACE AREA OF MARINA     (m2)      A  = ', F14.2)
          4 FORMAT(' RETURN FLOW FACTOR (dimensionless)   B  = ', F14.2)
          6 FORMAT(' TIDAL RANGE (m)                      R  = ', F14.2)
          7 FORMAT(' TIME after occurrence of spill (days) t  = ', F14.2)
          8 FORMAT(' Diurnal Tide                         TC =    25.0 hours')
          9 FORMAT(' Semi-diurnal Tide                    TC =    12.5 hours')
         10 FORMAT(' MASS OF POLLUTANT DISCHARGED INTO')
         11 FORMAT('          BASIN (mg)                  M  = ', F14.2)
         12 FORMAT(' Ambient Concentration of Pollutant Prior' )
         13 FORMAT('             to Discharge (mg/L)      CA = ', F14.2)
         14 FORMAT(' DECAY RATE (per day)                 K  = ', F14.2)
         15 FORMAT(//,' CONCENTRATION OF POLLUTANT AT ')
         16 FORMAT('             TIME t (mg/L)            CT = ', F14.5)

            RETURN
            END


            SUBROUTINE CONSERVAT
```

```
C     AUTHOR : M. ZAKI MOUSTAFA, Tetra Tech, Inc.
c
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)


C      This subroutine solves Equation # 5 in the User's manual.

      REAL L, Ka, k1, Mr, Kx
      character*1 ans

       WRITE(6,101)
  101  FORMAT(//,'Conservative Pollutant',//)

       WRITE(*,*) 'AVERAGE DEPTH AT LOW TIDE  L (m) : '
       READ (*,*) L
       WRITE(*,*)
       WRITE(6,1) L

       WRITE(*,*) 'AVERAGE DEPTH AT HIGH TIDE  H (m) : '
       WRITE(*,*)
       READ (*,*) H
       WRITE(6,2) H

       WRITE(*,*) 'SURFACE AREA OF MARINA  A (m2): '
       WRITE(*,*)
       READ (*,*) A
       WRITE(6,3) A

       WRITE(*,*) ' RETURN FLOW FACTOR (dimensionless)  B : '
       WRITE(*,*)
       READ (*,*) B
       WRITE(6,4) B

       WRITE(*,*) ' TOTAL MASS FLOW RATE OF POLLUTANT INTO BASIN'
       WRITE(*,*) 'INCLUDING INPUT BY FRESHWATER INFLOW (mg/day) '
       WRITE(*,*)
       READ (*,*) Mr
       WRITE(6,6)
       WRITE(6,7)
       WRITE(6,8) Mr

5     CALL SYSTEM ('CLS')

      WRITE(*,*) ' Enter Tidal Information.'
      WRITE(*,*) '(1)  Semi-diurnal Tide (12.5 hours).'
      WRITE(*,*) '(2)  Diurnal Tide (25.0 hours). '
      WRITE(*,*)
      WRITE(*,200)
200   FORMAT(1X,'Make a Selection and then Hit Return',//)

      READ (*,*,ERR=5) ITC

      IF ( ITC .EQ. 2 ) THEN
         TC = 25.0
         WRITE(6,9)
         GO TO 999
      ENDIF
      IF ( ITC .EQ. 1 ) THEN
         TC = 12.5
         WRITE(6,10)
         GO TO 999
```

```
          ELSE
          GO TO 5
          ENDIF

      999 CONTINUE

          WRITE(*,*) ' Ambient Concentration of Pollutant Prior'
          WRITE(*,*) ' to Discharge (mg/L) '
          WRITE(*,*)
          READ (*,*) CA
          WRITE(6,11)
          WRITE(6,12) CA

              VL   =  L * A
              VH   =  H * A
              VP   =  VH - VL

C   CALCULATE SOME CONSTANTS
           F12   = 4.7*(10.**(-5))
          TOP_C = Mr * TC * F12
          BOT_C = ( 1.0 - B ) * VP

