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A Modelling Study of the Water Quality of the Upper Tidal Rappahannock River

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A Report Submitted to the City of Fredericksburg and Counties of Spotsylvania and Stafford, VA

Special Report in Applied Marine Science and Ocean Engineering No. 314

College of William and Mary
Virginia Institute of Marine Science
School of Marine Science
Gloucester Point, VA 23062

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We wish to thank the many individuals who assisted VIMS with the project. In particular, staff from the City of Fredericksburg, Stafford County, and Spotsylvania County collected wastewater samples from the sewage treatment plants and composite samples from the river near the falls prior to each slackwater survey and prior to and during the intensive survey.

Some of these individuals and members of the group, The Friends of the Rappahannock, assisted with the sampling during the intensive survey. To each of them, we extend our appreciation.

We also wish to thank Mr. Dale Phillips of Virginia State Water Control Board, who offered valuable suggestions to the planning of this study and provided a constructive review of this report.
I. INTRODUCTION

The purpose of this report is to document the steps and the work that have resulted in a calibrated and verified model of water quality in the upper tidal Rappahannock River. Before doing this, it seems appropriate to discuss the steps in this process. Once it has been determined that a mathematical model should be used in the design and analysis of a management problem, a number of steps must be taken. First, a model that is appropriate to the management issue must be selected. Second, data must be assembled or new data collected to characterize the behavior of the system being modeled. Then the model can be applied to that system. During an often lengthy calibration and verification process, model coefficients and parameters are adjusted until the model reproduces the behavior of the real world system. If the model can simulate system responses for one set of conditions, it is said to be calibrated. If it can reproduce system responses for a range of conditions, it is said to be verified. Once these steps have been completed, the model is available for designing and analyzing management alternatives. An early step in this phase of the work is to assess the model’s accuracy and the sensitivity of model predictions to variations in model parameters.

For the case at hand, the water quality modelling was required by the Virginia Water Control Board as a condition for renewal of discharge permits for the wastewater treatment plants operated by the City of Fredericksburg, Spotsylvania County, and Stafford County.

"(T)he permittee shall gather the necessary data, and either recalibrate and
reverify the dataset for the existing AUTOSS Rappahannock River Model or develop a new model for the upper 30 miles of the Rappahannock Estuary, and submit such information to the State Water Control Board for review."

The AUTOSS model was no longer sufficient for two reasons: first, the data used to calibrate the model were gathered in the early 1970’s, and second, the model only simulated the impact of oxygen demanding materials (BOD) on the dissolved oxygen (DO) regime in the river. Recent water quality monitoring studies indicated that nutrients, in particular nitrogen and phosphorus, in the effluent from the wastewater treatment plants were promoting the growth of algae downriver. An expert panel convened by the Water Control Board to study nutrient enrichment in estuaries suggested that concentrations of chlorophyll ‘a’ greater than 25 µg/l indicated over-enriched conditions. The Water Control Board’s monitoring data showed that during water year 1987, "(S)tation TF3.2, the only tidal freshwater station sampled by this program, exhibited an average chlorophyll ‘a’ concentration of 57 µg/l, with a maximum of 114 µg/l during the fall" (VWCB, 1988). The station TF3.2 is located at Port Royal, about 30 miles below Fredericksburg. In addition, it was noted that the Governors’ Agreement of 1987 called for a 40% reduction in the nitrogen and phosphorus loadings to the Chesapeake Bay system. For these reasons, it was suggested that a state-of-the-art model be applied to the upper tidal Rappahannock River. This model includes calculations of tidal heights and currents plus water quality simulations of algal growth, the cycling of nitrogen and phosphorus, and the DO regime. The model is one-dimensional, meaning that water elevations, currents, and water quality variables are assumed to be constant at any river cross-section, but vary along the axis of the river. The water quality model is reasonably similar to the
model being applied to the Chesapeake Bay system for the Chesapeake Bay Program, except that the bay model includes all three space dimensions and it subdivides phytoplankton and nutrients into more species.

A field program was designed and sampling occurred during the summer of 1990. That field program will be described in Chapter II. The formulation of the mathematical model will be presented in Chapter III. Application of the hydrodynamic (water elevations and currents) model and application of the water quality model to the Rappahannock River will be covered in Chapters IV and V respectively. The sensitivity of the model predictions to various factors will be presented in Chapter VI. The report concludes with a discussion of the Rappahannock River model in Chapter VII.
II. FIELD PROGRAM

The purpose of the field program is to collect data that show how water quality varies in the upper reaches of the tidal Rappahannock River. Data are needed for a range of conditions to document the associated water quality variations and also to allow the model to be tested for that range of environmental conditions. The seasonal variation in water quality from late spring to early fall has been monitored through the use of slackwater surveys. For estuaries, the critical period is the summer, when water temperatures are high, and dissolved oxygen concentrations often are lower than at any other time of the year. A comprehensive and intensive survey of water quality was conducted in late July. The data have been used to calibrate the model. Both of these surveys will be described in the following sections.

A. Slackwater Surveys

The costs of field surveys and associated laboratory analyses can be quite high. When longer term monitoring is needed, a method of capturing the important aspects of the system is needed. For estuaries, slackwater surveys provide a "snapshot" of water quality conditions. The research vessel moves up the river with slackwater, sampling at predetermined stations along the axis of the river. In this study, all slackwater surveys were conducted at slack tide before flood. Generally speaking, water quality conditions will be poorest at slack before flood, because the water volume available to dilute wastewaters is at a minimum at this time. Conversely, water quality conditions will tend to be best at slack before ebb, because of the greater volume of water in each
section of the river.

Nine surveys were conducted at roughly two week intervals between May 22 and September 4, 1990. At each survey, water quality parameters were measured, or water samples collected for analysis, at each of the predetermined stations. The parameters measured or sampled included:

1. DO, Temperature
   Measured at surface, mid-depth, and bottom
2. Secchi depth
3. Chlorophyll ‘a’ (corrected for pheophytin):
   Samples collected at surface and bottom
4. \( \text{CBOD}_5, \text{PN}, \text{TDN}, \text{NH}_4-\text{N}, \text{NO}_2-\text{N}, \text{PP}, \text{TDP}, \text{OP} \)
   Samples collected at surface and bottom for stations greater than 4m depth, mid-depth only for stations less than 4 m depth.
5. \( \text{CBOD}_u, \text{DO} \)
   Collect three samples for each survey, alternate the sampling stations from survey to survey. The \( \text{CBOD}_u \) samples were used to establish the ratio of \( \text{CBOD}_u \) to \( \text{CBOD}_5 \). The DO samples were used to check DO probe calibration.

where

\[
\text{CBOD}_5 = \text{nitrogen inhibited 5-day BOD}
\]
\[
\text{PN} = \text{particulate nitrogen}
\]
\[
\text{TDN} = \text{total dissolved nitrogen}
\]
\[
\text{NH}_4-\text{N} = \text{ammonia nitrogen}
\]
\[
\text{NO23-N} = \text{nitrite plus nitrate nitrogen} \\
\text{PP} = \text{particulate phosphorus} \\
\text{TDP} = \text{total dissolved phosphorus} \\
\text{OP} = \text{ortho phosphorus}
\]

The data from these surveys are included in tables in Appendix 1. Samples were collected at nine stations between Port Royal and Fredericksburg (Figure 2-1). The three cruises near the beginning of June, July, and August began at the mouth of the river and included sampling stations from the mouth to the Route 3 bridge at Fredericksburg, some 175 kilometers upriver.

Water quality conditions in the tidal Rappahannock result from a number of factors, but two important ones are the quality of the water passing over the fall line and the quantity and quality of the wastewaters discharged to the river. This information is important to both understanding why conditions are as they are and also for the proper functioning of the model. For these reasons, water quality samples were collected at the fall line at Fredericksburg and at each of the major wastewater treatment plants on the day preceding each slackwater survey. These data have been tabulated and are included in Appendix 2.

B. Intensive Survey

The intensive survey is a focused study of water quality processes that is geared towards providing the detailed information needed to calibrate the model. It therefore must be comprehensive, including all features that are important determinants of water quality. In addition to intensive monitoring of water quality conditions, the study
Figure 2-1. Sampling and measuring stations, summer 1990.
included measurements of tidal elevations along the river, measurements of tidal currents between Port Royal and Fredericksburg, measurements of tidal dispersion by following a mass of tracer dye, and monitoring of the major sources of pollutants. Each of these will be discussed below.

B-1. Water quality

Water quality, especially the abundance of algae, varies with time of day. When there is a variation in water quality along the river axis, that pattern moves upriver and downriver with the tides. In order to capture these variations, the intensive survey lasted 25 hours, or two complete tidal cycles and one complete day-night cycle. Data were collected at six stations between Fredericksburg and Port Royal (see Figure 2-1). The dissolved oxygen (DO) concentration, water temperature and Secchi depth were measured every hour. Water samples were collected every other hour to determine the concentration of dye (see later section), carbonaceous biochemical oxygen demand (5-day CBOD), chlorophyll ‘a’, and nutrients. Once during the survey a sample was taken from each station and incubated for 30 days to determine the long term or ultimate oxygen demand (CBOD$_u$). The data from the intensive survey have been tabulated and are included in Appendix 3. The data were used in model calibration and are included in the figures in Chapter V.

B-2. Tide measurements

The tides are an important aspect of the physical environment and are important for calibration of the hydrodynamic model. Water surface elevations were measured at
three locations. A tide gage was installed near the mouth of the river and maintained for the entire study period, May to September. The data from this gage have been used as a downstream boundary condition. Two other tide gages were installed near Port Royal and near Fredericksburg for a period encompassing the intensive survey. These data are presented in Chapter IV as part of the application of the hydrodynamic model.

B-3. **Current measurements**

Current meters were installed at three locations between Port Royal and Fredericksburg (see station locations in Figure 2-1). Current speeds and directions were measured every thirty minutes for approximately five days, beginning about two days before the intensive survey and continuing until about two days after the intensive survey. The data have been plotted and are included in Appendix 4. The plots include (1) "stick diagrams" which show the currents as vectors and (2) scatter plots showing the principal direction of the flood and ebb currents. These data also have been used in the calibration of the hydrodynamic model (Chapter IV).

B-4. **Dye study**

Materials discharged to the river are not only moved downriver, they also are dispersed. Calibration of the hydrodynamic model requires measures of this mixing. A conservative tracer, the fluorescent dye Rhodamin-WT, was released to the river 4 kilometers below the fall line. Dye solution (7.3 kg in 6.7% concentration) was released from a small boat moving across the river at slack tide before flood (0530, July 25). During the intensive survey, water samples were collected hourly at the six sampling stations. In addition, a vessel equipped with fluorometer made longitudinal surveys at
slack tides. These slackwater dye surveys continued for about a week following the intensive survey. The dye distributions were used to verify the model simulation of mass transport in the upper reaches of the river (see Chapter IV).

B-5. **Point source pollutant loads**

The pollutants discharged to the rivers have a direct effect on water quality. Operation of the water quality model requires that the pollutant inputs be specified. Calibration of the model, therefore, requires that the pollutant loadings from the several sewage treatment plants (STP's) be specified for sampling periods. Wastewater samples were collected from each of the STP's for the three day prior to the intensive survey and each day of the survey so that pollutant discharges to the river were well known for the calibration period. As mentioned earlier, on the day prior to each slackwater survey wastewater samples were collected, for use in the verification of the model. The data for both the intensive and slackwater surveys have been tabulated and are included in Appendix 2.

Biochemical oxygen demand or BOD is a measure of the amount of oxygen that will be consumed as organic matter is degraded by bacteria in the water. The model employs the long term or ultimate carbonaceous BOD, whereas the standard method is for a sample to be incubated for 5 days only. Some means to relate the 5-day value to the ultimate CBOD is needed. A water sample was collected at each sampling station and wastewater samples were collected from each STP for long term incubation during the intensive survey. All STP's and a few river stations were sampled during each slackwater survey as well. The values for the ultimate and 5-day CBOD's for the
sewage treatment plants are listed in Table 2-1, along with the ratio of the two. The ratios for the STP's have been listed in Table 2-2. The ratios for the river stations also are listed in Table 2-2 and are shown graphically in Figure 2-2. The median of the river samples, 2.82, was used to convert 5-day CBOD to ultimate CBOD for all river samples.

B-6. **Nonpoint source pollutant loadings**

The sewage treatment plants are not the only source of pollutants. Runoff from the land and the water which flows over the falls both contain pollutants. The river water entering the upper end of the tidal river was sampled on the three days preceding the intensive survey and on each day of the survey. On each day, a 24-hour composite sample was collected. These data, and those for the slackwater surveys, are included in Appendix 2.

The river flow is monitored by the U.S. Geological Survey. These data were used to ensure that the intensive survey occurred during a period when the point sources were not overwhelmed by nonpoint sources of pollution. Although a fairly significant rain event occurred about ten days prior to the intensive survey, river flow had declined consistently and was within the limits set for the study.

B-7. **Internal sources of pollutants**

Much of the material that enters the river is transported downriver. Some of the material, however, settles to the bottom. Organic matter in the bottom sediments decomposes and eventually is released to the water column. Twenty years ago,
Table 2-1. Values of CBODu, CBOD5 and CBODu/CBOD5 for wastewater samples.

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<th>Date</th>
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<th>BODs</th>
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<th>FMC BODu</th>
<th>BODs</th>
<th>R</th>
<th>Fredericksburg BODu</th>
<th>BODs</th>
<th>R</th>
<th>Massaponax BODu</th>
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ave.: arithmetic average.
med.: median.
R: ratio of BODu to CBOD5.
BODu: ultimate CBOD (30 days).
BOD5: 5-day CBOD.
Table 2-2. Values of CBODu/CBOD5 for river water samples.

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t: top
b: bottom
avg.: arithmetic average
med.: median
Figure 2-2. Ratio of CBOD$_3$ to CBOD$_5$ for river water samples (different symbols for different dates).
wastewater treatment removed only a portion of the pollutants and the discharges were the primary factor affecting river water quality. Current wastewater treatment removes much more of the pollutants. As the point source contributions have decreased, the relative importance of other sources has increased. One source which now must be measured is the internal cycling of nutrients and organic matter in the sediments.

The fluxes of dissolved oxygen and nutrients between the river bed and the overlying water were measured prior to and following the intensive survey. Measurements were made at three stations (see Figure 2-1). The results of the benthic surveys are included in Appendix 5.

C. Discussion

As with all human endeavors, problems developed during the field program. For example, the slackwater survey on July 18th could not be completed because a cotter pin sheared and the propeller came off the engine of the vessel. Consequently, an additional survey was conducted on July 22. The number of stations monitored during the intensive survey was increased during the planning stage to ensure that there would be an adequate data base even if problems arose.

All in all, the field program was very successful. Few elements were not completed and data recovery was quite good. Much of the credit goes to the staff of the City of Fredericksburg and the two counties. These individuals collected the STP and fall line samples, and a number of them participated in the intensive survey as well.
III. DESCRIPTION OF THE MATHEMATICAL MODEL

The mathematical model employed in this study consists of two separate models, a hydrodynamic model and a water quality model. The hydrodynamic model provides predictions of surface level and current velocity throughout the system, and is also capable of predicting the transport of a conservative substance such as salt or dye. The water quality model employs information on the hydrodynamic provided by the first model to predict the concentrations of eight nonconservative dissolved substances: organic nitrogen, ammonia nitrogen, nitrite-nitrate nitrogen, organic phosphorus, ortho phosphorus, chlorophyll ‘a’, carbonaceous biochemical oxygen demand, and dissolved oxygen. Both models are real-time and one-dimensional. That is, they predict parameter variations within a tidal cycle and along the longitudinal axis of the system, but not along the lateral or vertical axis. Details of the formulations of the models are presented in this chapter.

A. Hydrodynamic Model

A-1. Basic equations

Assuming incompressible flow for estuarine rivers, the one-dimensional equations of continuity, momentum, and mass-balance for salt may be written, respectively, as

\[
\begin{align*}
B \frac{\partial \eta}{\partial t} + \frac{\partial Q}{\partial x} &= q, \\
\frac{\partial Q}{\partial t} + \frac{\partial \left(\frac{Q^2}{A}\right)}{\partial x} &= -gA \frac{\partial \eta}{\partial x} - \frac{gkA}{1 + kS} \frac{\partial S}{\partial x} - gn^2 \frac{Q}{A} |Q| R^{-4/3} + \frac{\tau_B}{\rho} + M
\end{align*}
\]
\[
\frac{\partial}{\partial t} (AS) + \frac{\partial}{\partial x} (QS) - \frac{\partial}{\partial x} \left( EA \frac{\partial S}{\partial x} \right) + So
\] (3-3)

where

\[t = \text{time},\]
\[x = \text{distance along river axis},\]
\[B = \text{the surface width of the river},\]
\[\eta = \text{the water surface elevation referenced to mean sea level},\]
\[Q = \text{discharge},\]
\[q = \text{the lateral inflow per unit length of the river},\]
\[A = \text{cross-sectional area},\]
\[g = \text{gravitational acceleration},\]
\[k = \text{a constant relating water density to salinity},\]
\[d_c = \text{the distance from the centroid of cross-sectional area to water surface},\]
\[S = \text{salinity},\]
\[n = \text{Manning friction coefficient},\]
\[R = \text{the hydraulic radius of the cross-section},\]
\[\tau_s = \text{the surface wind stress},\]
\[\rho = \text{the density of water},\]
\[M = \text{the momentum source from lateral inflow},\]
\[E = \text{the dispersion coefficient},\]
\[So = \text{source or sink of salt}.\]

The dispersion coefficient \(E\) is estimated following the formulation in Wilber and Kuo (1987), which is
\[ E = E_0 + 63.2 \, n |U| R^{5/6} \]  

(3-3a)

where

\[ E_0 = \text{minimum dispersion coefficient}, \]
\[ U = \text{cross-sectionally averaged longitudinal velocity} = Q/A, \]
\[ U_t = \text{amplitude of the tidal current}, \]
\[ T = \text{period of tidal oscillation}, \]
\[ Q_f, Q_t = \text{freshwater discharge and tidal flow at the river mouth, respectively}, \]
\[ T_s = \text{a constant on the order of } 10^4 \text{ to } 10^5, \]
\[ \nu = \text{a constant, about 4.0 for the Virginia estuaries, if metric units are used, and} \]
\[ \lambda = \text{a constant, about 10 for the Virginia estuaries if } x \text{ in km and all others in} \]
\[ \text{metric unit.} \]

The second term on the right hand side of the equation accounts for the dispersion due to the vertical and transverse shear of the tidal flow, and is applicable to the tidal river, including the freshwater portion. The third term on the right hand side accounts for the mass transport by estuarine gravitational circulation and which typically dominates in the saline portion of the river.


To facilitate the solution of differential equations by the finite difference method, the length of the estuary is divided into a number of reaches (or segments) bounded by transects at two ends. The top view of the longitudinal schematization is shown in Figure 3-1.
Figure 3-1. Method of schematization.

in which the parameters given are

\[ \Delta x_i = \text{the distance between the centers of two reaches adjoining the } i^{\text{th}} \text{ transect}, \]
\[ Q_i = \text{the flow rate through the } i^{\text{th}} \text{ transect}, \]
\[ A_i = \text{the cross-sectional area of the } i^{\text{th}} \text{ transect}, \]
\[ \eta_i = \text{the water surface elevation of the } i^{\text{th}} \text{ reach}, \]
\[ V_i = \text{the volume of the } i^{\text{th}} \text{ reach}, \]
\[ S_{a_i} = \text{the surface area of the conveyance channel in the } i^{\text{th}} \text{ reach}, \]
\[ S_{t_i} = \text{the surface area of the storage embayment in the } i^{\text{th}} \text{ reach}, \]
\[ q_i = \text{the rate of total lateral inflow in the } i^{\text{th}} \text{ reach}, \]
\[ S_i = \text{salinity in the } i^{\text{th}} \text{ reach}, \] and
\[ S^*_i = \text{salinity of the water flowing through the } i^{\text{th}} \text{ transect}. \]
A-3. Finite difference equations

To write equation 3-1 into finite difference form, it is first integrated with respect to x from the $i^{th}$ to the $(i+1)^{th}$ transects, and future time difference is substituted for time differentiation:

$$
(Sa_i + St_i) \frac{(\eta_i' - \eta_i)}{\Delta t} = \beta(Q_i' - Q_i) + \beta_c(Q_i' - Q_{i+1}) + q_i
$$

(3-4)

where $\Delta t$ is the time increment. The primed variables designate the quantities evaluated at time $t+\Delta t$ and the unprimed variables designate those at time $t$. $\beta$ and $\beta_c$ are weighting factors which satisfy

$$
\beta + \beta_c = 1
$$

The momentum equation, equation 3-2, may be written in finite difference form at the $i^{th}$ transect as

$$
\frac{(Q_i' - Q_i)}{\Delta t} + \frac{1}{A_i} \left[ \frac{Q_i + Q_{i+1}}{2} \left( \frac{Q_i}{A_i} + \frac{Q_{i+1}}{A_{i+1}} \right) - \frac{Q_{i-1} + Q_i}{2} \left( \frac{Q_{i-1}}{A_{i-1}} + \frac{Q_i}{A_i} \right) \right] + \frac{gA_i d_e(i)}{A_i} \frac{S_i - S_{i-1}}{1 + \kappa \frac{S_{i-1} + S_i}{2}} + \frac{1}{\rho_i} B_i + M_i
$$

(3-5)

$$
- \frac{1}{\rho_i} B_i + M_i
$$

where $\alpha$ and $\alpha_c$ are weighting factors which satisfy

$$
\alpha + \alpha_c = 1
$$

Similar to the continuity equation, the mass-balance equation for salt, equation 3-3, is first integrated with respect to $x$ and, then, written in terms of finite difference in time,
\[
\frac{V_i' S_i' - V S_i}{\Delta t} = \frac{Q_i' S_i' - Q_{i+1}' S_{i+1}'}{\Delta t} + \left( EA \frac{\partial S}{\partial x} \right)_{i+1} - \left( EA \frac{\partial S}{\partial x} \right)_{i} + S_{0} \quad (3-6).
\]

S' may be expressed as a function of salinities in the two adjacent reaches, i.e.,
\[
S' = \gamma_i S_{i-1} + \delta_i S_i
\quad (3-6a)
\]
where
\[
\gamma_i + \delta_i = 1 \quad \text{and} \quad 0.5 \leq \gamma_i \leq 1.0 \quad \text{if} \quad Q_i \geq 0
\]
\[
\gamma_i < 0.5 \quad \text{if} \quad Q_i < 0
\quad (3-6b).
\]
The dispersive term may be written as
\[
\left( EA \frac{\partial S}{\partial x} \right)_{i} = E_i A_i \left( S_i - S_{i-1} \right) \Delta x_i
\]

A-4. Method of solution
A-4-1. Continuity and momentum equations

Equations 3-4 and 3-5 are a coupled system of algebraic equations, which need to be solved simultaneously for \( \eta'_i \) and \( Q'_i \) for all \( i \). The system is solved by substitution and elimination processes. Equation 3-5 may be written as
\[
Q'_i = \alpha g A_i \frac{\Delta t}{\Delta x_i} \left( \eta'_{i-1} - \eta'_i \right) + (CQ)_i
\quad (3-7)
\]
where
\[
(CQ)_i = Q_i + \frac{1}{4} \frac{\Delta t}{\Delta x_i} \left[ (Q_{i-1} + Q_i) \left( \frac{Q_{i+1}}{A_{i-1}} + \frac{Q_i}{A_i} \right) - (Q_i + Q_{i+1}) \left( \frac{Q_i}{A_i} + \frac{Q_{i+1}}{A_{i+1}} \right) \right]
\]
\[
+ \alpha g \frac{\Delta t}{\Delta x_i} A_i (\eta_{i-1} - \eta_i) - \frac{\Delta t}{\Delta x_i} g k A_i \frac{d_i(i)}{1+k} (S_i - S_{i-1})
\]
\[
- g n_i^2 \frac{Q_i}{A_i} |Q_i| R_i^{-4/3} \Delta t + \frac{\tau_i}{\rho_i} B_i \Delta t + M_i \Delta t
\quad (3-7a).
\]
Substituting equation 3-7 into equation 3-4, it is obtained that

\[
\frac{(S_{a} + S_{t}) (\eta'_{i} - \eta_{i})}{\Delta t} = \alpha \beta g \left[ A_{i} \frac{\Delta t}{\Delta x_{i}} (\eta'_{i-1} - \eta'_{i}) - A_{i+1} \frac{\Delta t}{\Delta x_{i+1}} (\eta'_{i} - \eta'_{i-1}) \right] + \beta \left[ (CQ)_{i} - (CQ)_{i+1} \right] + \beta_{e} (Q_{i} - Q_{i+1}) + q_{i}
\]

or

\[
\eta'_{i} = a_{i} \eta'_{i+1} + b_{i} \eta'_{i-1} + c_{i}
\]

where

\[
a_{i} = \alpha \beta g A_{i} \frac{\Delta t}{\Delta x_{i}} \frac{1}{d_{i}}
\]

\[
b_{i} = \alpha \beta g A_{i} \frac{\Delta t}{\Delta x_{i}} \frac{1}{d_{i}}
\]

\[
c_{i} = \left[ (S_{a} + S_{t}) \frac{\eta_{i}}{\Delta t} + \beta \left[ (CQ)_{i} - (CQ)_{i+1} \right] + \beta_{e} (Q_{i} - Q_{i+1}) + q_{i} \right] \frac{1}{d_{i}}
\]

(3-8a).

\[
d_{i} = \frac{(S_{a} + S_{t})}{\Delta t} + \alpha \beta g \left[ A_{i} \frac{\Delta t}{\Delta x_{i}} + A_{i+1} \frac{\Delta t}{\Delta x_{i+1}} \right]
\]

To calculate the coefficients \(a_{i}, b_{i}\) and \(c_{i}\) at the most upstream reach, say \(i = m_{l}\), some upstream boundary condition is required. The most common boundary condition for a tidal river is the upstream nontidal discharge, specified as \(Q_{m_{l}}\) for all time. With \(Q'_{m_{l}}\) given, substitution of equation 3-7 with \(i = m_{l} + 1\) into equation 3-4 with \(i = m_{l}\), equation 3-4 becomes

\[
\frac{(S_{a} + S_{t}) (\eta'_{m_{l}} - \eta_{m_{l}})}{\Delta t} = \beta \left[ Q'_{m_{l}} - \alpha g A_{m_{l}+1} \frac{\Delta t}{\Delta x_{m_{l}+1}} (\eta'_{m_{l}} - \eta'_{m_{l}+1}) + (CQ)_{m_{l}+1} \right] + \beta_{e} (Q_{m_{l}} - Q_{m_{l}+1}) + q_{m_{l}}
\]

or

\[
\eta'_{m_{l}} = a_{m_{l}} \eta'_{m_{l}+1} + c_{m_{l}}
\]

(3-8b)
where

\[
\begin{align*}
a_{ml} & = \alpha \beta g A_{ml+1} \frac{\Delta t}{\Delta x_{ml+1}} \frac{1}{d_{ml}} \\
c_{ml} & = \left. \left( (Sa_{ml} + St_{ml}) \frac{\eta_{ml}}{\Delta t} + \beta Q_{ml} - \beta (CQ)_{ml+1} + \beta c (Q_{ml} - Q_{ml+1}) + q_{ml} \right) \right| \frac{1}{d_{ml}} \\
d_{ml} & = \left. \frac{(Sa_{ml} + St_{ml})}{\Delta t} + \alpha \beta g A_{ml+1} \frac{\Delta t}{\Delta x_{ml+1}} \right|
\end{align*}
\]

Equation 3-8 may be solved by elimination process if the downstream boundary condition \((\eta'_i)\) is given at the most downstream reach, say \(i = \mu\). Let

\[
\eta'_i = P_i \eta'_{i+1} + O_i
\]

where \(P_i\) and \(O_i\) are recursion coefficients yet to be determined. Substituting

\[
\eta'_{i+1} = P_{i-1} \eta'_i + O_{i-1}
\]

into equation 3-8, it becomes

\[
\eta'_i = a_i \eta'_{i+1} + b_i (P_{i-1} \eta'_i + O_{i-1}) + c_i
\]

or

\[
\eta'_i = \frac{a_i}{1 - b_i P_{i-1}} \eta'_{i+1} + \frac{b_i O_{i-1} + c_i}{1 - b_i P_{i-1}}
\]

Comparing equation 3-10 with equation 3-9, the recursion equations obtained are

\[
\begin{align*}
P_i & = \frac{a_i}{1 - b_i P_{i-1}} \\
O_i & = \frac{b_i O_{i-1} + c_i}{1 - b_i P_{i-1}}
\end{align*}
\]

Equation 3-8a gives

\[
P_{ml} = a_{ml}, \quad O_{ml} = c_{ml}
\]

In summary, the numerical calculation will proceed as follows:

i) Calculate \((CQ)_i\) for \(ml+1 \leq i \leq \mu\) using equation 3-7a,

ii) Calculate \(a_i, b_i, c_i\) for \(ml \leq i \leq \mu-1\) using equation 3-8a or 3-8c,
iii) Calculate $P_i$ and $O_i$ for $ml \leq i \leq mu-1$ using equation 3-11 or 3-11a,

iv) With $\eta_{i,mu}$ known, calculate $\eta_i$ for $i = mu-1, mu-2, ..., ml$ using equation 3-9,

v) Calculate $Q_i'$ for $ml+1 \leq i \leq mu$ using equation 3-7 or using equation 3-4 with $Q'_{ml}$ known.

A-4-2. Mass-balance equation

Equation 3-6 represents a system of algebraic equations, which may be solved by elimination process. Substituting $S'_{i,i}$ and $S'_{i+1,i}$ and rearranging the terms, equation 3-6 becomes

$$S'_i = \frac{\Delta t}{V'_i} \left[ Q'_i (\gamma S'_{i-1} + \delta S'_i) - Q'_{i+1} (\gamma_{i+1} S'_i + \delta_{i+1} S'_{i+1}) \right] + \frac{V_i}{V'_i} S_i$$

$$+ \frac{\Delta t}{V'_i} \left[ E_{i+1} A_{i+1} S_{i+1} - E_i A_i \frac{S_i - S_{i-1}}{\Delta x_i} \right] + \frac{\Delta t}{V'_i} S_{0,i} \tag{3-12}.$$ 

After substitution, equation 3-12 becomes

$$S'_i = a_i S'_{i+1} + b_i S'_{i-1} + c_i \tag{3-13}$$

where

$$a_i = - \frac{\Delta t}{V'_i} \frac{\delta_{i+1} Q'_{i+1}}{d_i} \frac{1}{d_i}$$

$$b_i = \frac{\Delta t}{V'_i} \gamma_i Q'_i \frac{1}{d_i}$$

$$c_i = \left[ \frac{V_i}{V'_i} S_i + \frac{\Delta t}{V'_i} \left( E_{i+1} A_{i+1} \frac{S_{i+1} - S_i}{\Delta x_{i+1}} - E_i A_i \frac{S_i - S_{i-1}}{\Delta x_i} \right) + \frac{\Delta t}{V'_i} S_{0,i} \right] \frac{1}{d_i} \tag{3-13a}.$$ 

$$d_i = 1 + \frac{\Delta t}{V'_i} (\gamma_{i+1} Q'_{i+1} - \delta_i Q'_i)$$

Given the upstream boundary condition ($S'_{ml+1}$), $S'_{ml}$ may be expressed in terms of $S'_{ml+1}$ through equation 3-13 with $i=ml$, i.e.,
\[ S'_{ml} = a_{ml}S'_{ml+1} + b_{ml}S'_{ml-1} + c_{ml} \]  

(3-14)

where the only unknown on the right hand side of the equation is \( S'_{ml+1} \). Equation 3-14 may in turn be substituted back into equation 3-13 with \( i=\text{ml+1} \), and thus one arrives at an expression for \( S'_{ml+1} \) in terms of \( S'_{ml+2} \). In general, there exists the following relation

\[ S'_i = P_iS'_{i+1} + O_i \]  

(3-15)

where the recursion coefficients \( P_i \) and \( O_i \) may be calculated from the upstream boundary condition \( (S'_{ml-1}) \).

Equation 3-15 is similar to equation 3-9 and, therefore, the recursion equations are the same as equation 3-11, i.e.,

\[ P_i = \frac{a_i}{1 - b_iP_{i-1}}, \quad O_i = \frac{b_iO_{i-1} + c_i}{1 - b_iP_{i-1}} \]  

(3-16).

Since \( S'_{ml-1} \) is a known quantity, the comparison between equation 3-14 and 3-15 with \( i=\text{ml} \) gives

\[ P_{\text{ml}} = a_{\text{ml}}, \quad O_{\text{ml}} = b_{\text{ml}}S'_{\text{ml-1}} + c_{\text{ml}} \]

or, comparing with equation 3-16 for \( i=\text{ml} \)

\[ P_{\text{ml-1}} = 0, \quad O_{\text{ml-1}} = S'_{\text{ml-1}} \]  

(3-16a).

Then, the order of numerical computations is

i) Calculate \( a_i, b_i, c_i \) for \( m1 \leq i \leq \text{mu-1} \) using equation 3-13a,

ii) Calculate \( P_i \) and \( O_i \) for \( \text{ml-1} \leq i \leq \text{mu-1} \) using equation 3-16 or 3-16a,

iii) With \( S'_{\text{mu}} \) known, calculate \( S'_i \) for \( i = \text{mu-1}, \text{mu-2}, ..., \text{ml} \) using equation 3-15.

The term \( S_0 \) in equation 3-12 may represent the effect of the change in storage volume with the change in tidal elevation. The storage in each segment will act as a
source to the main channel when the tide is falling and act as a sink on the rising tide.

The salinity in the storage area will remain the same on the falling tide, but will change on the rising tide because of the mixing between the incoming water and the water in the storage area. It can be written as

\[
S_{o_i} = - (V_{s'_i} - V_{s_i}) \cdot S_{s_i} \quad \text{if } V_{s'_i} < V_{s_i} \quad (3-17a)
\]
or

\[
S_{o_i} = - (V_{s'_i} - V_{s_i}) \cdot S_{i} \quad \text{if } V_{s'_i} > V_{s_i} \quad (3-17b)
\]

where

\[V_{s_i}, V_{s'_i} = \text{storage volumes of the } i^{th} \text{ segment at time } t \text{ and } t+\Delta t, \text{ respectively, and}\]

\[S_{s_i}, S_{s'_i} = \text{salinities in the storage portion of the } i^{th} \text{ segment at time } t \text{ and } t+\Delta t, \text{ respectively.}\]

B. Water Quality Model

B-1. Basic equations

The model is based on the one-dimensional equation describing the mass-balance of a dissolved or suspended substance in a water body. The equations for the water quality parameters have the general form

\[
\frac{\partial}{\partial t} (AC) + \frac{\partial}{\partial x} (QC) - \frac{\partial}{\partial x} \left( E A \frac{\partial C}{\partial x} \right) + A S_e + A S_i \quad (3-18)
\]

where

\[C = \text{concentration of dissolved or suspended substance in the water column,}\]

\[S_e = \text{the time rate of external addition (or withdrawal) of mass across the boundaries (i.e., free surface, bottom and lateral boundaries), and}\]
$S_i = \text{the time rate of increase (or decrease) of mass by internal biochemical processes in the water column.}$

The advective transport term, the second term on the left hand side of the equation 3-18, represents advection of mass by water movement; the dispersive transport term, the first term on the right hand side, represents dispersion of mass by turbulence and shearing flow. These two terms represent the physical transport processes in the flow field and are identical for all dissolved and suspended substances in the water. They will be treated in the same manner as those in the mass-balance equation of a conservative substance, i.e., equation 3-3. The last two terms of the equation represent the external additions and internal biochemical reactions, and differ for different substances.

The model treats nitrogen, phosphorus, oxygen demanding material, and dissolved oxygen through an interacting system of eight components as shown in the schematic diagram (Fig. 3-2). Each rectangular box represents a component simulated by the model. The arrows between components represent the biochemical transformation of one substance to the other. An arrow with one end unattached represents an external source (or sink) or an internal source (or sink) due to some natural process, such as settling and grazing. The mathematical expressions for the terms $S_e$ and $S_i$ for each of the eight components are presented in the following:

i). Phyttoplankton Population (Chl) - The phytoplankton population, quantified as the concentration of chlorophyll ‘a’, occupies a central role in the system shown in Figure 3-2 and influences, to a greater or lesser extent, all of the remaining non-conservative
source to the main channel when the tide is falling and act as a sink on the rising tide.

The salinity in the storage area will remain the same on the falling tide, but will change on the rising tide because of the mixing between the incoming water and the water in the storage area. It can be written as

\[ S_{o_i} = - (V_{s'_i} - V_{s_i}) \cdot S_{s_i} \quad \text{if} \quad V_{s'_i} < V_{s_i} \quad (3-17a) \]

or

\[ S_{o_i} = - (V_{s'_i} - V_{s_i}) \cdot S_i \]

\[ S_{s'_i} = \left( S_{s_i} V_{s_i} + S_i (V_{s'_i} - V_{s_i}) \right) / V_{s'_i} \quad \text{if} \quad V_{s'_i} > V_{s_i} \quad (3-17b) \]

where

\( V_{s_i}, \ V_{s'_i} = \) storage volumes of the \( i^{th} \) segment at time \( t \) and \( t+\Delta t \), respectively, and

\( S_{s_i}, \ S_{s'_i} = \) salinities in the storage portion of the \( i^{th} \) segment at time \( t \) and \( t+\Delta t \), respectively.

B. Water Quality Model

B-1. Basic equations

The model is based on the one-dimensional equation describing the mass-balance of a dissolved or suspended substance in a water body. The equations for the water quality parameters have the general form

\[ \frac{\partial}{\partial t} (AC) + \frac{\partial}{\partial x} (QC) - \frac{\partial}{\partial x} \left( EA \frac{\partial C}{\partial x} \right) + A \cdot S_e + A \cdot S_i \quad (3-18) \]

where

\( C = \) concentration of dissolved or suspended substance in the water column,

\( S_e = \) the time rate of external addition (or withdrawal) of mass across the boundaries (i.e., free surface, bottom and lateral boundaries), and
\[ S_i = \text{the time rate of increase (or decrease) of mass by internal biochemical processes in the water column.} \]

The advective transport term, the second term on the left hand side of the equation 3-18, represents advection of mass by water movement; the dispersive transport term, the first term on the right hand side, represents dispersion of mass by turbulence and shearing flow. These two terms represent the physical transport processes in the flow field and are identical for all dissolved and suspended substances in the water. They will be treated in the same manner as those in the mass-balance equation of a conservative substance, i.e., equation 3-3. The last two terms of the equation represent the external additions and internal biochemical reactions, and differ for different substances.

The model treats nitrogen, phosphorus, oxygen demanding material, and dissolved oxygen through an interacting system of eight components as shown in the schematic diagram (Fig. 3-2). Each rectangular box represents a component simulated by the model. The arrows between components represent the biochemical transformation of one substance to the other. An arrow with one end unattached represents an external source (or sink) or an internal source (or sink) due to some natural process, such as settling and grazing. The mathematical expressions for the terms \( S_e \) and \( S_i \) for each of the eight components are presented in the following:

1. Phytoplankton Population (Chl) - The phytoplankton population, quantified as the concentration of chlorophyll ‘a’, occupies a central role in the system shown in Figure 3-2 and influences, to a greater or lesser extent, all of the remaining non-conservative
Figure 372. Schematic diagram of interacting water quality parameters.
dissolved constituents. The mathematical representation describing internal biochemical interaction and external sources (or sink) are

\[ S_i = (G - R - P) \cdot \text{Chl} \]

\[ S_e = - \cdot \text{Chl} \frac{K_{\text{Chl}}}{h} + NPS\text{Chl} \]  \hspace{1cm} (3-19)

where

\text{Chl} = \text{chlorophyll 'a' concentration (µg/l)},

\text{G, R} = \text{growth and respiration rates, respectively, of phytoplankton (/day),}

\text{P} = \text{mortality rate due to predation and other factors (/day),}

\text{K_{Chl}} = \text{settling rate of phytoplankton (m/day),}

\text{h} = \text{local depth (m), and}

\text{NPS\text{Chl}} = \text{nonpoint source input of Chl (µg/l/day).}

Phytoplankton growth is dependent upon nutrient availability, ambient light and temperature. The functional relationships used in the model generally follow the forms of Di Toro et al. (1971) and are as follows:

\[ G = k_{GR} \theta_1 T^{-20} \cdot L(I_o, I, k_w, \text{Chl}, h) \cdot N(N2, N3, P2) \]  \hspace{1cm} (3-19a)

where

\text{k_{GR}} = \text{optimum growth rate at 20°C (/day),}

\text{θ_1} = \text{constant for temperature correction of growth rate,}

\text{T} = \text{temperature (°C),}

\text{L} = \text{attenuation of growth due to suboptimal lighting, and}

\text{N} = \text{attenuation of growth due to nutrient limitations.}

The light effect (L) is based on the available solar energy and the attenuation of light through the water column.
\[
L = \frac{e}{k_e h} \left[ \exp(-\alpha_1) - \exp(-\alpha_0) \right]
\]
\[
k'_e = k_e + 0.018 \cdot \text{Chl}
\]
\[
\alpha_1 = \frac{I_t}{I_s} \exp(-k_e h) - \alpha_0 \exp(-k_e h)
\]
\[
I_t = \begin{cases} 
I_a \cdot \frac{24}{t_d - t_u} \frac{\pi}{2} \sin \left( \frac{\pi \left( t - t_u \right)}{t_d - t_u} \right) & \text{if } t_u < t < t_d \\
0 & \text{if } t < t_u \text{ or } t > t_d
\end{cases}
\]

where

\( e = \) constant = 2.7183,

\( k_e = \) light extinction coefficient (/m) at zero chlorophyll concentration,

\( k'_e = \) light extinction coefficient (/m) corrected for self-shading of plankton,

\( I_s = \) optimum solar radiation rate (angleys/day),

\( I_t = \) solar radiation at time \( t \) (angleys/day),

\( I_a = \) total daily solar radiation (angleys/day),

\( t = \) time of day (in hours), and

\( t_u, t_d = \) time (in hours) of sunrise and sunset, respectively.

The nutrient effect (\( N \)) is based on the minimum limiting nutrient concept.

\[
N = \text{minimum} \left\{ \frac{N2 + N3}{K_{mn} + N2 + N3} \frac{P2}{K_{mp} + P2} \right\}
\]

where

\( N2, N3, P2 = \) concentrations (mg/l) of ammonia nitrogen, nitrite-nitrate nitrogen and ortho phosphorus, and

\( K_{mn}, K_{mp} = \) half-saturation concentrations (mg/l) for uptake of inorganic nitrogen and ortho phosphorus, respectively.