          C  = ( TOP_C / BOT_C ) + CA

          WRITE(6,13)
          WRITE(6,14) C

          WRITE(*,13)
          WRITE(*,14) C

        1 FORMAT(' AVERAGE DEPTH AT LOW TIDE  (m)       L  = ', F14.2)
        2 FORMAT(' AVERAGE DEPTH AT HIGH TIDE (m)       H  = ', F14.2)
        3 FORMAT(' SURFACE AREA OF MARINA     (m2)      A  = ', F14.2)
        4 FORMAT(' RETURN FLOW FACTOR (dimensionless)   B  = ', F14.2)
        6 FORMAT(' TOTAL MASS FLOW RATE OF POLLUTANT INTO')
        7 FORMAT(' BASIN,INCLUDING INPUT BY')
        8 FORMAT(' FRESHWATER INFLOW (mg/day)           Mr = ', F14.2)
        9 FORMAT(' Diurnal Tide                         TC =    25.0 hours')
       10 FORMAT(' Semi-diurnal Tide                    TC =    12.5 hours')
       11 FORMAT(' Ambient Concentration of Pollutant Prior' )
       12 FORMAT('           to Discharge (mg/L)        CA = ', F14.2)
       13 FORMAT(//,' CONCENTRATION OF CONSERVATIVE ')
       14 FORMAT('     POLLUTANT AT TIME t (mg/L)       C  = ', F14.5)

          return
          end


          SUBROUTINE NONCONSER

C     AUTHOR : M. ZAKI MOUSTAFA, Tetra Tech, Inc.

c
          IMPLICIT DOUBLE PRECISION (A-H,O-Z)

C     AUTHOR : M. ZAKI MOUSTAFA, Tetra Tech, Inc.
C     This program calculates the steady state Fecal Coliform ( or any
c     non-conservative substance) concentration for a semi-enclosed marina.
c     This subroutine solves Equation # 6 in the User's manual.

          REAL L, Ka, k1, Mr, Kx
          character*1 ans
```

```
        WRITE(6,101)
  101   FORMAT(//,'Nonconservative Pollutant',//)

        WRITE(*,*) 'AVERAGE DEPTH AT LOW TIDE  L (m) : '
        WRITE(*,*)
        READ (*,*) L
        WRITE(6,1) L

        WRITE(*,*) 'AVERAGE DEPTH AT HIGH TIDE  H (m) : '
        WRITE(*,*)
        READ (*,*) H
        WRITE(6,2) H

        WRITE(*,*) 'SURFACE AREA OF MARINA  A (m2) : '
        WRITE(*,*)
        READ (*,*) A
        WRITE(6,3) A

        WRITE(*,*) ' RETURN FLOW FACTOR   B (dimensionless) : '
        WRITE(*,*)
        READ (*,*) B
        WRITE(6,4) B

        WRITE(*,*) ' DESIRED DILUTION FACTOR  D (dimensionless) : '
        WRITE(*,*)
        READ (*,*) D
        WRITE(6,6) D
        WRITE(*,*) ' FECAL COLIFORM DIE-OFF RATE  Kx (per day) : '
        WRITE(*,*)
        READ (*,*) Kx
        WRITE(6,7) Kx

           VL   =  L * A
           VH   =  H * A
           VP   =  VH - VL

 5      CALL SYSTEM ('CLS')

        WRITE(*,*) ' Enter Tidal Information.'
        WRITE(*,*) '(1)  Semi-diurnal Tide (12.5 hours).'
        WRITE(*,*) '(2)  Diurnal Tide (25.0 hours). '
        WRITE(*,*)
        WRITE(*,200)
 200    FORMAT(1X,'Make a Selection and then Hit Return,',//)

        READ (*,*,ERR=5) ITC

        IF ( ITC .EQ. 2 ) THEN
           TC = 25.0
           WRITE(6,8)
           GO TO 999
        ENDIF
        IF ( ITC .EQ. 1 ) THEN
           TC = 12.5
           WRITE(6,9)
           GO TO 999
        ELSE
        GO TO 5
        ENDIF
```

```
  999 CONTINUE

C   CALCULATE SOME CONSTANTS
       TT    = TC / 24.0
       T1    = -1.0 * Kx * TT
       SS     =  EXP(T1)
      TOP_Tf = TC * ALOG10 (D)
      BOT_Tf = ALOG10 ( (VL + ( B * VP )) / VH)
      Tf   =  TOP_Tf / BOT_Tf
      WRITE(6,10) TF
      WRITE(6,11)  (TF/TC)
      NCYCLE = ANINT(Tf/TC)

C START FECAL COLIFORM CALCULATIONS

       WRITE(*,*) 'AMBIENT FECAL COLIFORM CONCENTRATION  Ca : '
       WRITE(*,*) ' MPN/100 mL '
       WRITE(*,*)
       READ (*,*)  Ca
       WRITE(6,12)
       WRITE(6,13) Ca