Respiration rate (\( R \)) is a function of temperature.
\[ L = \frac{e}{k_e} \left[ \exp(-\alpha_i) - \exp(-\alpha_0) \right] \]
\[ k_e = k_e' + 0.018 \cdot Chl \]
\[ \alpha_i = \frac{I_t}{I_s} \exp(-k_e' h) - \alpha_0 \exp(-k_e h) \quad (3-19b) \]
\[ I_t = I_a \frac{24}{t_d - t_u} \frac{\pi}{2} \sin \left( \frac{\pi}{t_d - t_u} \left( t - \frac{t_u}{2} \right) \right) \quad \text{if } t_u < t < t_d \]
\[ = 0 \quad \text{if } t < t_u \text{ or } t > t_d \]
where

\[ e = \text{constant} = 2.7183, \]
\[ k_e = \text{light extinction coefficient (Im) at zero chlorophyll concentration,} \]
\[ k_e' = \text{light extinction coefficient (Im) corrected for self-shading of plankton,} \]
\[ I_s = \text{optimum solar radiation rate (angleys/day),} \]
\[ I_t = \text{solar radiation at time } t \text{ (angleys/day),} \]
\[ I_a = \text{total daily solar radiation (angleys/day),} \]
\[ t = \text{time of day (in hours),} \] and
\[ t_u, t_d = \text{time (in hours) of sunrise and sunset, respectively.} \]

The nutrient effect (N) is based on the minimum limiting nutrient concept.

\[ N = \text{minimum} \left\{ \frac{N2 + N3}{K_{mn} + N2 + N3}, \frac{P2}{K_{mp} + P2} \right\} \quad (3-19c) \]
where

\[ N2, N3, P2 = \text{concentrations (mg/l) of ammonia nitrogen, nitrite-nitrate nitrogen and ortho phosphorus, and} \]
\[ K_{mn}, K_{mp} = \text{half-saturation concentrations (mg/l) for uptake of inorganic nitrogen and ortho phosphorus, respectively.} \]

Respiration rate (R) is a function of temperature.
\[ R = R(20) \theta_2 T^{-20} \]  

(3-19d)

where

\[ R(20) = \text{respiration rate at 20}^\circ C \text{ (/day), and} \]

\[ \theta_2 = \text{constant for temperature correction of respiration rate.} \]

Predation rate \( P \) should be dependent on the time-variable herbivore population which is in turn dependent upon the phytoplankton population. To avoid adding an additional trophic level to the model, however, \( P \) is assumed to be a function of temperature.

\[ P = P(20) \theta_3 T^{-20} \]  

(3-19e)

where

\[ P(20) = \text{mortality rate at 20}^\circ C \text{ (/day), and} \]

\[ \theta_3 = \text{constant for temperature correction of mortality rate.} \]

\[ ii. \text{ Organic Nitrogen (N1)} \]

\[ S_i = -\frac{K_{n12}N1}{K_{n12} + N1} + a_n (R + a_P F_n Chl) \]

\[ S_e = -N1 \frac{K_{n11}}{h} + \frac{BenN1}{h} + PSN1 + NPSN1 \]  

(3-20)

where

\[ N1 = \text{concentration of organic nitrogen (mg/l),} \]

\[ K_{n12} = \text{hydrolysis rate of N1 to N2 (mg/l/day) = } K_{n12}(20) \theta_4 T^{-20}, \]

\[ K_{n12}(20) = \text{hydrolysis rate at 20}^\circ C, \]

\[ \theta_4 = \text{constant for temperature correction of hydrolysis rate,} \]

\[ K_{n12} = \text{half-saturation concentration for hydrolysis (mg/l),} \]
\( a_n = \text{ratio of nitrogen to chlorophyll in phytoplankton (mg N per } \mu \text{g Chl),} \)

\( a_r = \text{fraction of consumed phytoplankton recycled by zooplankton,} \)

\( K_{n1} = \text{settling rate of N1 (m/day),} \)

\( F_n = \text{fraction of metabolically produced nitrogen recycled to the organic pool,} \)

\( \text{BenN1 = benthic flux of N1 (g/m}^2/\text{day), and} \)

\( \text{PSN1, NPSN1 = point and nonpoint sources, respectively, of N1 (mg/l/day).} \)

### iii). Ammonia Nitrogen (N2)

\[
S_i = -\frac{K_{n23} \cdot N2}{K_{h23} \cdot N2} + \frac{K_{n12} \cdot N1}{K_{h12} \cdot N1} + a_n(R + a_rP)(1 - F_n)Chl - a_nG \cdot PR \cdot Chl
\]

\[
S_e = \frac{\text{BenN2}}{h} + \text{PSN2} + \text{NPSN2}
\]

where

\( K_{n23} = \text{nitrification rate of N2 to N3 (mg/l/day) = } K_{n23}(20) \cdot \theta_5^{T-20}, \)

\( K_{n23}(20) = \text{nitrification rate at } 20^\circ \text{C,} \)

\( \theta_5 = \text{constant for temperature correction of nitrification rate,} \)

\( K_{h23} = \text{half-saturation concentration for nitrification (mg/l),} \)

\( \text{PR = preference of phytoplankton for N2 uptake,} \)

\[
PR = \frac{N2 \cdot N3}{(K_{mn} + N2) (K_{mn} + N3)} + \frac{N2 \cdot K_{mn}}{(N2 + N3) (K_{mn} + N3)}
\]

\( \text{BenN2 = benthic flux of N2 (g/m}^2/\text{day), and} \)

\( \text{PSN2, NPSN2 = point and nonpoint sources, respectively, of N2 (mg/l/day).} \)

### iv). Nitrite-Nitrate Nitrogen (N3)

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\[ S_i = \frac{K_{n33} \cdot N2}{K_{h23} + N2} - a_n G (1 - PR) Chl \]

\[ S_e = - N3 \frac{K_{n33}}{h} + \frac{BenN3}{h} + PSN3 + NPSN3 \]  \hspace{1cm} (3-22)

where

\[ K_{n33} = \text{denitrification rate or loss coefficient of N3 (m/day)}, \]

\[ BenN3 = \text{benthic flux of N3 (g/m}^2/\text{day)}, \]

\[ PSN3, NPSN3 = \text{point and nonpoint sources, respectively, of N3 (mg/l/day)}. \]

v). Organic Phosphorus (P1)

\[ S_i = - \frac{K_{p12} \cdot P1}{K_{hpi2} + P1} + a_p (R + a_p P) F_p Chl \]

\[ S_e = - P1 \frac{K_{p11}}{h} + \frac{BenP1}{h} + PSP1 + NPSP1 \]  \hspace{1cm} (3-23)

where

\[ P1 = \text{concentration of organic phosphorus (mg/l)}, \]

\[ K_{p12} = \text{hydrolysis rate of P1 to P2 (mg/l/day)} = K_{p12}(20) \theta_6^{T-20}, \]

\[ K_{nl2}(20) = \text{hydrolysis rate at 20°C}, \]

\[ \theta_6 = \text{constant for temperature correction of hydrolysis rate}, \]

\[ K_{hpi2} = \text{half-saturation concentration for hydrolysis (mg/l)}, \]

\[ a_p = \text{ratio of phosphorus to chlorophyll in phytoplankton (mg P per µg Chl)}, \]

\[ K_{p11} = \text{settling rate of P1 (m/day)}, \]

\[ F_p = \text{fraction of metabolically produced phosphorus recycled to the organic pool}, \]

\[ BenP1 = \text{benthic flux of P1 (g/m}^2/\text{day)}, \]

\[ PSP1, NPSP1 = \text{point and nonpoint sources, respectively, of P1 (mg/l/day)}. \]

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vi). Inorganic (Ortho) Phosphorus (P2)

\[
S_i = \frac{K_{p12} P}{K_{p12} + P} + a_p (R + a_P) (1 - F) Chl - a_p G \cdot Chl
\]

\[
S_e = - P2 \frac{K_{p22}}{h} + \frac{BenP2}{h} + PSP2 + NPSP2
\]

where

\[K_{p22}\] = settling rate of P2 (m/day),

\[BenP2\] = benthic flux of P2 (g/m²/day), and

\[PSP2, NPSP2\] = point and nonpoint sources, respectively, of P2 (mg/l/day).

vii). Carbonaceous Biochemical Oxygen Demand (CBOD)

\[
S_i = - K_c CBOD + a_c a_{co} (a_r P) Chl
\]

\[
S_e = - CBOD \frac{K_{BOD}}{h} + \frac{BenBOD}{h} + PSBOD + NPSBOD
\]

where

\[CBOD\] = concentration of carbonaceous biochemical oxygen demand (mg/l),

\[K_c\] = first-order decay rate of CBOD (/day) = \[K_c(20)\theta_7^{10}\],

\[K_c(20)\] = CBOD decay rate at 20°C,

\[\theta_7\] = constant for temperature correction of CBOD decay rate,

\[a_c\] = ratio of carbon to chlorophyll in phytoplankton (mg C per µg Chl),

\[a_{co}\] = ratio of oxygen demand to organic carbon recycled = 2.67,

\[K_{BOD}\] = settling rate of CBOD (m/day),

\[BenBOD\] = benthic flux of CBOD (g/m²/day), and

\[PSBOD, NPSBOD\] = point and nonpoint sources, respectively, of CBOD (mg/l/day).
viii). Dissolved Oxygen (DO)

\[
S_i = -K_e \cdot CBOD - a_{no} \cdot \frac{K_{n23+N2}}{K_{n23}+N2} + a_{no} \cdot P.Q \cdot G \cdot Chl - a_{no} \cdot \frac{R}{RQ} \cdot Chl
\]

\[
S_e = K_e \cdot (DO_s - DO) - \frac{SOD}{h} + PSDO + NPSDO
\]

(3-26)

where

DO = concentration of dissolved oxygen (mg/l),

a\text{no} = ratio of oxygen consumed per unit of ammonia nitrified = 4.57,

PQ = photosynthesis quotient (moles O\textsubscript{2} per mole C),

RQ = respiration quotient (moles CO\textsubscript{2} per mole O\textsubscript{2}),

K\text{r} = reaeration rate (/day),

DO\textsubscript{s} = saturation concentration of DO (mg/l),

SOD = sediment oxygen demand (g/m\textsuperscript{2}/day), and

PSDO, NPSDO = point and nonpoint sources, respectively, of DO (mg/l/day).

The reaeration coefficient (K\text{r}) includes reaeration by turbulence generated by bottom friction (O’Connor and Dobbins, 1958) and that by surface wind stress, that is,

\[
K_r(20) = K_{ro} \cdot \sqrt{\frac{U}{h}} + W_{rea} \cdot \frac{1}{h}
\]

(3-26a)

where

K\text{r}(20) = reaeration rate at 20°C,

K\text{ro} = proportionality constant = 3.933 when metric units are used for U and h, and

W_{rea} = wind-induced reaeration (m/day).

The reaeration rate is assumed to be temperature-dependent (Thomann and Mueller, 1987), i.e.,
\[
K_t = K_c(20) \theta_8^{T-20}
\]  
(3-26b)

where \( \theta_8 \) = constant for temperature correction of DO reaeration rate = 1.02.

Saturation dissolved oxygen concentration \((DO_s)\) is calculated as a function of water temperature and salinity \((S \text{ in psu})\) from a polynomial fitted to the tables of Green and Carritt (1967).

\[
DO_s = 14.6244 - 0.367134 T + 0.004497 T^2 - 0.0966 S + 0.00205 S T + 0.0002739 S^2
\]  
(3-26c).

**B-2. Finite difference approximation and method of solution.**

Equation 3-18 is approximated with a finite difference scheme and solved for the time varying concentration field in the same way as the mass-balance equation of a conservative substance, i.e., equation 3-3 in the hydrodynamic model. In instances where the equation of one water quality parameter involves other water quality parameters, the concentrations of the other water quality parameters are expressed in terms of known values at the beginning of time step. Therefore, the biochemical interaction terms in the coupled equations do not introduce additional unknowns for the finite difference equation of each individual water quality parameter over that of a conservative substance.
IV. APPLICATION OF THE HYDRODYNAMIC MODEL

Before the hydrodynamic model can be utilized, it must be supplied with the geometry of the estuary to be modelled. Next, the model should be calibrated such that it reproduces the tidal characteristics of the prototype. Model predictions of surface level and discharge, or current velocity, are then compared to field measurements of these parameters to validate the model. Finally, the ability of the model to predict the transport of dissolved substances should be verified through comparison of model predictions and field measurements of the concentration of some conservative substance such as dye. The completion of each of these procedures is detailed in this chapter.

A. Geometry

As noted in Chapter III, the solution to equations 3-1 through 3-3 is accomplished through division of the river into a series of finite segments which together approximate the continuous system. The hydrodynamic model must be supplied with the geometry of each of these segments including measures of length, depth, cross-sectional area, surface area and volume.

The tidal Rappahannock River has been divided into sixty-two segments along its axis from river mouth to fall line at Fredericksburg. Figure 4-1 shows the model segments for the reach of river upstream of Port Royal. The geometry of these segments is derived from bathymetry measurements taken in 1973 (Kuo et al., 1975) and from nautical charts (National Ocean Survey). Segment geometries at the mean
Figure 4-1. The model transects in the upper reach of the tidal Rappahannock River.
sea level are presented in Table 4-1.

B. Model Calibration

For convenience in specifying downstream boundary conditions, the hydrodynamic model was run to simulate the whole length of estuary. An M2 tide with an amplitude equal to half mean range at river mouth (18.3 cm) and freshwater discharge equal to long-term mean at fall line (45.3 m$^3$/s) were used to force the hydrodynamic model. The initial condition on the velocity field was zero. The free surface height was initially a level surface at mean-sea level. The simulations were carried out for 15 tidal cycles when the model results reached an equilibrium state, i.e., the surface elevation and velocity throughout the estuary repeated from tidal cycle to tidal cycle. The model results of the last tidal cycle were compared with predicted mean tide characteristics tabulated from tide tables (National Ocean Survey, 1989 a,b).

The Manning friction coefficient is the only calibration parameter affecting the calculation of surface elevation and water velocity. The coefficient was adjusted, within the range of commonly accepted values, until the calculated tidal range along the length of estuary agreed with tide table data (Fig. 4-2). The times of high tide, low tide, slackwater before flood (SBF) and slackwater before ebb (SBE) were used to fine tune the friction coefficient. The model predictions are compared with tide table and tide current table data in Figures 4-3 to 4-6. The calibrated model has a friction coefficient of 0.022 from the river mouth to km 46.5, 0.019 from km 50.8 to km 119.9, and 0.017 from km 123.1 to fall line.

Figure 4-2 shows that the tidal range increases upstream from the river mouth,
Table 4-1. Geometric data for the model transects and segments.

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DIST = distance (km) from river mouth to the transect.
BCM = width (m) at mean tide at the transect.
XAM = cross-sectional area in $10^3$ m$^2$ at mean tide at the transect.
VolM = volume of the main conveyance channel in $10^6$ m$^3$ at mean tide at the segment.
SAM = surface area of the main conveyance channel (km$^2$) at mean tide at the segment.
StSAM = surface area of the side storage area (km$^2$) at mean tide at the segment.
ARD = land drainage area (km$^2$) feeding into the segment.
DcM = centroid depth (m) at mean tide at the transect.
Table 4-1. (Continued).

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Figure 4-2. Mean tide calibration: mean tidal range.
Figure 4-3. Mean tide calibration: time of high tide.
Figure 4-4. Mean tide calibration: time of low tide.
Figure 4-5. Mean tide calibration: time of slack before flood.
Figure 4-6. Mean tide calibration: time of slack before ebb.
reaching a local maximum at km 55 (Bowler's Rock). Maximum tidal range occurs at Fredericksburg, near the head of the tidal estuary, whereas a local minimum occurs around km 92 (near Leedstown). This characteristic standing wave results from superposition of two progressive waves traveling in opposite directions. The outgoing reflected wave is out of phase with respect to the incoming wave at a distance of one quarter wave length from the head of the tide, and this results in a nodal point of minimum tidal range near Leedstown. The model reproduced this characteristic quite well. The decrease in tidal range near the head of tide is the results of freshwater inflow which damps the tidal wave propagation.

C. Model Validation

The model was validated with a simulation of river conditions from June 15 to August 20, 1990. The downstream boundary condition was specified with hourly surface elevation measured at river mouth. The model made a linear interpolation of the hourly data to obtain the surface elevation at each time step (7.5 minutes). Daily freshwater discharge measured by the U.S. Geological Survey at the Fredericksburg gauging station was used for the upstream boundary condition. The model updated the freshwater discharge by linear interpolation over a two hour period from 0000 to 0200 hours, and then held it constant for 22 hours.

Figures 4-7 and 4-8 present the comparisons of model predictions of surface elevation with field data measured at Fredericksburg and Port Royal respectively. They show that the model not only accurately reproduced the semi-diurnal tidal fluctuations but also adequately simulated the subtidal (longer-term) variations.
Figure 4-7. Tide simulation at 173 km upriver from mouth.
Figure 4-7. (continued).
Figure 4-7. (continued).
Figure 4-8. Tide simulation at 130 km upriver from mouth.
Figure 4-8. (continued)
Particularly the dispersion of a high freshwater pulse (which occurred in mid-July) from Fredericksburg to Port Royal was faithfully reproduced. However, the model did not reproduce the peak flood level observed in the prototype (Fig. 4-7, day 30). This may be attributable to the treatment of hydrograph in the model input data file rather than to the shortcoming of the model. The slight discrepancy in absolute height of surface elevation between day 35 and 42 may be the result of barometric forcing which is not accounted for in the model.

The comparisons of current meter data with model predictions are presented in Figures 4-9 through 4-11. It should be noted that the model predicts the cross-sectional average velocity while the current meter data are point measurements. Both the model results and field data illustrate an intrinsic characteristic of tidal wave propagation, the shortening of the flood cycle as the wave approaches the head of tide. This results from the combined effect of freshwater inflow at the fall line and the nonlinear interaction of tidal wave.

D. Verification of Mass Transport

In the last test of the hydrodynamic model, the ability to simulate the transport of a conservative substance was examined using the data from the dye release study. Dye was released into the river at the City of Fredericksburg STP outfall at 0525, 25 July 1990. To allow for initial period of mixing during which one-dimensional dispersion theory is not applicable, the dye concentrations measured at 1815, 26 July were used as initial condition. The measured concentration distributions at subsequent slackwater tides are compared with model predictions in Figures 4-12 through 4-17.
Figure 4-9. Current simulation at 129 km upriver from mouth.
Figure 4-10. Current simulation at 157 km upriver from mouth.
Figure 4-11. Current simulation at 169 km upriver from mouth.
Figure 4-12. Dye dispersion simulation: 0637 7/27/90.
Figure 4-13. Dye dispersion simulation: 1117 7/27/90.
Figure 4-14. Dye dispersion simulation: 1143 7/28/90.
Figure 4-15. Dye dispersion simulation: 1213 7/29/90.
Figure 4-16. Dye dispersion simulation: 1326 7/30/90.
Figure 4-17. Dye dispersion simulation: 1545 8/01/90.
Two physical processes are involved in the mass transport, the advective and the dispersive transports. The advective transport is affected by the current velocity which has been calibrated and validated. No further adjustments may be made. The locations of peak concentrations of the dye distributions at different times reflect the result of advective transport. The fact that the locations of peak concentrations predicted by the model agree with those of field measurements (Figs. 4-12 through 4-17) demonstrates the accuracy of model simulation of advective processes.

Both the dispersion coefficient and the advective weighting factor affect the model simulation of dispersive transport process. However, the dispersion coefficient of the real time model is negligibly small in the fresh water portion of tidal rivers. A value of $10^{5}$ was used for the constant $T_s$ of equation 3-3a. The advective weighting factor (equation 3-6a and 3-6b) was adjusted until the model adequately reproduced the concentration distributions observed in the river (Figs. 4-12 through 4-17). The figures indicate that the concentrations measured in the river tend to be lower than those predicted by the model near the tail ends of distribution curve. The absorption of dye by sediment particles may contribute to this discrepancy.
V. APPLICATION OF THE WATER QUALITY MODEL

The water quality model was applied to the reach of tidal Rappahannock River from Fredericksburg to Port Royal. This reach of river is 51.6 km long and was divided into 32 segments (see Fig. 4-1), which corresponds exactly the segments used in hydrodynamic model. In addition to the data provided by the output of hydrodynamic model, the water quality model must be supplied with appropriate input data pertaining to a particular simulation run. The model must be calibrated to reproduce the observed prototype behavior through the adjustment of various coefficients, most notably the biochemical rate constants described in Chapter III. Following the calibration, the model should be verified through comparison of model predictions with additional independent field data.

Calibrating and verifying the water quality model is much more difficult than the hydrodynamic model due to the number of predicted water quality parameters to be calibrated - organic, ammonia, and nitrite-nitrate nitrogen, organic and ortho phosphorus, chlorophyll 'a', CBOD, and DO - and to the large number of coefficients which may be adjusted in attaining the calibration. In some instances it may be possible for alternate sets of calibration parameters to provide roughly equivalent calibrations. To avoid this situation, it is desirable to minimize the number of coefficients which are evaluated through comparison of model results to field data.

There are a variety of sources for the data and coefficients used in this model. Among these are measurements, literature values, and calibration. Measurements include inputs such as water temperature, STP waste loadings, and solar radiation.
Literature values are coefficients which have been evaluated in published studies of similar systems. For this modelling effort, the primary literature sources are the studies of the Potomac Estuary (Thomann and Fitzpatrick, 1982), hereinafter referred to as the ‘COG Report’, the book by Thomann and Mueller (1987), EPA report on model rates, constants and formulations (Bowie et al., 1985), and Virginia Potomac Embayment Studies (e.g. Cerco and Kuo, 1983), hereinafter referred to as the ‘PES Reports’. Calibration coefficients are those which are obtained through fitting of the model results to field observations.

The number of calibration parameters employed in the calibration and verification procedures is minimized through adherence to the following principles in evaluating model parameters:

1) Utilize measurements of system inputs and biochemical constants and coefficients whenever these are available.

2) Utilize values from the literatures when measurements are not available.

3) Utilize calibration values only when no other sources are available or when other sources are proven unsuitable.

To be of optimal use, a water quality model ought to employ consistent values of biogeochemical constants and transformation rates. That is, these values should be transferable when the model is used to provide predictions for comparison with independent sets of observations. Coefficients which are not constant should be calculable based on ambient conditions of temperature, light, wind, etc. If the model is not consistent, then its predictive value is reduced since any predictions will depend upon the selection of coefficients from the range of values previously employed.
The ideal of consistency imposes a dilemma upon the modeler. He must provide a consistent model of an inconsistent world. In the prototype, biogeochemical constants and rates need not be consistent from survey to survey, season to season, or year to year, yet in the model this must be so.

In the calibration and verification to follow, the principle of consistency is adhered to wherever possible. The trade-off is that predictions and observations do not always agree as closely as they might if the model were adjusted to each survey individually. Discrepancies between predictions and observations must therefore be regarded as illustrative of the variability of natural processes rather than indicative solely of shortcomings in the model.

A. The Calibration and Verification Data Bases

A-1. Instream water quality data

The water quality data described in Chapter II may be grouped into two independent data sets. Model calibration is achieved using the data from the intensive survey, with verification conducted employing the data from the slackwater surveys.

A-2. Point source loadings

Four sewage treatment plants (STP’s) discharge wastewater into the upper segments of the river. Claiborne Run, FMC and Massaponax STP’s discharge into model segments 3, 5 and 9 respectively. The outfall of the Fredericksburg STP is located at the upstream end of segment 5, very close to the transect dividing segments 4 and 5. Since the model assumes that wastewater is mixed uniformly into the whole
segment once discharged, the wastewater from Fredericksburg STP is divided evenly between segments 4 and 5.

Two sources of discharge data are available. One is the monitoring described in Chapter II. The other is the discharge monitoring report which the STP operators submit to the state monthly. The data from the two sources are merged and presented in Appendix 2. The flow rates and DO concentrations were obtained from the reports by STP operators. The concentrations of other water quality parameters are the results of the monitoring program conducted for this project.

Daily flow rates, and concentrations or loadings of water quality parameters for each point source, were specified in the input data file for each day of the model simulation. The values for the times between dates of monitoring were obtained by linear interpretation of the data listed in Appendix 2.

A-3. Nonpoint source loadings

The nonpoint source contribution from the watershed above the fall line was calculated from flow rates and concentrations of water quality parameters at the fall line. Daily flow rates were obtained from USGS (United States Geological Survey) for the Fredericksburg gauging station (Fig. 5-1). The concentrations of water quality parameters were monitored under this project. The data are presented in Appendix 2.

A regression analysis was performed for the concentrations of all nutrient forms, i.e., organic N, ammonia N, nitrite-nitrate N, organic P, and ortho P. The regression formula was developed by Cohn et al. (1989) and adopted by Cerco (1991) in the modelling of Chesapeake Bay water quality. Figures 5-2 through 5-6 compare the
Figure 5-1. Nonpoint source (fall line) flow rate.
regression results with monitoring data. No regression formula is available for DO, CBOD and chlorophyll ‘a’ concentrations. Therefore daily input of these three parameters were obtained through linear interpolation of monitoring data. Because the measurements at fall line sometimes differ substantially from those at the most upstream station (Rt. 3 station) of the slackwater surveys, the values at the Rt. 3 station were used instead. The data are presented in Figure 5-7. Together with Figure 5-1, the data show that both CBOD and chlorophyll ‘a’ concentrations were severely depressed in response to high river discharge around date 80.

A-4. Benthic fluxes

The field measurements of benthic oxygen demand and nutrient fluxes are described in Appendix 5. The values used for model inputs are presented in Table 5-1. These values were derived either from field data or through model calibration. The sediment oxygen demand of 2.0 g/m²/day is near the upper limit of the measurements (0.78 to 2.14 g/m²/day). The ammonia flux of 0.05 g/m²/day is the average of all measurements. The measurements indicate that benthic flux of nitrite-nitrate and ortho phosphorus are nearly zero. Initial simulations with zero benthic fluxes of ortho phosphorus resulted in a complete depletion of ortho phosphorus downriver of km 150 under low flow conditions, thus severely limiting phytoplankton growth. In order for the model predictions to match field measurements of ortho phosphorus and chlorophyll ‘a’ concentrations, an ortho phosphorus benthic flux of 0.005 g/m²/day was used.

There were no measurements of benthic fluxes of organic matter. The fluxes of
Figure 5-2. Nonpoint source organic nitrogen concentration.
Figure 5-3. Nonpoint source ammonia nitrogen concentration.
Figure 5-4. Nonpoint source nitrite-nitrate nitrogen concentration.
Figure 5-5. Nonpoint source organic phosphorus concentration.
Figure 5-6. Nonpoint source ortho phosphorus concentration.
Figure 5-7. Nonpoint source DO, CBOD and chlorophyll 'a' concentrations.
CBOD, organic nitrogen and organic phosphorus were derived through model calibration.

Table 5-1. Benthic fluxes

<table>
<thead>
<tr>
<th></th>
<th>g/m²/day</th>
<th>Spatial distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOD (sediment oxygen demand)</td>
<td>-2.0</td>
<td>uniform</td>
</tr>
<tr>
<td>CBOD</td>
<td>0.0</td>
<td>uniform</td>
</tr>
<tr>
<td>Organic N</td>
<td>0.0</td>
<td>uniform</td>
</tr>
<tr>
<td>Ammonia N</td>
<td>0.05</td>
<td>uniform</td>
</tr>
<tr>
<td>Nitrite-Nitrate N</td>
<td>0.0</td>
<td>uniform</td>
</tr>
<tr>
<td>Organic P</td>
<td>0.0</td>
<td>uniform</td>
</tr>
<tr>
<td>Ortho P</td>
<td>0.005</td>
<td>downriver of km 150</td>
</tr>
<tr>
<td></td>
<td>0.0</td>
<td>upriver of km 150</td>
</tr>
</tbody>
</table>

A-5. **Boundary conditions**

The downstream boundary conditions were specified with the field data observed at Buoy 75 (Fig. 4-1). For the model verification run, the concentrations at the boundary were linearly interpolated between dates of slackwater surveys, when the data were available. For model calibration run, the boundary conditions were kept constant with the values observed on the July 22 slackwater survey.

A-6. **Water temperature**

Model input of water temperature was based on slackwater and intensive survey data, which indicate that daily average water temperature varied within a narrow range of 24.9 - 28.8°C over the period June 20 to September 4, 1990. A constant water temperature of 27.5°C was used for model calibration run, which simulated the period July 5 to July 26. For model verification the water temperature was kept at 22°C from May 22 to June 6 and then changed to a constant of 27.5°C for the remaining
simulation period.

A-7. Solar radiation and light extinction coefficient

Solar radiation and light extinction were calculated in the model with equation 3-19b. The daily solar radiation, $I_a$, times of sunrise and sunset, $t_u$ and $t_d$, were input everyday of model simulation. The data were obtained from the measurements at VIMS (Gloucester Point, Virginia).

Light extinction coefficients were derived from Secchi-depth measurements and are shown in Figure 5-8. A good deal of scatter is present in the data. The high values measured on July 18 were the results of very high flow around July 15. All other data are presented with their mean and range at given station. The values used for model are also indicated in the figure. These values were kept constant with respect to time.

B. Calibration with the Intensive Survey

The calibration was conducted using the observations collected on the July 5 slackwater survey as initial conditions in a model simulation of the period from July 5 through July 26. Model predictions for the period 1700 hours, July 25 to 1700 hours July 26 were then compared with the data collected in the same time interval. In successive model runs, calibration parameters were adjusted until agreement was achieved between the model predictions and the data.

To conduct the simulation, the model requires evaluation of a number of constants and coefficients. The manner in which these are obtained and the values
SLACKWATER SURVEY DATA on 7/18

RANGE AND MEAN OF ALL OTHER DATA

Figure 5-8. Light extinction coefficients (the horizontal lines represent the values used in model calibration).
employed are as significant as the achievement of calibration itself. Therefore, all model coefficients and their origins are presented before the calibration results.

B-1. Phytoplankton - related coefficients

The phytoplankton-related coefficients employed in the calibration are presented in Table 5-2. Thomann and Mueller (1987) provided definite values, instead of range of values, of the temperature dependent constants for phytoplankton growth, respiration and mortality. These values were used in this model application. The values of photosynthesis quotient (PQ) and respiration quotient (RQ) calculated from data reported in the EPA report (Bowie et al., 1985) fall within very narrow ranges. The mean values of these ranges were used. When coefficients had the same value in all of the Potomac Embayment Studies, those values were adopted. The values of other coefficients were either adopted from ‘COG Report’ or determined through calibration and kept within the range of literature values.

B-2. Nitrogen-related coefficients

The nitrogen-related coefficients employed in the calibration are presented in Table 5-3. The values in the PES Reports were adopted if all the Potomac Embayments used the same value for that coefficient. Otherwise, the coefficients were determined through calibration within the range of literature values.
### Table 5-2. Phytoplankton-related coefficients

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Equation</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_c$</td>
<td>3-26</td>
<td>0.050 mg/µg</td>
<td>Calibration</td>
</tr>
<tr>
<td>$a_n$</td>
<td>3-20</td>
<td>0.007 mg/µg</td>
<td>PES Reports</td>
</tr>
<tr>
<td>$a_p$</td>
<td>3-23</td>
<td>0.001 mg/µg</td>
<td>&quot;</td>
</tr>
<tr>
<td>$a_r$</td>
<td>3-20</td>
<td>0.4</td>
<td>&quot;</td>
</tr>
<tr>
<td>PQ</td>
<td>3-26</td>
<td>1.0 mole/mole</td>
<td>EPA Report</td>
</tr>
<tr>
<td>RQ</td>
<td>3-26</td>
<td>1.33 mole/mole</td>
<td>EPA Report</td>
</tr>
<tr>
<td>$K_{on}$</td>
<td>3-19c</td>
<td>0.025 mg/l</td>
<td>&quot;</td>
</tr>
<tr>
<td>$K_{mp}$</td>
<td>3-19c</td>
<td>0.001 mg/l</td>
<td>&quot;</td>
</tr>
<tr>
<td>$k_{gr}$</td>
<td>3-19a</td>
<td>2.0 /day</td>
<td>COG Report</td>
</tr>
<tr>
<td>R(20)</td>
<td>3-19d</td>
<td>0.17 /day</td>
<td>Calibration</td>
</tr>
<tr>
<td>$I_s$</td>
<td>3-19b</td>
<td>250 langleys/day</td>
<td>PES Reports</td>
</tr>
<tr>
<td>$K_{chl}$</td>
<td>3-19</td>
<td>0.1 m/day</td>
<td>COG Report</td>
</tr>
<tr>
<td>P(20)</td>
<td>3-19e</td>
<td>0.02 /day</td>
<td>&quot;</td>
</tr>
<tr>
<td>$\theta_1$</td>
<td>3-19a</td>
<td>1.066</td>
<td>Thomann &amp; Mueller</td>
</tr>
<tr>
<td>$\theta_2$</td>
<td>3-19d</td>
<td>1.080</td>
<td>&quot;</td>
</tr>
<tr>
<td>$\theta_3$</td>
<td>3-19e</td>
<td>1.000</td>
<td>&quot;</td>
</tr>
</tbody>
</table>

### Table 5-3. Nitrogen-related coefficients

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Equation</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_{n12}(20)$</td>
<td>3-20</td>
<td>0.075 mg/1/day</td>
<td>Calibration</td>
</tr>
<tr>
<td>$K_{n12}$</td>
<td>3-20</td>
<td>1.0 mg/1</td>
<td>PES Reports</td>
</tr>
<tr>
<td>$K_{n11}$</td>
<td>3-20</td>
<td>0.1 m/day</td>
<td>Calibration</td>
</tr>
<tr>
<td>$K_{n23}(20)$</td>
<td>3-21</td>
<td>0.2 mg/1/day</td>
<td>&quot;</td>
</tr>
<tr>
<td>$K_{n23}$</td>
<td>3-21</td>
<td>1.0 mg/1</td>
<td>PES Reports</td>
</tr>
<tr>
<td>$K_{n33}$</td>
<td>3-22</td>
<td>0.05 m/day</td>
<td>Calibration</td>
</tr>
<tr>
<td>$\theta_4$</td>
<td>3-20</td>
<td>1.04</td>
<td>PES Reports</td>
</tr>
<tr>
<td>$\theta_5$</td>
<td>2-21</td>
<td>1.04</td>
<td>&quot;</td>
</tr>
<tr>
<td>$F_n$</td>
<td>3-20</td>
<td>0.75</td>
<td>&quot;</td>
</tr>
</tbody>
</table>
B-3. **Phosphorus-related coefficients**

The phosphorus-related coefficients employed in the calibration are presented in Table 5-4. It should be noted that the ortho phosphorus settling rate is much higher than the phytoplankton, organic nitrogen and organic phosphorus settling rates. Furthermore, the settling rate is non-zero for only the river segments upriver of km 150. The use of this settling rate is necessary in order for the model predictions to match field measurements. The STP discharges are the primary sources of ortho phosphorus in the river. The model simulation without settling produced concentrations much higher than field measurements in all surveys. It was apparent that some of the ortho phosphorus from the STP settled before being transported out of this reach of the river.

Several investigators (Mayer and Gloss, 1980; Lake and MacIntyre, 1977; Parfitt et al., 1975; Veith and Sposito, 1977) have demonstrated a loss mechanism by absorption of phosphate to sediment particles. Experiments by Lake and MacIntyre (1977) indicated that phosphate and tripolyphosphate were readily absorbed to clay and estuarine sediments. The studies of the Potomac Estuary and Potomac Embayments also found it necessary to use high settling rate near STP discharges in order to model ortho phosphorus successfully.

B-4. **CBOD and DO-related coefficients**

The coefficients related to CBOD and DO employed in the calibration are presented in Table 5-5. The coefficient $K_{so} = 3.93$ is the metric equivalent of $K_{so} = 12.9$ given by O'Conner and Dobbins (1958) for the English system of units.
Table 5-4. Phosphorus-related coefficients

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Equation</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_{p12}$</td>
<td>3-23</td>
<td>0.06/mg/l/day</td>
<td>Calibration</td>
</tr>
<tr>
<td>$K_{p11}$</td>
<td>3-23</td>
<td>0.1 m/day</td>
<td>&quot;</td>
</tr>
<tr>
<td>$K_{np12}$</td>
<td>3-23</td>
<td>1.0 mg/l</td>
<td>PES Reports</td>
</tr>
<tr>
<td>$K_{p22}$</td>
<td>3-24</td>
<td>0.0-0.3 m/day</td>
<td>Calibration</td>
</tr>
<tr>
<td>$\theta_6$</td>
<td>3-23</td>
<td>1.04</td>
<td>PES Reports</td>
</tr>
<tr>
<td>$F_p$</td>
<td>3-23</td>
<td>0.75</td>
<td>&quot;</td>
</tr>
</tbody>
</table>

* 0.3 m/day upstream of km 150, 0.0 elsewhere.

Table 5-5. CBOD- and DO- related coefficients

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Equation</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_s$(20)</td>
<td>3-25</td>
<td>0.05 /day</td>
<td>Calibration</td>
</tr>
<tr>
<td>$K_{BOD}$</td>
<td>3-25</td>
<td>0.0 m/day</td>
<td>Calibration</td>
</tr>
<tr>
<td>$K_{so}$</td>
<td>3-26a</td>
<td>3.93</td>
<td>see text</td>
</tr>
<tr>
<td>$\theta_7$</td>
<td>3-25</td>
<td>1.05</td>
<td>Calibration</td>
</tr>
</tbody>
</table>

B-5. Calibration results.

Field data and model predictions for the July 25-26, 1990 intensive survey are plotted against distance from the river mouth in Figure 5-9. The mean and range of values for both observations and predictions are shown for dissolved oxygen, chlorophyll ‘a’, organic phosphorus, ortho phosphorus, organic nitrogen, ammonia nitrogen, nitrite-nitrate nitrogen and carbonaceous biochemical oxygen demand.

Good agreement is achieved between predicted and observed concentration distributions along the river. Discrepancies are often attributable to the objectives of
Figure 5-9. Model calibration results
Figure 5-9. (continued).
consistency between the calibration and verification rather than to failure to curve-fit the model to the data.

Significant difference does exist between the model predictions and the data. In general, the model predicted much smaller ranges of variations than the field data. This is expected because the model calculated average concentration over model segments while field data were either the value at single depth, or the average of values at two depths at a given station. The model predicted a gradual increase of chlorophyll 'a' concentration in the downriver direction while the field data indicated a much more abrupt increase near km 160. The observation may be reproduced by spatially varying phytoplankton-related coefficients. However, no such attempt was made because this abrupt increase of chlorophyll 'a' concentration was not a permanent feature.

C. Verification with the Slackwater Surveys

The objective of verification is not to fit the model to the data through evaluation of various coefficients. Rather, the purpose of verification is to test that previously evaluated coefficients are appropriate and consistent. This is done by comparing model predictions with observations collected independently of the calibration survey and under different ambient conditions and external loads. In the verification of the Rappahannock River model, the long-term predictive ability of the model was tested through comparisons of model predictions with observations collected in the June 6 through September 4 series of slackwater surveys. The model simulated the summer season in a single, three and one-half month run using the
May 22 observations as initial conditions and providing predictions for comparisons with data collected in the subsequent slackwater surveys.

All constants and kinetic coefficients employed in the seasonal verification are identical to those in the model calibration run. Results of model verification, presented as plots of predictions and observations along the river, are shown in Figures 5-10 through 5-17. The figures indicate the instantaneous data points and the range of predicted concentrations on the days of surveys. In evaluating the verification results, consideration must be given to the sparsity and variability of the observations and to the effects of potential inaccuracy of specifying nonpoint source loads in the input data file. While the model did not reproduce the detail behavior of each water quality parameter in every survey, it did predict the spatial trends and approximate magnitude of the observations in each survey.

A notable deviation of the predictions from the observations is the concentrations of organic nutrients on June 6, 20, and July 18, 22. These dates were preceded by significant nonpoint source run-off. The model predictions were, therefore, dominated by nonpoint source input. In order to demonstrate the impact of potential inaccuracy in nonpoint source input, an additional model simulation was performed. The nutrient concentrations measured at the most upriver station (Rt. 3 bridge) were used for the concentrations of the nonpoint source runoff (the discharge at fall line) at the dates of measurements. The concentrations for dates between successive slackwater surveys were obtained by linear interpolation. The new model results are compared with field data in Figures 5-18 through 5-21. The model results for other slackwater surveys are essentially the same as those predicted by the model.
Figure 5-10. Model verification results on 6/6/90.
Figure 5-10. (continued).
Figure 5-11. Model verification results on 6/20/90.
Figure 5-11. (continued).
Figure 5-12. Model verification results on 7/5/90.
Figure 5-12. (continued).
Figure 5-13. Model verification results on 7/18/90.
Figure 5-13. (continued).
Figure 5-14. Model verification results on 7/22/90.
Figure 5-14. (continued).
Figure 5-15. Model verification results on 8/7/90.
Figure 5-15. (continued).
Figure 5-16. Model verification results on 08/20/90.
Figure 5-16. (continued).
Figure 5-17. Model verification results on 9/4/90.
Figure 5-17. (continued).
Figure 5-18. Model results with nonpoint source input from measurements at Rt. 3 bridge versus field data from slackwater survey on 6/6/90.
Figure 5-18. (continued).
Figure 5-19. Model results with nonpoint source input from measurements at Rt. 3 bridge versus field data from slackwater survey on 6/20/90.
Figure 5-19. (continued).
Figure 5-20. Model results with nonpoint source input from measurements at Rt. 3 bridge versus field data from survey on 7/18/90.
Figure 5-20. (continued).
Figure 5-21. Model results with nonpoint source input from measurements at Rt. 3 bridge versus field data from slackwater survey on 7/22/90.
Figure 5-21. (continued).
verification run, and therefore, are not presented. These results indicate that most of the significant discrepancies between model predictions and observation may be eliminated through alternate specification of nonpoint source input.

Another area of discrepancy is the distribution of nitrite-nitrate nitrogen on June 20 (Fig. 5-11). The model predicted higher than observed values in most of the river. The prototype data show a spatial trend which is quite different from all other surveys. In fact, the spatial distribution predicted by the model agrees well with those of other surveys. Therefore, it is suspected that there might be some errors in field data.

Overall summer spatial distributions of water quality parameters are presented in Figure 5-22. All field data, including slackwater survey and intensive survey data, are included in the figure. The curves represent model predictions averaged over the period from June 6 to September 4. These figures demonstrate discernable concentration peaks for ortho phosphorus and ammonia nitrogen that are the result of point source discharges.

A second view of the seasonal verification is presented in the time-series plots of Figure 5-23 through 5-30 which illustrate the spatial average conditions throughout the season for each water quality parameter. Data points are the average of all samples collected in each survey while the model output is the average of all model segments. These plots are advantageous in that random variability in the data is, to some extent, averaged out and temporal trends in the predictions and observations are visible.
Figure 5-22. Model predictions (average over 6/6 - 9/4) versus field data from slackwater and intensive (vertical bars) surveys for dissolved oxygen.
Figure 5-22. (continued). For chlorophyll 'a'.

OVERALL MEAN CH (μg L⁻¹)

DISTANCE FROM MOUTH (km)
Figure 5-22. (continued). For organic phosphorus.
Figure 5-22. (continued). For ortho phosphorus.
Figure 5-22. (continued). For organic nitrogen.
Figure 5-22. (continued). For ammonia nitrogen.

DISTANCE FROM MOUTH (km)

OVERALL MEAN: NH₄ (mg L⁻¹)
Figure 5-22. (continued). For nitrite-nitrate nitrogen.
Figure 5-22. (continued). For CBOD.
Figure 5-23. Long-term verification of dissolved oxygen.
Figure 5-24. Long-term verification of chlorophyll 'a'.

Spatial Averages from
- Slackwater Survey
- Intensive Survey
- Model Result
Figure 5-25. Long-term verification of organic phosphorus.
Figure 5-26. Long-term verification of ortho phosphorus.
Figure 5-27. Long-term verification of organic nitrogen.
Figure 5-28. Long-term verification of ammonia nitrogen.
Figure 5-29. Long-term verification of nitrite-nitrate nitrogen.
Figure 5-30. Long-term verification of CBOD.
Interpretation of the time-series plots provides interesting insights into the effects of nonpoint source runoff on the water quality in the river. Nutrients and CBOD concentrations increased in the river in response to stormwater runoff around July 15-16. On the contrary, chlorophyll ‘a’ concentration decreased due to the flushing by storm water. The model predicted a lesser degree of DO decrease than that indicated by observations. This may be attributed to the inaccurate DO concentration being assigned to stormwater runoff. The daily values of DO concentrations in the nonpoint source runoff were obtained by linear interpolation of observed data, which missed the dates of high runoff. The organic phosphorus and organic nitrogen concentrations in the river responded to stormwater runoff to a much lesser degree than model predictions. It is suspected that a significant portion of organic materials washed into the river were in particulate form, and thus might settle quickly once in the tidal reach of the river.

D. Quantitative Analysis of Model Accuracy

The traditional assessments of model accuracy, the perceived agreement between predictions and observations, are qualitative and dependent upon the viewpoint and experience of the assessor. In order to form a more rigorous basis for the comparison of different models and to render the evaluation of models less subjective, quantitative assessments of model accuracy are desirable as well.

No single measure or set of measures is universally applicable in evaluating model accuracy. The selection of appropriate measures is dependent upon the nature of the model predictions and upon the quantity and quality of the observations. For
this study, two measures are reported: the root-mean-square (RMS) error and the
average error (E).

The RMS error is defined as:

\[ \text{RMS} = \left[ \frac{1}{n} \sum_{i=1}^{n} (P_i - O_i)^2 \right]^{1/2} \]  \hspace{1cm} (5-1)

in which

\[ P_i = \text{ith prediction} \]

\[ O_i = \text{ith observation} \]

\[ n = \text{number of observations} \]

The RMS error is a measure of the absolute difference between predictions and
observations. A large RMS error indicates the model is not accurately reproducing the
observations but does not distinguish between predictions which are consistently high,
predictions which are consistently low, or predictions which are centrally located
within widely scattered data. Thus, a second measure, the average error, is desirable.

The average error is defined as:

\[ E = \frac{1}{n} \sum_{i=1}^{n} (P_i - O_i) \]  \hspace{1cm} (5-2).

An average error which is large and positive indicates the model overpredicts
the observations. An average error which is large and negative indicates the model
underpredicts the observations. An average error which is near zero indicates the
model closely reproduces the observations in an average sense although the data may
be widely scattered.
The use of these two measures in evaluating the calibration and verification of the model is detailed in the remainder of this chapter.

D-1. Accuracy of the July, 1990 calibration

The accuracy of the calibration is evaluated through comparison of the daily-mean observations and predictions at each station for each parameter. Differences between the predicted and observed means are then used to compute river-wide RMS and average errors for each parameter, as presented in Table 5-6.