       WRITE(*,*) ' MASS OF POLLUTANT DISCHARGED INTO BASIN'
       WRITE(*,*)  ' FOR Fecal Coliform   =  mpn/day '
       WRITE(*,*)  ' FOR Other Pollutants =  mg/day '
       WRITE(*,*)
       READ (*,*) Mr
       WRITE(6,14)
       WRITE(6,15) Mr

         AA1 = ( VL + ( B * VP ) ) / VH
         AA = AA1**NCYCLE
         BB = ( EXP(T1) ) * Ca
      TERM1 = AA * BB * SS

         CON1 = ( TC * Mr) / ( 24000.0 * VH)
         CON2 = ( (1.-B) * VP * Ca ) / VH
      TERM2 = CON1 + CON2

         SUM = 0.0

      write(*,*) ' Flushing time = ', NCYCLE
      write(*,*) ' Do you want to change the flushing time ?'
      WRITE(*,*)
      read (*,'(a1)') ans
      if ( ans .eq. 'y' .or. ans .eq. 'Y') then
          write(*,*)' How many tidal cycles ? '
          read (*,*) ncycle
      endif

      DO 100 NTC = 1 , NCYCLE

         A1 = (( VL + ( B*VP) ) / VH ) * (EXP(T1))
         A2 = (A1)**(NTC-1)
         A3 = A2 * SS
         SUM = SUM + A3
C         WRITE(6,*)'SUM   ', SUM

 100   CONTINUE

      TERM3   = SUM
      RESULTS =  TERM1 + ( TERM2 * TERM3)
```

```
          write(*,*) ' Is this FECAL COLIFORM ?'
          write(*,*)
          read (*,'(a1)') ans
          if ( ans .eq. 'y' .or. ans .eq. 'Y') then

C TO CONVERT UNIT TO # OF ORGANISM/100 mL DIVIDE BY 10

          RESULTS = RESULTS / 10.0
          WRITE(6,16) results
          write(6,17) ncycle

          WRITE(*,16) results
          write(*,17) ncycle

          else

          WRITE(6,18) results
          write(6,19) ncycle
          WRITE(*,18) results
          write(*,19) ncycle

          endif

        1 FORMAT(' AVERAGE DEPTH AT LOW TIDE (m)   L   = ', F14.2)
        2 FORMAT(' AVERAGE DEPTH AT HIGH TIDE (m)  H   = ', F14.2)
        3 FORMAT(' SURFACE AREA OF MARINA (m2)     A   = ', F14.2)
        4 FORMAT(' RETURN FLOW FACTOR (dimensionless) B   = ', F14.2)
        6 FORMAT(' DESIRED DILUTION FACTOR (dimensionless) D  = ', F14.2)
        7 FORMAT(' DIE-OFF RATE (per day)          Kx  = ', F14.4)
        8 FORMAT(' Diurnal Tide                    TC  =      25.0 hours ')
        9 FORMAT(' Semi-diurnal Tide               TC  =      12.5 hours ')
       10 FORMAT(' FLUSHING TIME (in hours)        TF  = ', F14.2)
       11 FORMAT(' FLUSHING TIME (in tidal cycles) TF  = ', F14.2)
       12 FORMAT(' Ambient Concentration of Pollutant' )
       13 FORMAT(' Prior to Discharge (mg/day)       CA = ',  F14.2)
       14 FORMAT('MASS OF POLLUTANT DISCHARGED ')
       15 FORMAT('INTO BASIN (mpn/day)               Mr = ',  E14.4)
       16 format('FECAL COLIFORM CONCENTRATION/100 mL = ',  f14.4)
       17 format(' AFTER  ', i10, '   TIDAL CYCLE')
       18 format('POLLUTANT CONCENTRATION   (mg/L)    = ',  f14.4)
       19 format(' AFTER  ', i10, '   TIDAL CYCLE')

          RETURN

          END


          SUBROUTINE OXYGEN
c
          IMPLICIT DOUBLE PRECISION (A-H,O-Z)


C         AUTHOR : M. ZAKI MOUSTAFA, Tetra Tech, Inc.

C         This subroutine calculates Dissolved Oxygen concentrations successively at
c         high and low tide for a semi-enclosed marina.  This subroutine solve
c         Equations 7 and 7a in the user's manual.

          DIMENSION    DOH(50),  DOL(50)
          REAL*8 L, Ka, k1
```

```
      REAL*8 DOA, DOS, DOL1, DOI, Q, B,Cb,H,A
     1, VL, VH, VP, TC,T1,T2,TT,SS, TERM1, TERM2,TERM3,TERM4,TERM5,TERM6
     2, TERM7, TOP, BOTTOM

       WRITE(6,101)
  101  FORMAT(//,'Dissolved Oxygen',//)

       WRITE(*,*) 'AMBIENT DISSOLVED OXYGEN   DOA (mg/L) :
       WRITE(*,*)
       READ (*,*) DOA
       WRITE(6,1) DOA

       WRITE(*,*) 'SATURATED DISSOLVED OXYGEN CONCEN. DOS (mg/L) :
       WRITE(*,*)
       READ (*,*) DOS
       WRITE(6,2) DOS

       WRITE(*,*) 'DISSOLVED OXYGEN IN MARINA AT LOW TIDE DOL (mg/L) :
       WRITE(*,*)
       READ (*,*) DOL1
       write(6,3)
       WRITE(6,33) DOL1

       WRITE(*,*) ' DISSOLVED OXYGEN IN NONTIDAL
       WRITE(*,*) ' FRESHWATER MARINA INFLOW  DOI (mg/L) :
       WRITE(*,*)
       READ (*,*) DOI
       WRITE(6,4)
       WRITE(6,5) DOI

       WRITE(*,*) ' NONTIDAL FRESHWATER INFLOW (m3/hour) :
       WRITE(*,*)
       READ (*,*) Q
       WRITE(6,6) Q

       WRITE(*,*) 'REAERATION COEFFICIENT   Ka :
       WRITE(*,*) ' (Typical Ka = 0.7/day) '
       write(*,*)
       READ (*,*) Ka
       WRITE(6,7) Ka

       WRITE(*,*) 'OXIDATION COEFFICIENT  K1 (per day) :
       WRITE(*,*) ' (Typical K1 = 0.1/day) '
       write(*,*)
       READ (*,*) K1
       WRITE(6,8) K1

       WRITE(*,*) 'SEDIMENT OXYGEN DEMAND  B (g O2/m2-day):
       WRITE(*,*) ' Typical B = 1.5 g O2/m2-day '
       write(*,*)
       READ (*,*) B
       WRITE(6,9) B

       WRITE(*,*) 'BIOCHEMICAL OXYGEN DEMAND  Cb (mg/L) :
       WRITE(*,*) 'Typical Cb for Urban Runoff = 17 mg/L '
       write(*,*)
       READ (*,*) Cb
       WRITE(6,10) Cb

c  declare L as a real variable

       WRITE(*,*) 'AVERAGE DEPTH AT LOW TIDE  L (m) :
```

```
      WRITE(*,*)
      READ (*,*) L
      WRITE(6,11) L

      WRITE(*,*) 'AVERAGE DEPTH AT HIGH TIDE  H (m) : '
      WRITE(*,*)
      READ (*,*)  H
      WRITE(6,12) H

      WRITE(*,*) 'SURFACE AREA OF MARINA  A (m2) : '
      WRITE(*,*)
      READ (*,*)  A
      WRITE(6,13) A

      WRITE(*,*)'HOW MANY TIDAL CYCLES DO YOU NEED TO RUN THIS MODEL?'
      WRITE(*,*)
      READ (*,*) INUM

      ICYCLE  =  1

      VL   =  L * A
      VH   =  H * A
      VP   =  VH - VL

50    CALL SYSTEM ('CLS')

     WRITE(*,*) ' Enter Tidal Information.'
     WRITE(*,*) '(1)  Semi-diurnal Tide (12.5 hours).'
     WRITE(*,*) '(2)  Diurnal Tide (25.0 hours). '
     WRITE(*,*)
     WRITE(*,200)
200  FORMAT(1X,'Make a Selection and then Hit Return',//)

     READ (*,*,ERR=50) ITC

     IF ( ITC .EQ. 2 ) THEN
        TC = 25.0
        WRITE(6,14)
        GO TO 999
     ENDIF
     IF ( ITC .EQ. 1 ) THEN
        TC = 12.5
        WRITE(6,15)
        GO TO 999
     ELSE
     GO TO 50
     ENDIF

  999 CONTINUE

C   CALCULATE SOME CONSTANTS
      TT   = TC / 24.0
      T1   = -1.0 * Ka * TT
      T2   = -1.0 * K1 * TT

      TERM1 = 1000. * DOA * VP
      SS    =  EXP(T1)
      TERM2 = 1000. * (DOS -DOA) * VP *  ( 1.0 -  SS )
      TERM3 = 1000. * VL * Cb * ( 1.0 - EXP(T2) )
      TERM4 = B * A * TT
      TERM5 = 1000. * VL * DOL1
```