D-2. Accuracy of the June - September, 1990 verification

The accuracy of the June-September, 1990 verification is evaluated by comparison of the spatial-mean observations from each survey with the predicted mean for the same day. Differences between the predicted and observed means are then used to compute seasonal RMS and average errors for each parameter. Results of the analysis are presented in Table 5-7.
Table 5-6. Accuracy of model calibration, July 25-26, 1990.

<table>
<thead>
<tr>
<th>STATION</th>
<th>N1*</th>
<th>N2</th>
<th>N3</th>
<th>P1</th>
<th>P2</th>
<th>Chl</th>
<th>CBOD</th>
<th>DO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazel Run (O)</td>
<td>0.271</td>
<td>0.084</td>
<td>0.595</td>
<td>0.033</td>
<td>0.024</td>
<td>0.75</td>
<td>0.69</td>
<td>7.32</td>
</tr>
<tr>
<td>(P)</td>
<td>0.345</td>
<td>0.117</td>
<td>0.381</td>
<td>0.041</td>
<td>0.018</td>
<td>1.52</td>
<td>0.78</td>
<td>7.18</td>
</tr>
<tr>
<td>B131 (O)</td>
<td>0.309</td>
<td>0.115</td>
<td>0.649</td>
<td>0.043</td>
<td>0.038</td>
<td>0.83</td>
<td>0.82</td>
<td>6.88</td>
</tr>
<tr>
<td>(P)</td>
<td>0.350</td>
<td>0.146</td>
<td>0.468</td>
<td>0.048</td>
<td>0.037</td>
<td>1.70</td>
<td>0.78</td>
<td>6.95</td>
</tr>
<tr>
<td>B123 (O)</td>
<td>0.268</td>
<td>0.174</td>
<td>0.664</td>
<td>0.048</td>
<td>0.032</td>
<td>5.40</td>
<td>1.42</td>
<td>6.68</td>
</tr>
<tr>
<td>(P)</td>
<td>0.364</td>
<td>0.187</td>
<td>0.519</td>
<td>0.047</td>
<td>0.034</td>
<td>2.15</td>
<td>0.80</td>
<td>6.68</td>
</tr>
<tr>
<td>B110 (O)</td>
<td>0.308</td>
<td>0.133</td>
<td>0.649</td>
<td>0.039</td>
<td>0.026</td>
<td>18.73</td>
<td>2.19</td>
<td>6.79</td>
</tr>
<tr>
<td>(P)</td>
<td>0.310</td>
<td>0.159</td>
<td>0.547</td>
<td>0.042</td>
<td>0.031</td>
<td>4.54</td>
<td>0.86</td>
<td>6.55</td>
</tr>
<tr>
<td>B100 (O)</td>
<td>0.339</td>
<td>0.125</td>
<td>0.684</td>
<td>0.062</td>
<td>0.019</td>
<td>21.75</td>
<td>2.69</td>
<td>5.75</td>
</tr>
<tr>
<td>(P)</td>
<td>0.326</td>
<td>0.112</td>
<td>0.601</td>
<td>0.043</td>
<td>0.027</td>
<td>12.98</td>
<td>1.22</td>
<td>6.90</td>
</tr>
<tr>
<td>B79 (O)</td>
<td>0.548</td>
<td>0.108</td>
<td>0.694</td>
<td>0.066</td>
<td>0.022</td>
<td>22.72</td>
<td>2.48</td>
<td>5.53</td>
</tr>
<tr>
<td>(P)</td>
<td>0.519</td>
<td>0.071</td>
<td>0.760</td>
<td>0.064</td>
<td>0.022</td>
<td>25.87</td>
<td>2.22</td>
<td>7.02</td>
</tr>
<tr>
<td>AVERAGE (O)</td>
<td>0.341</td>
<td>0.123</td>
<td>0.656</td>
<td>0.048</td>
<td>0.027</td>
<td>11.70</td>
<td>1.72</td>
<td>6.41</td>
</tr>
<tr>
<td>(P)</td>
<td>0.369</td>
<td>0.132</td>
<td>0.546</td>
<td>0.048</td>
<td>0.028</td>
<td>8.13</td>
<td>1.11</td>
<td>6.88</td>
</tr>
</tbody>
</table>

ERROR
: RMS 0.054 0.027 0.142 0.009 0.005 7.07 0.86 0.80
: AVERAGE 0.028 0.009 -0.110 -0.001 0.001 -3.57 -0.61 0.47

* N1, N2, N3 = concentrations (mg/l) of organic, ammonia and nitrite-nitrate nitrogens, respectively, P1, P2 = concentrations (mg/l) of organic phosphorus and ortho-phosphorus, respectively, Chl = concentration (µg/l) of chlorophyll ‘a’, CBOD = concentration (mg/l) of carbonaceous biochemical oxygen demand, and DO = concentration (mg/l) of dissolved oxygen.

* O = observed mean over 25 hours (1700 7/25/90 to 1800 7/26/90), and P = predicted mean over one day (1700 7/25/90 to 1700 7/26/90).
Table 5-7. Accuracy of model verification, June 6 - September 4, 1990.

<table>
<thead>
<tr>
<th>SURVEY DATE</th>
<th>N1*</th>
<th>N2</th>
<th>N3</th>
<th>P1</th>
<th>P2</th>
<th>Chl</th>
<th>CBOD</th>
<th>DO</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 6</td>
<td>0.188</td>
<td>0.083</td>
<td>0.786</td>
<td>0.044</td>
<td>0.016</td>
<td>5.07</td>
<td>0.94</td>
<td>8.11</td>
</tr>
<tr>
<td></td>
<td>0.370</td>
<td>0.153</td>
<td>0.802</td>
<td>0.090</td>
<td>0.028</td>
<td>3.22</td>
<td>1.11</td>
<td>7.75</td>
</tr>
<tr>
<td>June 20</td>
<td>0.264</td>
<td>0.108</td>
<td>0.379</td>
<td>0.033</td>
<td>0.011</td>
<td>9.08</td>
<td>2.38</td>
<td>6.94</td>
</tr>
<tr>
<td></td>
<td>0.281</td>
<td>0.114</td>
<td>0.697</td>
<td>0.054</td>
<td>0.026</td>
<td>6.11</td>
<td>1.42</td>
<td>6.88</td>
</tr>
<tr>
<td>July 5</td>
<td>0.226</td>
<td>0.173</td>
<td>0.411</td>
<td>0.040</td>
<td>0.018</td>
<td>19.51</td>
<td>3.02</td>
<td>6.95</td>
</tr>
<tr>
<td></td>
<td>0.263</td>
<td>0.087</td>
<td>0.505</td>
<td>0.042</td>
<td>0.017</td>
<td>18.42</td>
<td>1.48</td>
<td>7.55</td>
</tr>
<tr>
<td>July 18</td>
<td>0.201</td>
<td>0.170</td>
<td>0.798</td>
<td>0.101</td>
<td>0.026</td>
<td>7.65</td>
<td>3.38</td>
<td>6.21</td>
</tr>
<tr>
<td></td>
<td>0.945</td>
<td>0.164</td>
<td>0.941</td>
<td>0.114</td>
<td>0.036</td>
<td>9.74</td>
<td>2.56</td>
<td>7.36</td>
</tr>
<tr>
<td>July 22</td>
<td>0.230</td>
<td>0.156</td>
<td>0.710</td>
<td>0.043</td>
<td>0.033</td>
<td>10.06</td>
<td>1.52</td>
<td>5.56</td>
</tr>
<tr>
<td></td>
<td>0.500</td>
<td>0.134</td>
<td>0.683</td>
<td>0.062</td>
<td>0.034</td>
<td>12.29</td>
<td>2.00</td>
<td>6.98</td>
</tr>
<tr>
<td>August 7</td>
<td>0.365</td>
<td>0.116</td>
<td>0.293</td>
<td>0.030</td>
<td>0.014</td>
<td>20.84</td>
<td>3.51</td>
<td>7.64</td>
</tr>
<tr>
<td></td>
<td>0.275</td>
<td>0.114</td>
<td>0.427</td>
<td>0.034</td>
<td>0.021</td>
<td>16.60</td>
<td>1.79</td>
<td>7.18</td>
</tr>
<tr>
<td>August 20</td>
<td>0.329</td>
<td>0.111</td>
<td>0.241</td>
<td>0.031</td>
<td>0.012</td>
<td>20.05</td>
<td>4.83</td>
<td>7.13</td>
</tr>
<tr>
<td></td>
<td>0.270</td>
<td>0.110</td>
<td>0.275</td>
<td>0.033</td>
<td>0.014</td>
<td>16.94</td>
<td>3.37</td>
<td>6.65</td>
</tr>
<tr>
<td>September 4</td>
<td>0.345</td>
<td>0.084</td>
<td>0.297</td>
<td>0.031</td>
<td>0.012</td>
<td>14.73</td>
<td>3.27</td>
<td>6.55</td>
</tr>
<tr>
<td></td>
<td>0.231</td>
<td>0.113</td>
<td>0.234</td>
<td>0.022</td>
<td>0.016</td>
<td>11.04</td>
<td>2.96</td>
<td>6.55</td>
</tr>
<tr>
<td>AVERAGE</td>
<td>0.268</td>
<td>0.125</td>
<td>0.489</td>
<td>0.044</td>
<td>0.018</td>
<td>13.37</td>
<td>2.86</td>
<td>6.89</td>
</tr>
<tr>
<td></td>
<td>0.392</td>
<td>0.124</td>
<td>0.571</td>
<td>0.056</td>
<td>0.024</td>
<td>11.79</td>
<td>2.09</td>
<td>7.11</td>
</tr>
</tbody>
</table>

ERROR

- RMS: 0.293 0.041 0.139 0.020 0.008 2.83 1.09 0.73
- AVERAGE: 0.123 -0.002 0.081 0.012 0.006 -1.58 -0.77 0.22

* N1, N2, N3 = concentrations (mg/l) of organic, ammonia and nitrite-nitrate nitrogens, respectively,
P1, P2 = concentrations (mg/l) of organic phosphorus and ortho-phosphorus, respectively,
Chl = concentration (µg/l) of chlorophyll 'a',
CBOD = concentration (mg/l) of carbonaceous biochemical oxygen demand, and
DO = concentration (mg/l) of dissolved oxygen.

b O = observed mean over all stations.
P = predicted mean over all segments, and over one day.
VI. SENSITIVITY ANALYSIS

Through sensitivity analysis, a primary use for the calibrated and verified model, the modeler can examine the response of the model and the prototype to alterations in external loadings, ambient conditions, or internal biogeochemical processes.

Sensitivity analysis on the model itself may be intended to examine the effect on predictions of the selected values for crucial rates and coefficients. If a small change in a coefficient produces a large alteration in results, then the coefficient must be carefully evaluated. If alterations in a coefficient produce little effect on the output, then the value can be assigned with less concern that model predictions will be adversely affected by deviations from the ‘true’ value of the coefficient.

A second major use for sensitivity analysis is to explore, through experiments conducted on the model, factors which influence water quality in the prototype. In alternate model runs, the effects on the water quality of eliminating point-source and nonpoint-source loadings might be examined, for example. Experiments of this nature would be difficult or impossible to conduct on the prototype.

A. Sensitivity of the Water Quality Model

Evaluation of the chlorophyll growth rate, $k_{gr}$, is crucial to the validity of the model. Thus this coefficient is a prime candidate for sensitivity analysis. The analysis is conducted by running the model with all parameters as in the calibration run except for the growth rate. The revised model predictions are then compared to those for the calibrated model.
The sensitivity of the model predictions to the chlorophyll growth rate was examined by alternately increasing or decreasing the rate by 20 percent. That is, value $k_{gr} = 2.4 \text{ /day or } k_{gr} = 1.6 \text{ /day}$ was employed. Results of the analysis are presented in Figure 6-1. The figure compares the average of model predictions from sensitivity runs with that from calibration run. It shows that the model predictions are very sensitive to the value of chlorophyll growth rate, except in the first 15 km of the river. Under the freshwater discharge condition (about 25 m$^3$/s) used for the model simulation, the residence time in the first 15 km reach of river is less than two days, which is too short to allow for significant chlorophyll growth with the growth rates employed.

The nitrification rate of 0.2 mg/l/day was obtained through calibration of model results to observations. The sensitivity of the model to the nitrification rate was tested in sensitivity runs in which the rates of 0.3 and 0.1 mg/l/day were used. In Figure 6-2 it can be seen that the changes affects only the transfer of ammonia nitrogen to nitrite-nitrate nitrogen. It has little effect on DO concentration because of the low ammonia concentration in the river.

The CBOD decay rate of 0.05/day was also obtained through model calibration. This value falls at the low end of the range of literature values. The sensitivity of the model was tested in model runs in which the decay rates of 0.10 and 0.00/day were used. The effects of rate changes on CBOD and DO concentration distributions are shown in Figure 6-3. The maximum changes in daily average DO are 0.2 and 0.4 mg/l for the higher rate and no decay respectively.
Figure 6-1. Sensitivity to chlorophyll growth rate.
Figure 6-2. Sensitivity to nitrification rate.
Figure 6-3. Sensitivity to CBOD decay rate.
B. Sensitivity of the Prototype

Sensitivity analysis directed towards the prototype behavior was conducted in a manner similar to the analysis directed towards the model. In this analysis, however, attention was devoted primarily to the external loads and ambient conditions which determine prototype water quality rather than to examination of the model coefficients.

It should be clearly noted that the results of subsequent sensitivity analysis are not precise predictions of prototype behavior under alternate sets of conditions. The variability of natural systems and the effects of random events may act to produce results which would differ from the predictions. The model results should be viewed as best estimates if the conditions remain at their calibrated levels except for the sensitivity parameters. Sensitivity analysis was again based on the July 1990 calibration period.

The sensitivity analysis is directed toward examining those factors which enhance or limit the algal population and DO concentration. These include sources of the nutrients, nitrogen and phosphorus, and the influence of light extinction, and boundary conditions.

B-1. Downstream boundary conditions

As discussed in Section V-A5, the concentrations of water quality parameters at the downstream boundary were specified with values measured in prototype. The sensitivity of the model predictions to these specified values was tested in 4 sets of model runs in which the boundary conditions for DO, chlorophyll 'a', CBOD and organic nitrogen were lowered or raised. The results, shown in Figure 6-4 to 6-7,
Figure 6-4. Sensitivity to DO downstream boundary condition.
Figure 6-5. Sensitivity to chlorophyll 'a' downstream boundary condition.
Figure 6-6. Sensitivity to CBOD downstream boundary condition.
Figure 6-7. Sensitivity to organic nitrogen downstream boundary condition.
indicate that the effects of the downstream boundary conditions are limited to the lower 10 km of the modeled reach of the river. Thus it may be concluded that the specification of boundary conditions is not crucial to model predictions.

B-2. Sediment oxygen demand

Sediment oxygen demand is spatially and temporally variable, and difficult to measure. A value of 0.5 to 1.5 g/m$^2$/day is typical for an unpolluted estuarine bottom. The values measured in the river range from 0.78 to 2.14 g/m$^2$/day. A constant, uniform value of 2.0 g/m$^2$/day was used in the model. Sensitivity to SOD values was tested in two model runs, with values of 1.0 to 3.0 g/m$^2$/day respectively.

The SOD affects only the dissolved oxygen concentration, shown in Figure 6-8. The maximum changes of DO concentration in both cases are about 1.0 mg/l. This result indicates that SOD plays an important role in the dissolved oxygen concentration.

B-3. Point sources

The effect of waste waters discharged from sewage treatment plants was examined with a model simulation in which all point source discharges were eliminated. Figure 6-9 shows that, though there are significant reductions in ortho phosphorus and ammonia nitrogen concentrations, the effects on chlorophyll ‘a’ and DO concentrations are small. This is because that the calibration period had relatively higher nonpoint source runoff, which dominated over point source discharges.

The effect of point sources in a dry period was examined in an additional model
Figure 6-8. Sensitivity to sediment oxygen demand.
Figure 6-9. Sensitivity to point source input (intensive survey on 7/25 - 7/26).
Figure 6-9. (continued).
run simulating August 7 condition, freshwater discharge about 10 m$^3$/s. Figure 6-10 shows that, without point source of nutrients, the chlorophyll ‘a’ is phosphorus-limited and DO concentration is depressed. It should be noted that in these sensitivity runs, the benthic oxygen demand was not altered even though the phytoplankton population might decrease. It is believed that the net effect of nutrient reduction will be improved DO conditions in the river, if the accompanying change in benthic oxygen demand is accounted for. Unfortunately there is little information relating SOD changes directly to altered water column conditions, so selection of model inputs for the altered conditions is problematic.

B-4. Nonpoint source

The contribution of nonpoint source was examined by model sensitivity runs in which all nonpoint source pollutants were eliminated but river flow, DO and chlorophyll ‘a’ concentrations were held the same as before. The results are presented in Figures 6-11 and 6-12. Without nonpoint source inputs of nutrients, the phytoplankton growth is severely limited and DO is depressed. Comparison of Figures 6-11 and 6-12 indicates that the nutrient concentrations on August 7 (dry period) are reduced much less than those on July 25-26, the intensive survey. However, the effects on chlorophyll ‘a’ and DO concentrations are just as great because the August 7 condition is phosphorus-limited to start with.

B-5. Benthic phosphorus flux

Field measurements suggested that the benthic flux of ortho phosphorus were
Figure 6-10. Sensitivity to point source input (slackwater survey on 8/7/90).
Figure 6-10. (continued).
Figure 6-11. Sensitivity to nonpoint source input (intensive survey on 7/25 - 7/26).
Figure 6-11. (continued).
Figure 6-12. Sensitivity to nonpoint source input (slackwater survey on 8/7/90).
Figure 6-12. (continued).
negligibly small. Model predictions with zero phosphorus benthic flux are compared to those for model calibration. Figure 6-13 shows that elimination of benthic flux has little effect on chlorophyll growth on July 25-26 since the condition has not reached phosphorus-limited. However, Figure 6-14 show that, in a low flow condition when phosphorus limits the chlorophyll growth, the elimination of the benthic flux has a significant effect on chlorophyll ‘a’ and DO concentrations.

B-6. **Light limitation.**

The availability of light is as important to phytoplankton growth as the availability of nutrients. The role of light limitation was examined by alternately increasing and decreasing the light-extinction coefficients by about 50% and 30% respectively. These correspond roughly the upper and lower limit of field data (Figure 5-8). Results, shown in Figure 6-15, indicate that the phytoplankton growth is sensitive to light availability. Altering light extinction coefficient has significant effects on the concentrations of chlorophyll ‘a’, DO and inorganic nutrients.
Figure 6-13. Sensitivity to benthic flux of phosphate (intensive survey on 7/25 - 7/26).
Figure 6-14. Sensitivity to benthic flux of phosphate (slackwater survey on 8/7/90).
Figure 6-15. Sensitivity to extinction coefficient.
VII. SUMMARY AND DISCUSSION

A mathematical water quality model has been applied to the upper portion of the tidal Rappahannock River. The model consists of two separate models, the hydrodynamic and water quality models. Both are one-dimensional, time variable models, the former is based on the principles of conservation of volume, momentum and mass, the latter is based on the conservation of mass alone.

The hydrodynamic model provides real-time predictions of surface level, current velocity, and transport of a conservative substance. Calibration results show that the model provides very good description of the tidal characteristics along the river. Real-time predictions of surface level and current velocity also agree very well with prototype measurements. The ability of the model to predict mass transport and dispersion has been verified by successfully simulating the nonsteady-state longitudinal distribution of dye.

The water quality model provides one-dimensional, real-time predictions of eight water quality parameters. They are

- organic nitrogen,
- ammonia nitrogen,
- nitrite-nitrate nitrogen,
- organic phosphorus,
- ortho phosphorus,
- chlorophyll ‘a’,
- carbonaceous biochemical oxygen demand,
dissolved oxygen.

The water quality model has been calibrated and verified against two independent data sets. These are


-- Verification of long-term predictive ability through simulation of longitudinal distributions of all water quality parameters. June - September, 1990 slackwater surveys.

-- Additional verification of long-term predictive ability was achieved through (1) simulation of time varying spatial-average concentrations of all water quality parameters, using the June - September, 1990 slackwater surveys and the intensive survey, and (2) longitudinal distributions of time-averaged predictions versus the data from all surveys.

The agreement between predictions and observations is more than satisfactory. In general, the predictive ability of the model and agreement between predictions and observations are dependent upon both the quality and quantity of input data and the nature and number of observations. The water quality model results are commensurate with the data available to this study. Two quantitative measures of accuracy, RMS error and average error, have been determined.

Some discrepancies between predictions and observations are the results of the random variability inherent to natural systems. Another cause of discrepancies is the goal of consistency which motivated the calibration and verification processes. The objective of these procedures was to find a single set of kinetic coefficients and model
parameters which would provide satisfactory predictions in all cases rather than to employ survey-specific coefficients and parameters in an effort to obtain the best fit to the data. The goal of consistency was fulfilled in this study.

Both the field observations and model simulations demonstrate the impact of point source discharges on the concentrations of ammonia nitrogen and ortho phosphorus in the river. Both have distinctive peaks around km 170, where the STP’s are located. These concentration peaks were pronounced during low flow periods, e.g., August 7, 1990. These inorganic nutrients, together with those from nonpoint source from upriver of fall line, contribute to substantial phytoplankton growth in this reach of the river. One consequence of the excessive growth is the higher benthic oxygen demand than normally observed in unpolluted estuaries.

There was also evidence of a DO sag as a result of the point source discharges. The DO sag was located around km 160 at times of low flow, e.g., August 7, 1990. However, it was pushed farther downriver at times of high flow, e.g., July 18, 1990. Because of contribution from phytoplankton photosynthesis, the DO concentration was above 5 mg/l except during the period following very high runoff, e.g., July 18, 1990.

The model simulations indicate that both point source and nonpoint source inputs have significant impacts on water quality in the upper tidal Rappahannock River. The relative importance of the two sources depends on the magnitude of the river discharge. Table 7-1 presents the average loadings from point sources and the nonpoint source respectively. It also gives the nonpoint source loadings at several levels of freshwater flows. The nonpoint source loadings at 1.36 m$^3$/s of freshwater flow, the 7-day 10-year low flow, was estimated by assuming concentrations of water...
Table 7-1. Comparison of point and nonpoint source loadings.

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a Average of all measurements.
b 7-day, 10-year low flow.
quality parameters the same as those observed at flow of 9.5 m$^3$/s, the lowest flow measured in the summer of 1990.
REFERENCES


Appendix 1.