```
          TERM6 = DOI * Q * TC
          TERM7 = 1000. * VH
          TOP   = TERM1 + TERM2 - TERM3 - TERM4 + TERM5 + TERM6
          BOTTOM= TERM7
          DOH1   = TOP / BOTTOM
          DOH(ICYCLE) = DOH1

         TERML1 = 1000. * DOH1 * VL
         TERML2 = 1000 * VL * Cb * (1.0 -  EXP(T2) )
         TERML3 = B * A * TT
         TOPL    = TERML1 - TERML2 - TERML3

         BOTTOML = 1000. * VL

         DOL1 = TOPL / BOTTOML
         DOL(ICYCLE) = DOL1

C start the successive calculation for DO @ high tide and @ low tide

         WRITE(6,17)
         WRITE(6,19)
         WRITE(6,18)
         WRITE(6,16) DOH(1), DOL(1)

         WRITE(*,17)
         WRITE(*,19)
         WRITE(*,18)
         WRITE(*,16) DOH(1), DOL(1)

         DO 100 ICYCLE = 2 , INUM

            TERM1 = 1000. * DOA * VP
            TERM2 = 1000. * (DOS -DOA) * VP * ( 1.0 - EXP(T1) )
            TERM3 = 1000. * VL * Cb * ( 1.0 - EXP(T2) )
            TERM4 = B * A * TT
            TERM5 = 1000. * VL * DOH(ICYCLE-1)
            TERM6 = DOI * Q * TC
            TERM7 = 1000. * VH
            TOP   = TERM1 + TERM2 - TERM3 - TERM4 + TERM5 + TERM6
            BOTTOM= TERM7

            DOH(ICYCLE)   = TOP / BOTTOM

            TERML1  = 1000. * DOH(ICYCLE) * VL
            TERML2  = 1000 * VL * Cb * (1.0 - EXP(T2) )
            TERML3  = B * A * TT
            TOPL    = TERML1 - TERML2 - TERML3
            BOTTOML = 1000. * VL
            DOL(ICYCLE)  = TOPL / BOTTOML

         WRITE(6,16) DOH(ICYCLE), DOL(ICYCLE)
         WRITE(*,16) DOH(ICYCLE), DOL(ICYCLE)

 100     CONTINUE

       1 FORMAT(' AMBIENT DISSOLVED OXYGEN (mg/L)                   =', F14.4)
       2 FORMAT(' SATURATED DISSOLVED OXYGEN CONCENTRATION (mg/L)=', F14.4)
       3 FORMAT(' DISSOLVED OXYGEN CONCENTRATION AT LOW TIDE' )
      33 format('          (mg/L)                                   =', F14.4)
       4 FORMAT(' DISSOLVED OXYGEN IN NON-TIDAL FRESH WATER')
       5 FORMAT(' INFLOW  DOi (mg/L)                                =', F14.4)
       6 FORMAT(' FRESHWATER INFLOW INTO MARINA (cub_meter/hour) =', F14.4)
```

```
    7 FORMAT(' REAERATION COEFFICIENT (per day)          Ka  =', F14.4)
    8 FORMAT(' OXIDATION COEFFICIENT  (per day)          K1  =', F14.4)
    9 FORMAT(' SEDIMENT OXYGEN DEMAND (g O2/m2-day)      B   =', F14.4)
   10 FORMAT(' BIOCHEMICAL OXYGEN DEMAND (mg/L)          Cb  =', F14.4)
   11 FORMAT(' AVERAGE DEPTH AT LOW TIDE  (m)            L   =', F14.2)
   12 FORMAT(' AVERAGE DEPTH AT HIGH TIDE (m)            H   =', F14.2)
   13 FORMAT(' SURFACE AREA OF MARINA     (m**2)         A   =', F14.2)
   14 FORMAT(' Diurnal Tide                    TC  =     25.0 hours ')
   15 FORMAT(' Semi-diurnal Tide               TC  =     12.5 hours ')
   16 FORMAT(F10.2,10X,F10.2)
   17 FORMAT(//,3X,'   DOH                DOL    ',/)
   19 FORMAT(3x,'   mg/L              mg/L    ',/)
   18 FORMAT('-------------------------------')

      RETURN
      END
```

APPENDIX B:

USER'S GUIDE FOR

MICROCOMPUTER VERSION OF

NCDEM DO MODEL

INTRODUCTION

This user's guide describes the input required to run the NCDEM DO model (NCDEM, 1990). This version of the model assumes that the marina to be evaluated can be approximated by two segments: an inlet channel and the marina basin.

Runoff is assumed to be equal to zero, and the volume of wastewater discharged to the basin other than from boats is also assumed to be equal to zero. The net flow out of the basin is therefore zero. The forcing function is the changing depth of the ambient water, primarily due to tidal forces, which brings water into the marina during the rising tide and takes water out of the marina during the falling tide.

The tidal variations are assumed to follow a sinusoidal distribution. For simplicity, a 12-hour tidal cycle is used. Calculations are performed at hourly time increments. Each segment is assumed to be completely mixed at the end of each time increment.

Changes in dissolved oxygen are possible from advection, reaeration, or bottom sediment oxygen demand. Boat discharges are not included since they have been shown to have a minor effect or no effect on DO concentrations.

Figure B1 is a schematic of the basin illustrating some of the associated terms used in the model. The NCDEM DO model runs interactively on a DOS-compatible PC. To access the program, enter the program name (NCDEM_DO) then be prepared to supply the model with the information listed in Table B-1.

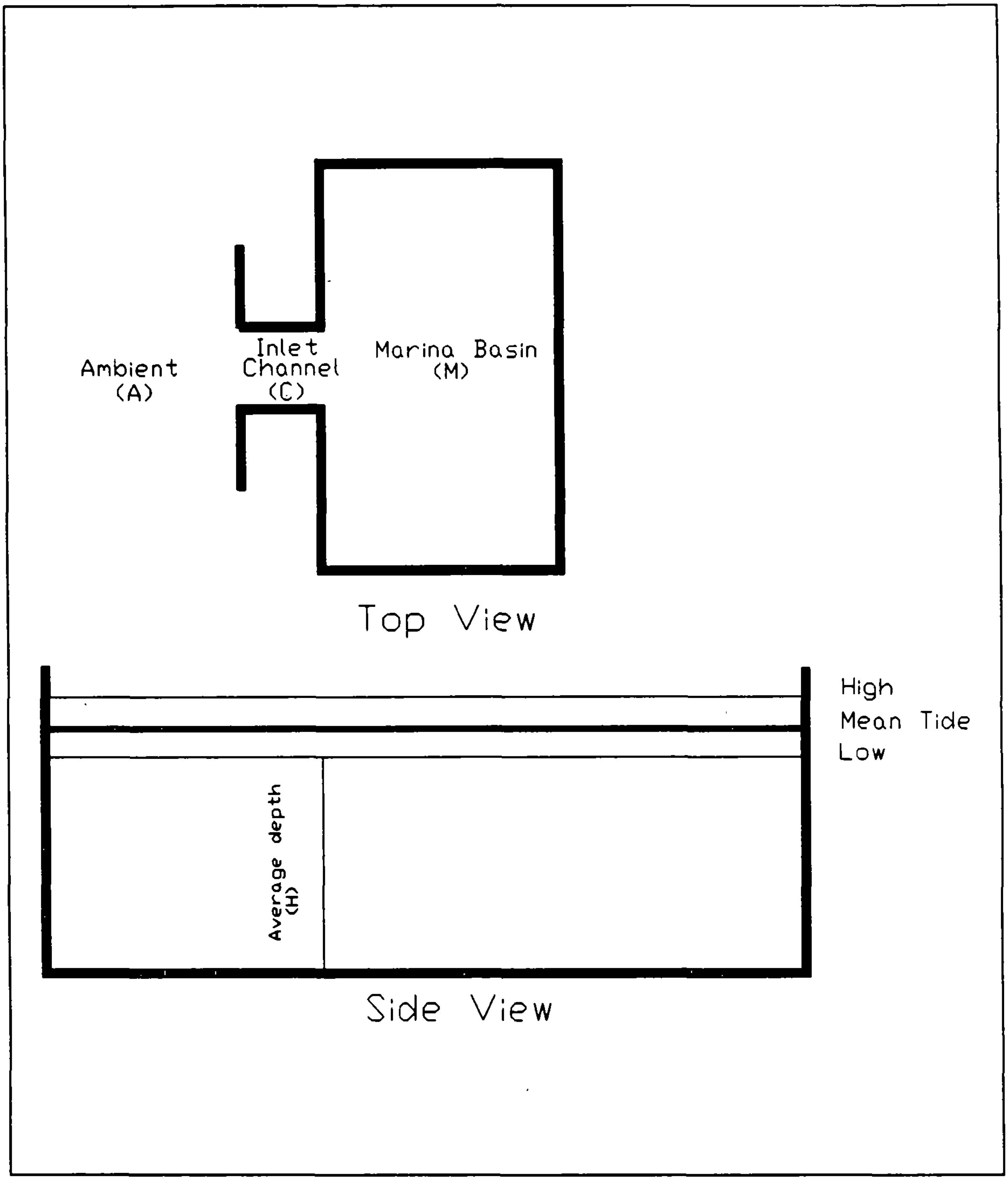

Figure B1. Schematic of Model Terms.

TABLE B-1. NCDEM DO Model Input Data Requirements.

Variable	Description
HM	Average marina depth (m)
HC	Average channel depth (m)
AC	Channel surface area
AM	Marina surface area
TA	Tidal amplitude (m) ; half the tidal range
SOD	Sediment oxygen demand (gm/m^2-day)
DO_A	Ambient DO (mg/L)
DO_S	Saturation DO (mg/L)
K_d	Decay coefficient (per day)
K_r	Reaeration rate (per day)
NBC	Channel boat activity (boat-hrs/day)
NBM	Marina boat activity (boat-hrs/day)
DOC	Channel dissolved oxygen
DOM	Marina dissolved oxygen

NCDEM DO PROGRAM LISTING