Slackwater Survey Data

(May 22, June 6, June 20, July 5, July 18, July 22, August 7, August 20, September 4, 1990)
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| Salinity | | | | | | | | | |

| Dissolved Oxygen | 8.73 | 9.30 | 8.40 | 8.30 | 8.20 | 7.60 | 7.40 | 7.30 | 7.80 | 7.45 |
|Particulate N | 0.0590 | 0.0850 | 0.0870 | 0.1590 | 0.1290 | 0.1650 | 0.1050 | 0.1490 | 0.1760 | 0.2000 |
|Total Dissolved N | 0.8810 | 0.8930 | 0.9050 | 0.9660 | 0.9440 | 0.9720 | 0.9470 | 0.9470 | 0.9660 | 0.9350 |
|Ammonia N | 0.0110 | 0.0110 | 0.0460 | 0.0980 | 0.0950 | 0.1460 | 0.1390 | 0.1400 | 0.1170 | 0.1220 |
|Nitrite + Nitrate N | 0.7720 | 0.7872 | 0.7720 | 0.7681 | 0.7796 | 0.7872 | 0.7567 | 0.7796 | 0.8102 | 0.7720 |
|Particulate P | 0.0080 | 0.0090 | 0.0160 | 0.0240 | 0.0340 | 0.0420 | 0.0310 | 0.0350 | 0.0340 | 0.0480 |
|Total Dissolved P | 0.0350 | 0.0350 | 0.0410 | 0.0390 | 0.0380 | 0.0380 | 0.0360 | 0.0340 | 0.0300 | 0.0310 |
|Phosphate P | 0.0160 | 0.0166 | 0.0196 | 0.0196 | 0.0209 | 0.0196 | 0.0160 | 0.0160 | 0.0130 | 0.0124 |
|BODS | .30 | .20 | .10 | .30 | .10 | .20 | .30 | .20 | .40 | .30 |
|Chlorophyll A (ug/l) | .66 | 1.46 | 1.36 | 2.27 | 1.91 | 3.13 | 3.35 | 3.88 | 3.51 | 5.93 |

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### Additional Data

- **BODS**: 0.80, 0.80, 7.00, 6.00, 5.93, 5.93
- **Chlorophyll A (ug/l)**: 22.77, 21.41, 18.05, 17.59, 10.38, 10.96

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| Dissolved Oxygen | .0400 | .0350 | .0470 | .1650 | .1030 | .0940 | .1650 | .1090 | .1920 | .2320 | .1950 |
| Particulate N | .0260 | .0340 | .1030 | .0980 | .0970 | .2170 | .1670 | .1830 | .0800 | .0880 | .0670 |
| Total Dissolved N | .5503 | .4960 | .3442 | .2139 | .2093 | .2186 | .2232 | .3883 | .4279 | .4302 | .5270 |
| Ammonia N | .0070 | .0080 | .0100 | .0300 | .0330 | .0330 | .0420 | .0470 | .0620 | .0490 | .0560 |
| Nitrite + Nitrate N | .0190 | .0180 | .0180 | .0270 | .0230 | .0270 | .0190 | .0230 | .0230 | .0220 | .0220 |
| Particulate P | .0056 | .0056 | .0092 | .0152 | .0134 | .0152 | .0104 | .0104 | .0128 | .0128 | .0104 |
| Total Dissolved P | .0180 | .0180 | .0180 | .0270 | .0230 | .0270 | .0190 | .0230 | .0230 | .0220 | .0220 |
| Phosphate P | .0056 | .0056 | .0092 | .0152 | .0134 | .0201 | .0140 | .0104 | .0104 | .0128 | .0128 |
| BOD5 | .06 | .50 | .20 | 1.80 | 1.00 | 1.10 | .90 | 1.00 | .80 | .60 | 1.40 |
| Chlorophyll A (ug/l) | 1.49 | 1.57 | 1.17 | 8.93 | 3.86 | 8.17 | 17.90 | 15.85 | 13.80 | 14.95 | 14.01 |</p>
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| Disk visibility (m) | 1.4 | 1.5 | 1.7 | 1.6 |
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Appendix 2.

Fall Line and Point Source Loads

(Summer of 1990)
## Fall Line loads (1990)

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<th>TDP</th>
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All units reported as mg/l unless otherwise noted.

- PN = particulated N
- TDN = total dissolved N
- NH4 = ammonia N
- NO23 = nitrite + nitrate N
- PP = particulated P
- TDP = total dissolved P
- PO4 = phosphate P
- Chl 'a' = chlorophyll 'a'
Claiborne Run STP (1990)

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PN = particulated N
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NH4 = ammonia N
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PP = particulated P
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All units reported as mg/l unless otherwise noted.
- PN = particulated N
- TDN = total dissolved N
- NH4 = ammonia N
- NO23 = nitrite + nitrate N
- PP = particulated P
- TDP = total dissolved P
- PO4 = phosphate P
Appendix 3.

Intensive Survey Data

(July 25 - 26, 1990)
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** Distance from river mouth in kilometers
Rappahannock River Intensive Survey  
25 - 26 July, 1990

Chlorophyll A (ug/l)

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* Upriver of the mouth of Hazels Run (HR) or Bouy Number  
** Distance from river mouth in kilometers
### Virginia Institute of Marine Science
Feb 13, 1991

**Rappahannock River Intensive Survey**
25 - 26 July, 1990

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* Upriver of the mouth of Hazels Run (HR) or Buoy Number
** Distance from river mouth in kilometers
## Rappahannock River Intensive Survey
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* Upriver of the mouth of Hazels Run (HR) or Buoy Number
** Distance from river mouth in kilometers
### Virginia Institute of Marine Science - Feb 13, 1991

**Rappahannock River Intensive Survey**

25 - 26 July, 1990

**Total Dissolved N (mg/l)**

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**STD** | .0725 | .0417 | .0739 | .0956 | .0576 | .0569 | .0622 |

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* Upriver of the mouth of Hazels Run (HR) or Buoy Number

** Distance from river mouth in kilometers
### Rappahannock River Intensive Survey

#### 25 - 26 July, 1990

Ammonia N (mg/l)

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* Upriver of the mouth of Hazels Run (HR) or Bouy Number
** Distance from river mouth in kilometers
### Rappahannock River Intensive Survey

#### 25 - 26 July, 1990

**Nitrite + Nitrate N (mg/l)**

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**Mean**

- .5952

**STD**

- .0362

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* Upriver of the mouth of Hazels Run (HR) or Bouy Number

** Distance from river mouth in kilometers
Virginia Institute of Marine Science · Feb 13, 1991

Rappahannock River Intensive Survey
25 - 26 July, 1990

Particulate P (mg/l)

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* Upriver of the mouth of Hazels Run (HR) or Buoy Number
** Distance from river mouth in kilometers
### Rappahannock River Intensive Survey
25 - 26 July, 1990

**Total Dissolved P (mg/l)**

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</table>

* Upriver of the mouth of Hazels Run (HR) or Buoy Number
** Distance from river mouth in kilometers
### Phosphate P (mg/l)

<table>
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<tr>
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<th>2</th>
<th>3</th>
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* Upriver of the mouth of Hazels Run (HR) or Bouy Number
** Distance from river mouth in kilometers
### Rappahannock River Intensive Survey
25 - 26 July, 1990

800-5 (mg/l)

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<th>4</th>
<th>5</th>
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<tbody>
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<td>169.4</td>
<td>163.8</td>
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<tr>
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<td>.60</td>
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<tr>
<td>1.0</td>
<td>.50</td>
<td>.60</td>
</tr>
<tr>
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<td>.70</td>
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<td>2.00</td>
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<tr>
<td>9.0</td>
<td>.90</td>
<td>1.00</td>
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<tr>
<td>10.0</td>
<td>1.20</td>
<td>.80</td>
</tr>
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<td>.80</td>
<td>1.00</td>
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<tr>
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<td>1.00</td>
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<td>15.0</td>
<td>1.00</td>
<td>1.00</td>
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<td>1.00</td>
</tr>
<tr>
<td>23.0</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

| Mean  | .25 | .29 | .54 | .47 | .78 | .89 |
| STD   | .11 | .14 | .21 | .16 | .29 | .38 |

* Upriver of the mouth of Hazels Run (HR) or Bouy Number
** Distance from river mouth in kilometers
Appendix 4.

Plots of Current Meter Data
Appendix 5.

Sediment Oxygen Demand and Nutrient Exchange; Rappahannock River Water Quality Studies, Summer 1990.

Richard L. Wetzel and Betty E. Berry

College of William & Mary
Virginia Institute of Marine Science
School of Marine Science
Gloucester Point, VA 23062
both near surface (ca. 1 m) and bottom water (ca. 0.5 m above bottom) by pumping using a submersible, 12 VDC impeller pump. Water was pumped to an onboard 20 litre carboy from which oxygen measurements were made and water samples taken. Oxygen was determined using a Clark type oxygen sensor (Orbisphere O2 Monitor model 2604) calibrated against water-saturated air. Temperature was determined using thermistor probes incorporated in the sensing head of the oxygen electrode. For the May preliminary studies, nutrient samples were dispensed to acid-cleaned, 50 ml polyethylene sample tubes and stored in ice for transport to the laboratory. All analyses were run in triplicate. For the July intensive studies, nutrient samples for in situ conditions were taken from the initial BOD incubations (see below).

Intact benthic sediment samples and bottom water samples were taken for incubation experiments to determine oxygen uptake and nutrient exchange rates. Intact sediment samples were obtained by SCUBA using 11.5 cm (4.5 in) diameter X 30 cm height (12 in) acrylic core tubes fitted with "O"-ring sealed top and bottom closures. For the May preliminary studies, the sediment samples were returned to the VIMS laboratory at Gloucester Point and incubated in a temperature-controlled, environmental chamber at in situ temperature. Time series measurements of oxygen and nutrient concentrations were made on the cores using a multi-channel oxygen monitor and 50 ml syringe samples of overlying water respectively. Stirring was provided by stirrers incorporated in the oxygen probes and water taken for nutrient analyses was replaced using separately incubated ambient bottom water. Replicate sediment samples were taken at each station for each study. Single readings (oxygen) and single water samples (nutrients) were taken from each core at one to two hour
intervals for the duration of an experiment (total time of 6 to 8 hours). For the July studies, all procedures were as described except the incubations were carried out aboard ship using an ambient water bath for temperature control.

Bottom water samples were obtained by pumping as for water sampling (above) and incubated in 300 ml, acid-cleaned, standard glass BOD bottles. For each site, six bottles were filled by siphoning from a 20 litre reservoir of ambient bottom water and capped immediately. Three bottles were read initially for dissolved oxygen and nutrient samples taken and stored in ice. The remaining three were incubated with the sediment cores and sampled at termination of the core incubations.

Nutrient concentrations were determined using standard methods. Water samples were analyzed for ammonium ($\text{NH}_4^+$), nitrite ($\text{NO}_2^-$), nitrate ($\text{NO}_3^-$) and ortho phosphate ($\text{PO}_4^{3-}$). Ammonium was determined at the time of sampling using an indophenol method. Nitrite, nitrate and phosphate samples were stored in acid cleaned polycarbonate tubes until time of analysis.

Oxygen demand of sediments and water was calculated as the rate of change in oxygen concentration during the incubation experiments. The rates reported for sediments were estimated by linear regression of concentration and incubation time (corrected for electrode drift and uptake due to water alone) and reported on a surface area basis ($\text{mgO}_2/\text{m}^2/\text{h}$). Oxygen demand of bottom water was estimated as the mean difference between initial and final incubation bottle concentrations and is reported on a volume basis ($\text{mgO}_2/\text{m}^3/\text{h}$). Nutrient exchange rates were estimated as for sediment and bottom water oxygen demand and reported using the convention that a positive rate indicates "release" of the nutrient compound in question and a negative rate
indicates "uptake" of the compound.

Results

The results of the these studies are presented in the following figures and tables. Table 1 gives the dates, times and general sampling conditions at each site for each study. Figure 1 illustrates both in situ concentration of bottom water dissolved oxygen and relative percent saturation (i.e. relative to 100 % saturation at in situ water temperature and barometric pressure) at the time of sampling. Table 2 summarizes the results of the oxygen demand and exchange studies (ammonium only). Figures 2 and 3 present these data graphically. Since some benthic and water column exchange models use "flux-flux" relationships to describe nutrient exchanges, flux ratios for oxygen and nitrogen as ammonium are given in the table and illustrated in Figure 4. Tables 3 and 4 summarize the results of nitrite-nitrate and ortho phosphorus exchanges. In general, no significant exchange was observed.
Table 1. Sampling regimes for Rappahannock River Oxygen and Nutrient Exchanges  
Summer, 1990.

<table>
<thead>
<tr>
<th>DATE</th>
<th>SITE</th>
<th>RM (KM)</th>
<th>TOS (hrs)</th>
<th>TEMP (°C)</th>
<th>DEPTH (m)</th>
<th>SDO (mgO2/L)</th>
<th>BDO (mgO2/L)</th>
<th>DOsat (mgO2/L)</th>
<th>SAT (%)</th>
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</thead>
<tbody>
<tr>
<td>05/31/90</td>
<td>C-79</td>
<td>129</td>
<td>14:30</td>
<td>17.6</td>
<td>6.1</td>
<td>7.95</td>
<td>7.77</td>
<td>9.57</td>
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<td>28.2</td>
<td>5.2</td>
<td>ND</td>
<td>5.30</td>
<td>7.94</td>
<td>66.8</td>
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<tr>
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<td>7.90</td>
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<td>7.94</td>
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</table>

LEGENDS:
RM = Distance Upriver in Kilometers
TOS = Time of Sampling; 24 hour clock
TEMP = Temperature in degrees Celsius
SDO = Surface Water Dissolved Oxygen
BDO = Bottom Water Dissolved Oxygen
DOsat = In situ Dissolved Oxygen Saturation Value
SAT = Percent O2 Saturation of Bottom Water
Figure 1. Bottom Water DO and % Saturation
Table 2. Rappahannock River Sediment and Water Column Oxygen and Nutrient Exchanges ("-" = Uptake; "+" = Release).

A. Water Column Exchanges; mgO2/m3/h and mgN/m3/h.

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<th>C-123 NH4</th>
<th>C-131 O2</th>
<th>C-131 NH4</th>
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B. Sediment Exchanges; mgO2/m2/h and mgN/m2/h.

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<th>C-79 NH4</th>
<th>C-123 O2</th>
<th>C-123 NH4</th>
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<table>
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<th>DATE</th>
<th>C-79 O2</th>
<th>C-123 O2</th>
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<td>9.4</td>
<td>9.0</td>
<td>10.5</td>
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</table>
Figure 2. Water and Sediment O2 Uptake
Figure 3. Water and Sediment NH$_4$ Exchange.

mgN-NH$_4$/m$^3$/h or mgN-NH$_4$/m$^2$/h

Sampling Dates

05/31/90 07/24/90 07/27/90

RELEASE

UPTAKE

C-79 (H$_2$O) C-123 (H$_2$O) C-131 (H$_2$O)

C-79 (SED) C-123 (SED) C-131 (SED)
Figure 4. Sediment O2:N-NH4 Exchange Ratios.

O2:N-NH4 Ratio (atoms)

Sampling Dates

- C-79
- C-123
- C-131
TABLE 3
RAPPAHANNOCK RIVER SONE (1990)
NOx AND PO4 SEDIMENT EXCHANGE RATES

(NOx AND PO4 SEDIMENT EXCHANGE RATES

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<td>C-131</td>
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<td>NS</td>
</tr>
<tr>
<td>07/24/90 thru 07/25/90</td>
<td>C-79</td>
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<td>NS</td>
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* NS = NO SIGNIFICANT CHANGE (≤0.05)

** NOTE ONLY ONE OF THE TWO CORES AT EACH OF THESE SITES SHOWED A SIGNIFICANT EXCHANGE RATE
### TABLE 4

RAPPAHANNOCK RIVER SONE (1990)
NOx AND PO4 WATER COLUMN EXCHANGE

<table>
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<td>NS</td>
<td>NS</td>
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<tr>
<td>thru 07/25/90</td>
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<td>NS</td>
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<td>C-131</td>
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<td>C-131</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

* NS = NO SIGNIFICANT CHANGE (α=0.05)
Appendix 6.

Model Program Code
• The hydrodynamic model source code consists of 5 programs:
  1) HEM-HYD.FOR is the main program for hydrodynamic model,
  2) HYDPLT.FOR has subroutines to calculate tidal cycle mean, maximum and minimum of hydrodynamic parameters for graphic interface and to write them for Post-Processor,
  3) ASKPLT-H.FOR has some subroutines for graphic interface of hydrodynamic model,
  4) COM-HYD.INC has the common block for hydrodynamic model,
  5) BLKD-HYD.INC has the block data for hydrodynamic model: it includes COM-HYD.INC.

• The water quality model source code consists of 5 programs:
  6) HEM-WQ.FOR is the main program for water quality model,
  7) WQPLT.FOR has subroutines to calculate daily mean, maximum and minimum of water quality parameters for graphic interface and to write them for Post-Processor,
  8) ASKPLT-W.FOR has some subroutines for graphic interface of water quality model,
  9) COM-WQ.INC has the common block for water quality model,
  10) BLKD-WQ.INC has the block data for water quality model: it includes COM-WQ.INC.

• One source program, MDLPLT.FOR, has subroutines for graphic interface that are used for both hydrodynamic and water quality models.

This appendix lists 8 of the 11 source programs: HEM-HYD.FOR, HYDPLT.FOR, COM-HYD.INC, BLKD-HYD.INC, HEM-WQ.FOR, WQPLT.FOR, COM-WQ.INC and BLKD-WQ.INC. The other 3 source programs do not affect the mode calculation.
A6-1. HEM-HYD.FOR

PROGRAM HEM_HYD
C: This program solves 1-D Continuity, Momentum and Salt Balance Eqns.
C: Written in FORTRAN 77 (ANSI x3.9-1978) except DO WHILE & END DO.
INCLUDE ‘COM-HYD.INC’
INCLUDE ‘SPINATTR.HDR’
Parameter (g=9.8)
Common/Ecal(UA(iX,220)),TavgU(220),UT(iX),UTrms(iX),Ebase,VS,TS,
* FEXP,CRi,PET,GRVCR
C+++s
Common/MeanPLT/YmaxPLT(iX),QmaxPLT(iX),SmaxPLT(iX),UmaxPLT(iX),
* EmaxPLT(iX),DmaxPLT(iX),YminPLT(iX),QminPLT(iX),SminPLT(iX),
* UminPLT(iX),EminPLT(iX),DminPLT(iX),YavgPLT(iX),QavgPLT(iX),SavgPLT(iX),
* UavgPLT(iX),EavgPLT(iX),DavgPLT(iX)
Character title1*20,title2*20,yunit1*14,yunit2*14
Character*2 pltdatal,pltdata2, VK*l
Logical hydplt,first1,first2,newclock,kpress,ISKEY,cancel,redrawl,
* redraw2, LFile,FEXIST
Integer*2 iCL,iRL
Data keyval(1)
Dimension Ampl(9),Phase(9),SIC(iX)
Character*30 Gin
C+++s
CALL Hheading
1111 CONTINUE
CALL SETATTR(BLKBKG+LBLUCHR+BRITE)
CALL LOCATE(3,10)
CALL PRINTS(‘** General input data file ’)
CALL CURON
CALL GETPOS(iRL,iCL)
CALL SETATTR(WHITECHR)
CALL LOCATE(iRL,iCL+1)
CALL PRINTS(VK)
CALL LOCATE(iRL,iCL+2)
READ(*,’(a)’) Gin
C+++e
Gin = VK // Gin
END IF
LFile = FEXIST(Gin)
IF (.NOT.LFile) THEN
CALL CUROFF
CALL SETATTR(BLKBKG+REDCHR+BRITE)
CALL LOCATE(9,5)
CALL PRINTS(‘WARNING !!!’)
CALL LOCATE(11,2)
CALL PRINTS(}
* 'Specified file does not exist in the current directory')
CALL LOCATE(12,2)
cALL PRINTS('Press (Y)es to try again or ANY OTHER KEY to exit')
ITMP = IXKEY()
cALL SETATTR(BLK BKG+WHITECHR)
cALL CLS
IF (ITMP.EQ.121 .OR. ITMP.EQ.89) THEN
  GOTO 1111
ELSE
  STOP
END IF
END IF

1001 CONTINUE
TinDay=0.0
Tday=0.0
TinTC=0.0
IterN=0
Day=1.0
NCOUNT=1000
NDC=1000
DO 421 i=ML,MU
  SIC(i)=0.0
421 CONTINUE

OPEN(8,FILE=Gin,STATUS='OLD')
OPEN(6,FILE='hyd.out')
READ(8, '(8i5) ') iSalt,iWQ,iSatDB,iUatUB,iTide,iUBC,iPSQ,iDye
READ(8, '(iS)') iPLT
IF (iSalt .EQ. 1) THEN
  WRITE(6,801) '* Salt is modeled.
ELSE
  WRITE(6,801) '* Salt is not modeled.
END IF
IF (iWQ .EQ. 1) THEN
  CALL PLOTS(0,1,0)
  CALL N:S:WPEN(13)
  CALL GTEXT(S,5, 'NOTE!!!')
  CALL GTEXT(7,2,
    '*If you do not complete the model run, the existing output files
    *including binary file (WQ.HYD), if any, will be erased."
  iTMP = IXKEY()
  CALL PLOT(0.0,0.0,999)
  IF (iTMP.NE.121 .AND. iTMP.NE.89) THEN
    CLOSE(6,STATUS='DELETE')
    STOP
  END IF
END IF
OPEN(9,FILE='WQ.HYD',FORM='UNFORMATTED')
WRITE(6,801) '* Hydraulics will be passes to WQ model.
ELSE
  WRITE(6,801) '* Hydraulics will not be passes to WQ model.
END IF
IF (iSatDB .EQ. 1) THEN
  OPEN(5,FILE='SALT.IN',STATUS='OLD')
  WRITE(6,801) '* Unsteady S bdry condition at downstream bdry.
ELSE