```

      PROGRAM NCDEM_DO

      CHARACTER  NAME*40, OUTFILE*12
      REAL*8 HC, AC, AM, TA, B, SOD, DOA, DOS, Kd, Kr, NBC, NBM
     1, X, Y, DOC, DOM, DOCAVG,SC, SM, LC, LM, A, ADOT, VC
     2, VCDOT, VM, VMDOT, QA, QB, ADC, ADM, RC, RM, BC, BM, NC
     3, NM, DOMAVG

      INTEGER*4 T, Z

      data NBC, NMB /0,0/

      call system ('cls')

      WRITE(*,*) '          NCDEM_DO  Model      '
      write(*,*)
      write(*,*) '  Two Segment Marina-Tidal Amplitude Method '
      write(*,*)
      write(*,*) '       FORTRAN 77 VERSION '
      write(*,*)
      write(*,*) '         Developed By  '
      write(*,*) '       Tetra Tech, Inc.  '
      write(*,*)
      write(*,*) '         Developed For   '
      write(*,*) '         EPA Region IV   '
      write(*,*)

      WRITE (*, 6000)
 6000 FORMAT(2X,' Enter The Name of The Output File --> ')
C
      READ (5, 5000) OUTFILE
 5000 FORMAT(A12)
C
      OPEN (UNIT=6,ACCESS='SEQUENTIAL',STATUS='unknown',FILE=outfile)

 7000 CONTINUE

      WRITE(*,*) ' Name Of Marina ? '
      READ (*,'(A40)') Name
      WRITE(6,10) NAME

      WRITE(*,*) ' Average Channel Depth (Feet) ? '
      READ (*,*) HC
      WRITE(6,11) HC
         HC  = 0.3048 * HC

      WRITE(*,*) ' Average Marina Depth (Feet) ? '
      READ (*,*) HM
      WRITE(6,12) HM
         HM  = 0.3048 * HM

      WRITE(*,*) ' Channel Surface Area (Feet**2) ? '
      READ (*,*) AC
      WRITE(6,25) AC
         AC  = 0.0929 * AC

      WRITE(*,*) ' Marina Surface Area (Feet**2) ? '
      READ (*,*) AM
      WRITE(6,13) AM
```

```
          AM  = 0.0929 * AM

       WRITE(*,*) ' Input Tidal Amplitude (Feet) ? '
       READ (*,*)  TA
       WRITE(6,14) TA
       A0 = 0.3048 * TA

       WRITE(*,*) ' Return Flow Factor (Dimensionless) ? '
       READ (*,*) B
       WRITE(6,15) B

       WRITE(*,*) ' Sediment Oxygen Demand (g/m**2/day) ? '
       READ (*,*) SOD
       WRITE(6,16) SOD

       WRITE(*,*) ' Ambient DO (mg/L) ? '
       READ (*,*) DOA
       WRITE(6,17) DOA

       WRITE(*,*) ' Saturation DO (mg/L) ? '
       READ (*,*) DOS
       WRITE(6,18) DOS

       WRITE(*,*) ' Decay Coefficient (1/day) ?'
       READ (*,*) Kd
       WRITE(6,19) Kd

       WRITE(*,*) ' Reaeration Coefficient (1/day) ? '
       READ (*,*) Kr
       WRITE(6,20) Kr

       WRITE(*,*) ' Channel Boat Activity (Boat-hours/day) ?'
       READ (*,*) NBC
       WRITE(6,21) NBC