WRITE(6,801)'* Steady S bdry condition at downstream bdry.'
END IF
IF (iUatUB .EQ. 1) THEN
OPEN(11,FILE='FLOW.IN',STATUS='OLD')
WRITE(6,801)'* Unsteady f.w. inflow through upstream bdry.'
ELSE
WRITE(6,801)'* Steady f.w. inflow through upstream boundary.'
END IF
IF (iTide .EQ. 1) THEN
OPEN(12,FILE='TIDE.IN',STATUS='OLD')
WRITE(6,801)'* Hourly tidal heights are used for BC at DB.
ELSE
WRITE(6,801)'* Tidal heights at DB are generated by harmonics.'
END IF
IF (iUBC .EQ. 1) THEN
WRITE(6,801)'* No momentum (only mass) flux from f.w. discharge'
ELSE
WRITE(6,801)'* Both momentum & mass flux from f.w. discharge.'
END IF
IF (iPSQ .EQ. 1) THEN
OPEN(13,FILE='PSQ.IN',STATUS='OLD')
WRITE(6,801)'* Daily-varying point source discharges.
ELSE
WRITE(6,801)'* Timewise constant point source discharges.'
END IF
IF (iDye .EQ. 1) THEN
WRITE(6,801)'* Instantaneous dye release, point or distributed '
ELSE IF (iDye .EQ. 2) THEN
WRITE(6,801)'* Continuous dye release, point or distributed
ELSE
WRITE(6,801)* No dye release
END IF
IF (iPLT .EQ. 1) THEN
OPEN(14,FILE='HYD-PLT.DAT')
WRITE(6,801)'* Generate tidal cycle max, mean & min output.'
ELSE
WRITE(6,801)'* No tidal cycle max, mean & min output.'
END IF
OPEN(7,FILE='TRANGE.OUT')
OPEN(10,FILE='SLACK.OUT')
C**********************************************************************C
C ReadGH reads in the geometry & initial conditions from unit #8.
C If iWQ=1, the time constant geometric informations are written in binary
C to unit #9.
C**********************************************************************C
CALL ReadGH(iUBC)
IF (iWQ .EQ. 1) WRITE(9) ML,MU,DistT,StSAM,ARD,Darea
C**********************************************************************C
C DT/DTD = time interval in seconds/days.
C rNTSiH = number of time steps in one hour.
C iTMAX number of time steps (DT's) in TMAX.
C iTPSi = time to start to calculate cycle mean, max and min.
C iTprn = here, # of time steps from model-start to the first output print.
C**********************************************************************C
READ(8,9004) TMAX, DTT, NP
WRITE(6,802)'** Number of tidal cycles for model to be run =',TMAX,
* * Time increment in tidal cycles =',DTT
WRITE(6,'(A46,I10)')
* * Number of times to print output =',NP
READ(8,'(8F10.0)') (TOUT(m), m=1,NP)
WRITE(6,'(8F10.6)') (TOUT(m), m=1,NP)
DT = DTT * 44712.0
DTD = DTT * 0.5175
A6-4
rNTSiH = 1.0 / (DTT*12.42)
MTMAX  NINT(TMXX/DTT)
iTPrn = NINT(TOUT(IncP)/DTT)
iTPrs1 = NINT((TOUT(IncP)-1.0)/DTT)
DO 10 i=MLl,MU
   DTX(i) = DT / DX(i)
10 CONTINUE
IF (iPLT.EQ.l) THEN
   WRITE(14,9999)'* Upstream boundary transect number ML,
   * Downstream boundary transect number MU
   WRITE(14,9998) '* Model run duration in tidal cycles TMAX
END IF
9999 FORMAT((a40,i5))
9998 FORMAT(a40,fl0.5)
C********************************************************************************
C READ(8,9004) SPT, EPT, iNTS
WRITE(6,889) '* Start passing hydraulics to WQM',
  * 'from ',SPT,' to ',EPT,' days',
  * 'every ', iNTS, ' time steps.'
889 FORMAT(/, A33, /, A9, F8.2, AS, F8.2, A6, /, AlO, IS, Al3, /)
C********************************************************************************
C READ(8,(2F8.0)) Alp,Beta
WRITE(6,802)'* Implicit weighting factor for sfc gradient =', Alp,
  * for velocity gradient =', Beta
AlpC = 1.0 - Alp
BetaC = 1.0 - Beta
ABG = Alp * Beta * g
C********************************************************************************
C Read in Wind in dynes/cm**2 & convert to stress/density (m**2/s**2).
C Air density is assumed to be 1.
C********************************************************************************
C READ(8,9001) Wind
WRITE(6,802) '* Wind stress in dynes/cm**2 =', Wind
Wind = Wind / 1.0E4
C********************************************************************************
C Read in parameters related to dispersion coefficient.
C: UTrms(i) = r.m.s. tidal current speed = UT(i) / SQRT(2). Wilber (1986)
C argued that UTrms(MU) for whole river, instead of UTrms(i), gave
C better results.
C: NTS2 = number of time steps in 2 tidal cycles.
C********************************************************************************
C READ(8,9001) Ebase, VS, TS, GRVCR, CRi, FEXP
WRITE(6,802) '* Minimum dispersion coeff at slack tide =', Ebase
  * 'Multiplier for vertical shear =', VS
  * 'transverse shear =', TS
  * 'gravitational circulation =', GRVCR
  * 'f.w. & tidal current ratio =', CRi
  * 'Exponent for freshwater inflow =', FEXP
READ(8,9001) (UT(i), i=ML,MU)
WRITE(6,'(A32,/,(10F7.3))')
  '* Tidal current amplitude (m/s): ', (UT(i), i=ML,MU)
DO 20 i=ML,MU
   UTrms(i) = UT(i) / 1.4142
   UT(i) = UT(i) * 44712.0
20 CONTINUE
C For the tidal river only, don’t need IterN,NTS2 in SUBR CalcE
C: NTS2 = NINT(2.0/DTT)
C********************************************************************************
C READ(8,9001) rk, Dcay
WRITE(6,802) '* proportionality constant bet/ S and density=', rk,
  * '1st order decay rate (per day) =', Dcay
C********************************************************************************
C READ(8,9001) SatUB, DatUB, TOFH
WRITE(6,8C2) '* S at upstream boundary =', SatUB
WRITE(6,802)'* Dye at upstream boundary
WRITE(6,802)'* Hours to reach SFLDM from SBF at the DB
MST = NINT(3600.0*TOFH/DT)
C**********************************************************************
C: If iTide /= 1, read in the Ampl & Phase of 9 important tidal constituents
C: which will be used to generate the harmonic tides in FUNC. HTide.
C: If iTide=1, ReadTD reads in observed hourly tidal data for the first day.
C**********************************************************************
READ(8,'(2F8.3)') (Ampl(k), Phase(k), k=1,9)
IF (iTide .EQ. 1) THEN
  CALL ReadTD(Day)
ELSE
  WRITE(6,888) (Ampl(k), Phase(k), k=1,9)
END IF
888 FORMAT('* Tidal amplitudes (cm) & phases (radian)', /*
C**********************************************************************
C: Read in the constant SFLDM, QML2 & PSQ(i), and QML2 & PSQ(i) are passed to
C: SUBR GetQLat to compute QLat(i) if iSatUB =/= 1.
C: If iSatDB=1 (iSatUB=1), reads in the SFLDM (QML2) for the first day.
C**********************************************************************
READ(8, (IS)) NS2Sal
READ(8,9001) TSIC
READ(8,9001) (SIC(i), i=ML,MU)
IF (NS2Sal .NE. 0) THEN
  WRITE(6,803)'* Time (in day) to specify soar dye cone.
  WRITE(6,804): Concentration to be injected,
  WRITE(6,9001) (SIC(i), i=ML,MU)
iTSIC = NINT(TSIC/DTD)
END IF
READ(8,9001) TDye
READ(8,9001) (DIC(i), i=ML,MU)
IF (iDye.EQ.1) THEN
  WRITE(6,803)* Days to specify instantaneous dye release='', TDye
  WRITE(6,803): Amount of dye to be released in kg
  WRITE(6,9001) (DIC(i), i=ML,MU)
iTDIC = NINT(TDye/DTD)
ELSE IF (iDye.EQ.2) THEN
  WRITE(6,803)* Days to specify continuous dye release -= TDye
  WRITE(6,803): Amount of dye to be released in kg/day
  WRITE(6,9001) (DIC(i), i=ML,MU)
iTDIC = NINT(TDye/DTD)
ELSE
  WRITE(6,803)'* The TDye & DIC(i) will not be used
END IF
C Convert tons/d into ppb (DIC will be divided by VOL*Rho-w later).
 xTmp = 1.0E6 * DTD
 DO 120 i=ML,MU
   DIC(i) = xTmp * DIC(i)
 D2(i) = 0.0
120 CONTINUE
READ(8,9001) SFLDM, DFLDM, QML2
READ(8, (IS)) NS2
IF (iPSQ .EQ. 1) THEN
  WRITE(6,804)* PS discharges (m**3/s) at the Day,
  ' th days
  DO 30 m=1,NS2
  A6-6
READ(13,'(9X,I5,F10.4)') i, PSQ(i)
WRITE(6,'(I5,A2,F10.4)') i, ': ', PSQ(i)
CONTINUE
ELSE
WRITE(6,803)'* Timewise constant PS discharge (m**3/s);
DO 40 m=1,NS2
READ(8,'(9X,I5,F10.4)') i, PSQ(i)
WRITE(6, '(IS,A2,Fl0.4) ') i, ' : ', PSQ(i)
CONTINUE
END IF
IF (iSatDB .EQ. 1) THEN
READ(S, '(lOX,Fl0.2)') SFLDM
WRITE(6,804) '* Maximum salinity at DB at the ', Day,
* th days = ', SFLDM
ELSE
WRITE(6,803) '* Constant S at downstream boundary ',SFLDM
END IF
IF (iUatUB .EQ. 1) THEN
READ(ll,9001) FDTL
READ(ll,'(lOX,Fl0.2)') QML2
WRITE(6,803) '* Time lag (days) to adjust fw discharge = ',FDTL
WRITE(6,804)'* Discharge (m**3/s) at UB at the ', Day,
* th days = ', QML2
QML1 = QML2
ELSE
WRITE(6,803) '* Upstream freshwater inflow (m**3/sec) ',QML2
CALL GetQLat(QML2,iUBC)
END IF
C**********************************************************************
C+++s: entry point for plots
hydplt=.TRUE.
first1=.TRUE.
first2=.TRUE.
kpress=.FALSE.
cancel=.FALSE.
newclock=.TRUE.
redrawl=.FALSE.
redraw2=.FALSE.
nseg=MU-ML+1
iTinTC=0
C 83=S, 115=s, 18=640x480x16 VGA card
IF (keyval.NE.83 .AND. keyval.NE.115) THEN
CALL PLOTS(0,1,0)
ipltnum=1
CALL AskPLTH(ipltnum,pltdatal,titlel,yunitl,yminl,ymaxl)
ipn=2
CALL AskPLTH(ipltnum,pltdata2,title2,yunit2,ymin2,ymax2)
CALL PLOT(0.0,0.0,-999)
ENDIF
C 11=cyan
CALL NEWPEN(11)
CALL GTEXT(29,0, '(P)ause (R)esume re(S)tart (O)ther-plots (Y)s
*cale-change (Q)uit-or-ESC')
C+++e
C*******************************************************************************
C Iteration begins here.
C: IterN = number of iteration (count).
C: TinTC(TinDay) = time in tidal cycles (in days).
******************************************************************************
DO WHILE (IterN .LE. iTMAX)
IF (pltdatal.EQ.'mp') CALL mappltl(title1,first1,redrawl)
IF (pltdatal.EQ.'y2') CALL mdpltl(Y2,title1,yunit1,ML,MU,nseg,
* yminl,ymaxl,TinTC,first1,redrawl,hydplt,DistS)
IF (pltdatal.EQ. 'q2') CALL mdlplt1(Q2,title1,yunit1,ML,MU,nseg, ymin1,ymax1,TinTC,first1,redrawl,hydplt,DistT)
IF (pltdatal.EQ. 'u ') CALL mdlplt1(U ,title1,yunit1,ML,MU,nseg, ymin1,ymax1,TinTC,first1,redrawl,hydplt,DistT)
IF (pltdatal.EQ.'s2') CALL mdlplt1(S2,title1,yunit1,ML,MU,nseg, ymin1,ymax1,TinTC,first1,redrawl,hydplt,DistS)
IF (pltdatal.EQ.'e ') CALL mdlplt1(E ,title1,yunit1,ML,MU,nseg, ymin1,ymax1,TinTC,first1,redrawl,hydplt,DistT)
IF (pltdatal.EQ.'d2') CALL mdlplt1(D2,title1,yunit1,ML,MU,nseg, ymin1,ymax1,TinTC,first1,redrawl,hydplt,DistT)
IF (pltdatal.NE.'no') CALL PLOT(-1.0,-4.75,-3)
IF (pltdata2.EQ. 'mp') CALL mapplt2(title2,first2,redraw2)
IF (pltdata2.EQ.'y2') CALL mdlplt2(Y2,YminPLT,YmaxPLT,YavgPLT, *title2,yunit2,ML,MU,nseg,ymin2,ymax2,TinTC,first2,redraw2, *hydplt,DistS)
IF (pltdata2.EQ. 'q2') CALL mdlplt2(Q2,QminPLT,QmaxPLT,QavgPLT, *title2,yunit2,ML,MU,nseg,ymin2,ymax2,TinTC,first2,redraw2, *hydplt,DistT)
IF (pltdata2.EQ. 'u ') CALL mdlplt2(U ,UminPLT,UmaxPLT,UavgPLT, *title2,yunit2,ML,MU,nseg,ymin2,ymax2,TinTC,first2,redraw2, *hydplt,DistT)
IF (pltdata2.EQ. 's2') CALL mdlplt2(S2,SminPLT,SmaxPLT,SavgPLT, *title2,yunit2,ML,MU,nseg,ymin2,ymax2,TinTC,first2,redraw2, *hydplt,DistS)
IF (pltdata2.EQ. 'e ') CALL mdlplt2(E ,EminPLT,EmaxPLT,EavgPLT, *title2,yunit2,ML,MU,nseg,ymin2,ymax2,TinTC,first2,redraw2, *hydplt,DistT)
IF (pltdata2.EQ. 'd2') CALL mdlplt2(D2,DminPLT,DmaxPLT,DavgPLT, *title2,yunit2,ML,MU,nseg,ymin2,ymax2,TinTC,first2,redraw2, *hydplt,DistT)
IF (pltdata2.NE. 'no') CALL PLOT(-1.0,-0.8,-3)
CALL pltclock(hydplt,IterN,iTMAX,TinTC,newclock)
CALL PTime(TinTC,hydplt)
keyval=O
kpress=ISKEY()
1100 CONTINUE
C 27=ESC 113=q 81=Q, 112=p 80=P, 82=r 114=R, 83=s 115=S, 111=o 79=O
IF (kpress) keyval=IXKEY()
IF (keyval.EQ.27 .OR. keyval.EQ.81 .OR. keyval.EQ.113) *
cancel=.TRUE.
IF (cancel) GOTO 1999
IF (keyval.EQ.80 .OR. keyval.EQ.112) GOTO 1100
IF (keyval.EQ.82 .OR. keyval.EQ.114) GOTO 1200
IF (keyval.EQ.83 .OR. keyval.EQ.115) THEN
CLOSE(5)
CLOSE(6)
CLOSE(7)
CLOSE(8)
CLOSE(9)
CLOSE(10)
CLOSE(11)
CLOSE(12)
CLOSE(13)
CLOSE(14)
CALL PLOT(0.0,0.0,-999)
GOTO 1001
END IF
IF (keyval.EQ.79 .OR. keyval.EQ.111) THEN
CALL PLOT(0.0,0.0,-999)
ipltnum=1
CALL AskPLTH(ipltnum,pltdatal,title1,yunit1,ymin1,ymax1)
redrawl=.TRUE.
CALL AskPLTH(ipltnum,pltdatal,title2,yunit2,ymin2,ymax2)
redraw2=.TRUE.
newclock=.TRUE.
CALL PLOT(0.0,0.0,-999)
CALL NEWPEN(11)
CALL GTEXT(29,0,'(P)ause (R)esume re(S)tart (O)ther-plots
*(Y)scale-change (Q)uit-or-ESC')
END IF
IF (keyval.EQ.89 .OR. keyval.EQ.121) THEN
IF (pltdatal.NE. 'mp' .AND. pltdatal.NE.'no') THEN
CALL SETATTR(LBLUCHR+BRITE)
CALL LOCATE(5,15)
CALL PRINTS('_________________________________________
CALL LOCATE(6,15)
CALL PRINTS('│
CALL LOCATE(7,15)
CALL PRINTS('│
CALL LOCATE(8,15)
CALL PRINTS('│
CALL LOCATE(9,15)
CALL PRINTS('│
CALL SETATTR(YELLOCHR+BRITE)
CALL LOCATE(6,18)
CALL PRINTS('press ESC for no change or ANY OTHER KEY')
CALL LOCATE(7,18)
CALL PRINTS('to proceed')
Kvall=IXKEY()
IF (Kvall.NE.27) THEN
CALL SETATTR(LBLUCHR+BRITE)
CALL LOCATE(6,15)
CALL PRINTS('│
CALL LOCATE(7,15)
CALL PRINTS('│
CALL LOCATE(8,15)
CALL PRINTS('│
CALL SETATTR(YELLOCHR+BRITE)
CALL LOCATE(6,18)
CALL PRINTS('press ESC for no change or ANY OTHER KEY')
CALL SETATTR(YELLOCHR+BRITE)
CALL LOCATE(6,18)
CALL PRINTS(': type 2 values separated by comma, and ENTER')
CALL SETATTR(YELLOCHR+BRITE)
CALL LOCATE(6,18)
CALL PRINTS('Type Y-min & Y-max for PLOT 1: ')
CALL GETPOS(iRL,iCL)
CALL LOCATE(iRL,iCL+1)
READ(*,*) yminl,ymax1
END IF
END IF
IF (pltdatal.NE. 'mp' .AND. pltdatal.NE.'no') THEN
CALL SETATTR(LBLUCHR+BRITE)
CALL LOCATE(19,15)
CALL PRINTS('_________________________________________
CALL LOCATE(20,15)
CALL PRINTS('│
CALL LOCATE(21,15)
CALL PRINTS('│
CALL LOCATE(22,15)
CALL PRINTS('│
CALL LOCATE(23,15)
CALL PRINTS('│
CALL SETATTR(YELLOCHR+BRITE)
CALL LOCATE(20,18)
CALL PRINTS('press ESC for no change or ANY OTHER KEY')
CALL LOCATE(21,18)
CALL PRINTS('to proceed')