       WRITE(*,*) ' Marina Boat Activity (Boat-hours/day) ?'
       READ (*,*) NBM
       WRITE(6,22) NMB

       WRITE(6,1)
     1 FORMAT(//,5X,' T  (HRS) ,     DOC (mg/L),     DOM (mg/L) ')
       WRITE(6,'(/)')

       X  = 0
       Y  = 0
       Z  = 0
       DOC = 6
       DOM = 6
       DOCAVG = 6

       SC = SOD*AC*41.67
       SM = SOD*AM*41.67

       T  = 0
       LC = 1.135 * (NBC+NBM) / ( A0*(AC+AM) * (1-B) )
       LM = LC + 1.135*NBM/(A0*AM)

       KD  = KD / 24.0
       KR  = KR / 24.0
   370 A   = A0*SIN(.5236*T)
       ADOT = 0.5236*A0*COS(.5236*T)
```

```
      VC   = (HC+A)*AC*1000
      VCDOT = ADOT*AC*1000
      VM   = (HM+A)*AM*1000
      VMDOT =ADOT*AM*1000
      QA    = ADOT*(AC+AM)*1000
      QB    = ADOT*AM*1000

         IF ( ADOT .LT. 0 ) GO TO 490
      ADC = QA*((1-B)*DOA+B*DOCAVG) -QB *DOC
      ADM = QB*DOC
      GO TO 510
  490 ADC = QA*DOC-QB*DOM
      ADM = QB *DOM
  510 RC   = Kr * (DOS - DOC ) * VC
      RM   = Kr * (DOS - DOM ) * VM
      BC   = KD*LC*VC
      BM   = KD *LM *VM
      NC   = ADC + RC -SC -BC
      NM   = ADM + RM -SM -BM
      DOC = (NC+(VC-VCDOT)*DOC) / VC
      DOM = (NM+(VM-VMDOT)*DOM) / VM

         T   = T + 1
         Z   = Z + 1
         X   = X + DOC
         Y   = Y + DOM

      IF ( Z .LT. 12 ) GO TO 690
      DOCAVG = X / 12.0
      DOMAVG = Y / 12.0

         X   = 0
         Y   = 0
         Z   = 0

  690 IF ( T .LT. 216 ) GO TO 370
      WRITE(6,2)  T, DOC,  DOM
2     FORMAT(5X,I10,5X,F10.4,5X,F10.4)
      IF ( T .EQ. 227 ) GO TO 725
      IF ( T .LT. 239 ) GO TO 370
  725 CONTINUE
      WRITE(6,23) DOCAVG
      WRITE(6,24) DOMAVG
      IF ( T .LT. 239 ) GO TO 370


800   CALL SYSTEM ('CLS')

      WRITE(*,*) ' Make a Selection and then Hit Return'
      WRITE(*,*)
      WRITE(*,*)'(1)  Go Back to Make Another Run.'
      WRITE(*,*)'(2)  Exit the Program.'
      WRITE(*,*)
      READ (*,*) IEND
      IF ( IEND .EQ. 2 )  THEN
         CLOSE (6)
         GO TO 900
      ENDIF

      IF ( IEND .EQ. 1 ) THEN
         GO TO 7000
      ELSE
```

```
         GO TO 800
      ENDIF


c   format statements

   10 format(20x,a40,// )
   11 format(' Average Channel Depth (Feet)          = ', f10.2)
   12 format(' Average Marina Depth (Feet)           = ', f10.2)
   13 format(' Marina Surface Area (Feet**2)         = ', f10.2)
   14 format(' Input Tidal Amplitude (Feet)          = ', f10.2)
   15 format(' Return Flow Factor (Dimensionless)    = ', f10.2)
   16 format(' Sediment Oxygen Demand (g/m**2/day)   = ', f10.2)
   17 format(' Ambient DO (mg/L)                     = ', f10.2)
   18 format(' Saturation DO (mg/L)                  = ', f10.2)
   19 format(' Decay Coefficient (1/day)             = ', f10.2)
   20 format(' Reaeration Coefficient (1/day)        = ', f10.2)
   21 format(' Channel Boat Activity (Boat-hours/day) = ', f10.2)
   22 format(' Marina Boat Activity (Boat-hours/day) = ', f10.2)
   23 format('  DOCAVG (mg/L) = ', f12.4)
   24 format('  DOMAVG (mg/L) = ', f12.4)
   25 format(' Channel Surface Area (Feet**2)        = ', f10.2)

  900 STOP
      END
```