A6-9
Kval2 = IXKEY()
IF (Kval2.NE.27) THEN
   CALL SETATTR(LBLUCHR+BRITE)
   CALL LOCATE(20,15)
   CALL PRINTS(' | ')
   CALL LOCATE(21,15)
   CALL PRINTS(' | ')
   CALL LOCATE(22,15)
   CALL PRINTS(' | ')
   CALL SETATTR(WHITECHR+BRIGHT)
   CALL LOCATE(22,16)
   CALL PRINTS(' | ')
   CALL LOCATE(21,15)
   CALL PRINTS(' | ')
   CALL LOCATE(20,15)
   CALL PRINTS(' | ')
   CALL SETATTR(YELLOCHR+BRITE)
   CALL LOCATE(20,18)
   CALL PRINTS('Type Y-min & Y-max for PLOT 2: ')
   CALL GETPOS(iRL,iCL)
   CALL LOCATE(iRL,iCL+1)
   READ(*,*) ymin2,ymax2
   newclock=.TRUE.
   redrawl=.TRUE.
   redraw2=.TRUE.
   firstl=.TRUE.
   first2=.TRUE.
   CALL PLOT(0.0,0.0,-999)
   CALL NEWPEN(11)
   CALL GTEXT(29,0,'(P)ause (R)esume re(S) tart (O)ther-plots
   *(Y)scale-change (Q)uit-or-ESC')
END IF
END IF
newclock=.TRUE.
redrawn=.TRUE.
redraw2=.TRUE.
first2=.TRUE.
CALL PLOT(0.0,0.0,-999)
CALL NEWPEN(11)
CALL GTEXT(29,0,'(P)ause (R)esume re(S) tart (O)ther-plots
   *(Y)scale-change (Q)uit-or-ESC')
END IF
C+++
1200 CONTINUE
IF (IterN.EQ.iTprn) THEN
   CALL Output(iTPsl)
   IncP = IncP + 1
   iTprn = NINT(TOUT(IncP)/DTT)
   iTprn = NINT(TOUT(IncP)-1.0)/DTT
END IF
C**********************************************************************
IF (iWQ.EQ.1) THEN
   IF (TinDay.GE.SPT.AND.TinDay.LE.EPT) THEN
      IF (MOD(IterN,iNTS).EQ.0)
         WRITE(9) XA,Vol2,U,E,HR,SAt,StVol2,QML2
   END IF
   END IF
C**********************************************************************
IterN = IterN + 1
TinTC = IterN * OTT
TinDay = TinTC * 0.5175
C**********************************************************************
C: Tday = time in day (bet/ 0 & 1)
C1 At the beginning of each day, if time-varying BC’s are used,
C read in the observed tidal data (ReadTD), and SPLDM, PSQ(i) & QML2.
C : Note Day=2.0 means that it is the very beginning of the second day.
C2 GetQLat calculates QLat.
C : QML = linear interpolation bet/ (time in Tday,Q) = (0,QML1) & (1,QML2).
C**********************************************************************
newTinTC = INT(TinTC)
IF (iTinTC.NE.newTinTC) THEN
   CALL OutPLT(TinTC,iPLT)
   iTinTC=newTinTC
END IF
Tday = Tday + DTD
IF (Tday .GE. 1.0) THEN
  Tday = Tday - 1.0
  Day = TinDay + 1.0
END IF
IF (iTide .EQ. 1) CALL ReadTD(Day)
IF (iSatDB .EQ. 1) THEN
  READ(S,'(14X,F8.1)') SFLDM
  WRITE(6,804)' Maximum salinity at DB at the ', Day,
  ' th days = ', SFLDM
END IF
IF (iPSQ .EQ. 1) THEN
  DO 50 m=1,NS2
    READ(13,'(9X,I5,F10.4)') i, PSQ(i)
    WRITE(6,'(I5,2X,F10.4)') i, ' : ', PSQ(i)
  CONTINUE
END IF
IF (iUatUB .EQ. 1) THEN
  QML = QML1 + (QML2 - QML1)/FDTL * Tday
  ELSE
    QML = QML2
END IF
CALL GetQLat(QML,iUBC)
END IF
*
C2  IF (iTide .NE. 1) THEN
    Y2(MU) = HTide(TinDay,Ampl,Phase)
  ELSE
    CALL OTide(Y2(MU),rNTSiH)
  END IF
CALL GetYQ(Beta,AlpC,BetaC,ABG,rk)
END IF
C2  IF (iSat.EQ.1 .OR. iWQ.EQ.1) CALL CalcE(IterN,NTS2,TinTC)
IF (iSat.EQ.1) THEN
  CALL HDnBdry(MST,SFLDM,DS,NCOUNT)
  CALL CalcS(SatUB)
  IF (NS2Sal .NE. 0) THEN
    DO 100 i=ML,MU
      S2(i) = SIC(i)
      StS(i) = SIC(i)
  100 CONTINUE
  END IF
END IF
END IF
END IF
C2  IF (iSat.EQ.1 .OR. iWQ.EQ.1) CALL CalcE(IterN,NTS2,TinTC)
IF (iSat.EQ.1) THEN
  CALL HDnBdry(MST,SFLDM,DS,NCOUNT)
  CALL CalcS(SatUB)
  IF (NS2Sal .NE. 0) THEN
    IF (IterN .EQ. iTSIC) THEN
      DO 100 i=ML,MU
        S2(i) = SIC(i)
        StS(i) = SIC(i)
    100 CONTINUE
    END IF
  END IF
END IF
END IF
A6-l l
IF (iDye.EQ.1 .OR. iDye.EQ.2) THEN
    IF (IterN.GT.iTDIC) THEN
        CALL CalcD(DatUB,MST,DFLDM,DD,NDC)
        IF (iDye.EQ.2) THEN
            DO 300 i=ML,MUS1
                D2(i) = D2(i) + DIC(i) / (Vol2(i) * (1.0+rk*S2(i)))
                IF (StSAM(i).NE.0.0) StD(i) = StD(i) + DIC(i) /
                    (StVol2(i) * (1.0+rk*StS(i)))
            CONTINUE
        END IF
    END IF
    IF (IterN.EQ.iTDIC) THEN
        DO 200 i=ML,MUS1
            D2(i) = DIC(i) / (Vol2(i) * (LO + rk*S2(i)))
            IF (StSAM(i).NE.0.0) StD(i) = DIC(i) / (StVol2(i) *
                (1.0 + rk*StS(i)))
        CONTINUE
    END IF
    DO 70 i=ML,MU
        U(i) = Q2(i) / XA(i)
    CONTINUE
C+++s
C+++e
CALL AvgPLT
IF (iTPs1 .GE. 0 .AND. IterN.GT.iTPs1) CALL Average(TinTC)
C5
    CALL ResetV
END DO
9001 FORMAT(1F8.3)
9004 FORMAT(2F10.0, I10)
801 FORMAT(A50)
802 FORMAT(/, (A46, F15.7))
803 FORMAT(/, A44, F15.7)
804 FORMAT(/, A34, F8.3, A11, F15.5)
1999 CONTINUE
    CALL PLOT(0.0,0.0,999)
C+++s
    IF (keyval.EQ.27 .OR. keyval.EQ.81 .OR. keyval.EQ.113) THEN
        CLOSE(5,STATUS='KEEP')
        CLOSE(6,STATUS='DELETE')
        CLOSE(7,STATUS='DELETE')
        CLOSE(8,STATUS='KEEP')
        CLOSE(9,STATUS='DELETE')
        CLOSE(10,STATUS='DELETE')
        CLOSE(11,STATUS='KEEP')
        CLOSE(12,STATUS='KEEP')
        CLOSE(13,STATUS='KEEP')
        CLOSE(14,STATUS='DELETE')
        STOP '***Aborted. WQ.HYD file not complete for WQ.EXE !**'
    ELSE
        CLOSE(5)
        CLOSE(6)
        CLOSE(7)
        CLOSE(8)
        CLOSE(9)
        CLOSE(10)
        CLOSE(11)
        CLOSE(12)
        CLOSE(13)
        CLOSE(14)
        STOP '*** Successful Run !!!!! **'
    ENDIF
SUBROUTINE ReadGH(iUBC)
C**********************************************************************
INCLUDE 'COM-HYO.INC'
READ(8,'(2I5)') ML,MU
WRITE(6,801)'* Upstream boundary transect number = ', ML,
  ' Downstream boundary transect number = ', MU
MLl = ML + 1
MLs1 = ML - 1
MUsl = MU - 1
READ(8,9001) Darea
WRITE(6,803) 'Reach DIST BCM XAM SAM StSAM VOLM ARD SS SIDES DCM StH', /
  '(km) (m) (10**3 (km**2) (km**2) (10**6) (km**2) m**2) m**3')
READ(8,9001) (DistT(i), i=ML,MU)
READ(8,9001) (BCM(i), i=ML,MU)
READ(8,9001) (XAM(i), i=ML,MU)
READ(8,9001) (SAM(i), i=ML,MU)
READ(8,9001) (StSAM(i), i=ML,MU)
READ(8,9001) (VolM(i), i=ML,MU)
READ(8,9001) (ARD(i), i=ML,MU)
READ(8,9001) (SS(i), i=ML,MU)
READ(8,9001) (SIDES(i), i=ML,MU)
READ(8,9001) (DCM(i), i=ML,MU)
READ(8,9001) (StH(i), i=ML,MU)
WRITE(6,804) (i, DistT(i),BCM(i),XAM(i),SAM(i),StSAM(i),VolM(i),
  ARD(i),SS(i),SIDES(i),DCM(i),StH(i), i=ML,MU)
804 FORMAT(I2,2F9.3,3F7.3,F8.3,F7.2,4F6.2)
803 FORMAT(//, 'No. (km) (m) (10**3 (km**2) (km**2) (10**6) (km**2) m**2) m**3')
C ARD'll be used in km**2 & all the others are changed to m equivalent.
DO 200 i=ML,MU
  XAM(i) = XAM(i) * 1.0E3
  SAM(i) = SAM(i) * 1.0E6
  StSAM(i) = StSAM(i) * 1.0E6
  VolM(i) = VolM(i) * 1.0E6
200 CONTINUE
C DX(i) = distance (m) bet/ the center of segment i-1 and i.
C : To get DX(ML), assumed that DistS(MLs1)-DistT(ML) = DistT(ML)-DistS(ML)
C DistS(i) = distance (km) from the mouth to the center of segment i.
C : Note that the mouth is the center of the segment MU. So, DistS(MU)=0.
DO 210 i=ML,MU
  DX(i) = (DistT(i-1) - DistT(i+1))/2.0 * 1.0E3
210 CONTINUE
C A6-13
distS(i) = (distT(i) + distT(i+1)) / 2.0

continue

distS(MU) = 0.0

read(8,9001) (Q2(i), i=ML,MU)
read(8,9001) (Y2(i), i=ML,MU)
read(8,9001) (S2(i), i=ML,MU)
read(8,9001) (rMan(i), i=ML,MU)
read(8,9001) (ALPHA(i), i=ML,MU)
write(6,'(/, A63, /, A63, /)')
* reach Initial Initial Initial Manning Weighting
* No. Y1 (m) Q1 (m**3/s) S (ppt) Coefficient Factor
write(6,802) (i, Y2(i), Q2(i), S2(i), rMan(i), ALPHA(i), i=ML,MU)
if (iUBC .NE. 1 .AND. ALPHA(ML) .NE. 1.0)
   * stop ** ALPHA(ML) should be 1 if momentum flux from f.w.*

DO 230 i=ML,MU
   ! 230 continue
sts(i) = s2(i)

230 CONTINUE

S2(MLS1) = S2(ML)
if (iUBC .EQ. 1) Q2(ML) = 0.0

CALL SetGeo
CALL ResetV

DO 240 i=ML,MU
   ! 240 continue
   u(i) = Q1(i) / xa(i)

240 CONTINUE

9001 format(10F8.0)
801 format(/, (A40, IS))
802 format(I4, SF11.3)
return

end

C***************
SUBROUTINE SetGeo
C**********************************************************************
C Update the geometry w/t the fluctuation of sfc elevation.
C: Note that cross-section is assumed to be trapezoidal.
C: YatT = time-varying Y at the transect i.
C: BCT(i) & XA(i) = time-varying width & x-sectional area at the transect i.
C: HR(i) = hydraulic radius = assumed to be equal to depth since BC >> depth.
C: SAT(i) = time-varying surface area of conveyance channel.
C: Vol2(i) = time-varying volume of conveyance channel at the segment i.
C: StVol2(i) = time-varying volume of storage area at the segment i.
C**********************************************************************

include 'COM-HYO.INC'

Y2(MLS1) = Y2(ML)

DO 300 i=ML,MU
   ! 300 continue
   yatT = (Y2(i-1) + Y2(i)) * 0.5
   bct(i) = BCM(i) + YatT*SS(i)
   xa(i) = XAM(i) + 0.5*(BCM(i) + BCT(i))*YatT
   hr(i) = xa(i) / bct(i)
   if (hr(i) .LT. 0.01) hr(i) = 0.01
   sat(i) = sam(i) + SIDES(i)*Y2(i)
   if (i .NE. MU) then
      vol2(i) = volM(i) + sat(i)*Y2(i)
      if (StSAM(i) .NE. 0.0) StVol2(i) = StSAM(i) * (stH(i)+Y2(i))
   end if
300 CONTINUE

return

end

C*************
FUNCTION Htide(TIME,Ampl,Phase)
C****************************************************************************
C Calculate sfc elevation (m) at the downstream bdry.
C: Sigma speed in radians/day for each of M2,S2,K1,M4,O1,MM,SSA,SA.
C***************************************************************************
Dimension Ampl(9),Phase(9),Sigma(9)
Data Sigma/12.1408,12.56637,11.913,6.3,24.282,5.84,0.228,0.034,
* 0.017/
SUM = 0.0
DO 400 k=1,9
SUM = SUM + Ampl(k)*COS( Phase(k) + TIME*Sigma(k) )
400 CONTINUE
HTide = SUM / 100.0
RETURN
END
C**************
SUBROUTINE OTide(Y,rNTSiH)
C***************************************************************************
C Do linear interpolation of sfc elevation every time step using hourly data.
C***************************************************************************
Common/ObsTd/Tdata(0:25),rNTC
rNTC = rNTC + 1.0
DT = MOD(rNTC,rNTSiH)
IF (DT .LE. 0.01) THEN
n = NINT(rNTC/rNTSiH)
Y = Tdata(n)
ELSE
n = rNTC/rNTSiH + 1.0
Y = Tdata(n-1) + DT * (Tdata(n)-Tdata(n-1)) / rNTSiH
END IF
Y = Y / 100.0
RETURN
END
C**************
SUBROUTINE GetYQ(Beta,AlpC,BetaC,ABG,rk)
C***************************************************************************
C1 Calculate Q(i) from i=MLl to MU.
C: XA*Dc = XAM*(DCM+YatT) {think of moment in rotating arm}
C + (BCM+BCt)/2.0*YatT * YatT/2.
C2 Calculate recursion coefficients from i=ML to MUsl.
C3 Calculate Y2(i) from i=MUsl to ML.
C4 Update the geometry and Calculate Q2(i) from i=MLl to MU, using CONT Eqn.
C: If using MOMENTUM Eqn, Q2(i)=Alp*g*XA(i)*DTX(i)*(Y2(i-l)-Y2(i))+CQ(i).
C***************************************************************************
INCLUDE 'CQ-HYD.INC'
Parameter (g=9.8)
Dimension P(iX),O(iX),CQ(iX)
QU1 = (Ql(ML) + Ql(MLl)) * (U(ML) + U(MLl))
DO 500 i=MLl,MU
YatT = 0.5 * (Yl(i-1) + Yl(i))
DC = XAM(i)*(DCM(i)+YatT) + 0.25*(BCM(i)+BCt(i))*YatT*ABS(YatT)
GRAD=DTX(i)*DC*g*rk*(Sl(i)-Sl(i-1))/(1.0+0.5*rk*(Sl(i-1)+Sl(i)))
QU2 = (Ql(i) + Ql(i+1)) * (U(i) + U(i+1))
IF (i .LT. MU) THEN
ADV = DTX(i) * (QU1 - QU2) * 0.25
ELSE
ADV = DTX(i) * (3.0*Ql(i)-Ql(i-1))*(3.0*U(i)-U(i-1)) ) * 0.25
END IF
QU1 = QU2
FRC = DT*g*rMan(i)*rMan(i) / HR(i)**1.333 * ABS(U(i))**Ql(i)
CQ(i) = Ql(i) + ADV + DT*Wind*BCt(i) - FRC - GRAD

A6-15
* + AlpC*g*DTX(i)*XA(i)*(Yl(i-1)-Yl(i))

500 CONTINUE

C2

DTXgA1 = DTX(MLl) * ABG * XA(MLl)
Surf = (Sat(ML) + StSAM(ML)) / DT
DIV = Surf + DTXgA1
P(ML) = DTXgA1 / DIV
O(ML) = ( Beta*(Q2(ML)-CQ(MLl)) + BetaC*(Q1(ML)-Q1(MLl))
* + Surf*Yl(ML) + QLat(ML) ) / DIV
DO 510 i=MLl,MUsl
  DTXgA2 = DTX(i+1) * ABG * XA(i+1)
  Surf = (Sat(i) + StSAM(i)) / DT
  DIV = Surf + DTXgA1 + DTXgA2
  AA = DTXgA2 / DIV
  BB = DTXgA1 / DIV
  CC = ( Surf*Yl(i) + Beta*(CQ(i)-CQ(i+l))
    + BetaC*(Ql(i)-Ql(i+l)) + QLat(i) ) / DIV
  PODIV = 1.0 - BB*P(i-1)
  P(i) = AA / PODIV
  O(i) = (CC + BB*O(i-1)) / PODIV
  DTXgA1 = DTXgA2
510 CONTINUE

C3

DO 520 i=MUsl,ML,-1
  Y2(i) = P(i)*Y2(i+l) + O(i)
520 CONTINUE

C4

CALL SetGeo
DO 530 i=MLl,MU
  Q2(i) = Q2(i-1) + ( QLat(i-1) + BetaC*(Ql(i-1)-Ql(i))
    - (Sat(i-1)+StSAM(i-1))*(Y2(i-1)-Yl(i-1))/DT ) / Beta
530 CONTINUE
RETURN
END

C***************
SUBROUTINE CalcE(IterN,NTS2,TinTC)
C**********************************************************************
C unchanged from previous time step is used to ensure stability.
C**********************************************************************
INCLUDE 'COM-HYO.INC'
Common/Ecal/UA(iX,220),TavgU(220),UT(iX),UTrms(iX),Ebase,VS,TS,
  FEXP,CRi,FET,GRVCR

C UT(i) = UT(i) * 44712
C and now UT(i)/b (actually UT(i)*T/b) = tidal excursion to width ratio.

DO 60 i=ML,MU
  Lateral = TS * (UT(i)/BCT(i)) * (UT(i)/BCT(i))
  Eshear = VS*rMan(i)*ABS(U(i))*HR(i)**0.833 * (1.0 + Lateral)
C For the fresh part of the river, no dispersion due to the gravitational
C circulation. So, set Egrav=0.
C For the first 4 tidal cycles, UFT can be very large, so set Egrav=0.
IF (IterN .LE. NTS2) THEN
  UA(i,IterN) = U(i)
  TavgU(i) = (TavgU(i)*(IterN-1) + UA(i,IterN)) / IterN
  UFT = 0.0
ELSE
  UA(i,NTS2+1) = U(i)
  TavgU(i) = (TavgU(i)*NTS2 + UA(i,NTS2+1) - UA(i,1)) / NTS2
  UFT = ABS(TavgU(i))*XA(i) / (UTrms(MU)*XA(MU))
DO 61 m=2,NTS2+1
  UA(i,m-1) = UA(i,m)
60 CONTINUE

A6-16
**CONTINUE**

**C 1000 because DX here should be in km**

IF (TinTC.GT.4.0) THEN
  Sgrad = ABS(Sl(i) - Sl(i-1))*1000.0 / DX(i)
  Ri = CRi * (Sl(i-1) + Sl(i))/2.0 * UFT**FEXP
  Egrav = GRVCR * (1.0 + Ri)**4 * Sgrad*Sgrad
ELSE
  Egrav = 0.0
END IF
E(i) = Ebase + Eshear + Egrav

**CONTINUE**

**RETURN**

**END**

**C*****************

**SUBROUTINE HDbdry(MST,SFLDM,DS,NCOUNT)**

**C**********************************************************************C**

**SUBROUTINE CalcS(SatUB)**

**C**********************************************************************C**

**C Ebb**

**C Flood**

**C*****************

**SUBROUTINE Calc2(SatUB)**

**C*****************
Delta2 = 1.0 - Gamma2
Dif(i+1) = E(i+1) * XA(i+1) / DX(i+1)
  Tmp = DT / Vol2(i)
DIVS(i) = 1.0 + Tmp * (Gamma2*Q2(i+1) - Delta1*Q2(i))
AAS = - Tmp * Delta2*Q2(i+1) / DIVS(i)
BBS(i) = Tmp * Gamma1*Q2(i) / DIVS(i)
CCS = ( Vol1(i)*S1(i)/Vol2(i) + Tmp*( Dif(i+1)*(S1(i+1)-S1(i))
  - Dif(i)*(S1(i)-S1(i-1)) ) - Sink ) / DIVS(i)
PODIVS(i) = 1.0 - BBS(i)*PS(i-1)
PS(i) = AAS / PODIVS(i)
OS(i) = (CCS + BBS(i)*OS(i-1)) / PODIVS(i)
Gamma1 = Gamma2
Delta1 = Delta2

600 CONTINUE
DO 610 i=MUsl,ML,-1
  S2(i) = PS(i)*S2(i+l) + OS(i)
610 CONTINUE
C need S2(MLs1) for CalcE
S2(MLs1) = S2(ML)
RETURN
END

C***************
SUBROUTINE CalcD(DatUB,MST,DFLDM,DD,NDC)
C**********************************************************************C
INCLUDE 'COM-HYO.INC'
Dimension OD(iX)
IF (Q1(MU) .GE. 0.0) THEN
  NDC = 0
  Change = DTX(MU) * U(MU)
  D2(MU) = D1(MU) - (D1(MU) - D1(MUsl))*Change
ELSE
  IF (NDC .GE. MST) THEN
    D2(MU) = DFLDM
  ELSE
    IF (NOC .EQ. 0) DD = (DFLDM - D1(MU)) / MST
    NDC = NDC + 1
    D2(MU) = D1(MU) + DD
  END IF
END IF
OD(MLs1) = DatUB
DO 600 i=ML,MUsl
  IF (StSAM(i) .NE. 0.0) THEN
    DelStVol = StVol2(i) - StVoll(i)
    IF (Y2(i) .GT. Y1(i)) THEN
      SinkD = D1(i) * DelStVol / Vol2(i)
      StD(i) = (StD(i)*StVoll(i) + D1(i)*DelStVol) / StVol2(i)
    ELSE
      SinkD = 0.0
    END IF
  ELSE
    SinkD = 0.0
  END IF
  CCD = ( Vol1(i)*D1(i)/Vo12(i) + DT/Vol2(i)*( Dif(i+1)*
    * (D1(i+1)-D1(i)) - Dif(i)*(D1(i)-D1(i-1)) - Dcay*
    * Vol1(i)*D1(i) ) - SinkD ) / DIVS(i)
  OD(i) = (CCD + BBS(i)*OD(i-1)) / PODIVS(i)
600 CONTINUE
DO 610 i=MUsl,ML,-1
  D2(i) = PS(i)*D2(i+l) + OD(i)
610 CONTINUE
RETURN
C***************
SUBROUTINE ResetV
C**********************************************************************
INCLUDE 'COM-HYO.INC'
Yl(MLsl) = Y2(MLsl)
Sl(MLsl) = S2(MLsl)
DO 90 i = ML,MU
   Yl(i) = Y2(i)
   Ql(i) = Q2(i)
   Vol1(i) = Vol2(i)
   Sl(i) = S2(i)
   Dl(i) = D2(i)
   StVol1(i) = StVol2(i)
90 CONTINUE
RETURN
END
C***************
SUBROUTINE ReadTD(Day)
C**********************************************************************
C Read in observed hourly tidal heights in ft from unit #12 and convert to cm.
C**********************************************************************
Common/ObsTd/Tdata(0:25),rNTC
rNTC = 0.0
Tdata(0) = Tdata(24)
READ(l2, '(7X,12F6.2) ') (Tdata(n), n=1,24)
DO 30 n=1,24
   Tdata(n) = Tdata(n) * 30.48
30 CONTINUE
WRITE(6,'(/, A9,F8.3,A33, /, (8F8.2))')'* At the ', Day,* 'th days, tidal heights (cm) are;', (Tdata(n), n=1,24)
RETURN
END
C***************
SUBROUTINE GetQLat(QatUB,iUBC)
C**********************************************************************
C: If iUBC=1, only mass (no momentum) input from QatUB (freshwater discharge
C at UB). This is so, when the fall line is well developed to create
C subcritical flow at UB. In this case, QatUB is included in lateral inflow,
C QLat(ML) and Q2(ML)=0 (i.e., no momentum input).
C Otherwise, use QatUB as BC, i.e., Q2(ML), and QLat(ML) only include the
C lateral inflow.
C: Compute QLat(i), for i=ML1-MUsl, from the linear interpolation.
C: QLaatUB = fw discharge per unit area of drainage area upriver of UB.
C**********************************************************************
INCLUDE 'COM-HYD.INC'
QLaatUB = QatUB / Darea
IF (iUBC .EQ. 1) THEN
   Q2(ML) = 0.0
   QLat(ML) = QatUB + QLaatUB*ARD(ML) + PSQ(ML)
ELSE
   Q2(ML) = QatUB
   QLat(ML) = QLaatUB*ARD(ML) + PSQ(ML)
END IF
DO 20 i=ML1,MUsl
   QLat(i) = QLaatUB*ARD(i) + PSQ(i)
20 CONTINUE
RETURN
END
C***************
SUBROUTINE Average(TinTC)
INCLUDE 'COM-HYO.INC'
Common/Mean/Ymax(iX),Umax(iX),Ymin(iX),Umin(iX),
* TLO(iX),THI(iX),TFL(iX),TEB(iX),TSF(iX),TSE(iX),SSF(iX),SSE(iX)

TPP = (TinTC - (TOUT(IncP)-1.0)) * 12.42
DO 80 i=ML,MU
  IF (Y2(i) .LT. Ymin(i)) THEN
    Ymin(i) = Y2(i)
    TLO(i) = TPP
  END IF
  IF (Y2(i) .GT. Ymax(i)) THEN
    Ymax(i) = Y2(i)
    THI(i) = TPP
  END IF
  IF (U(i) .LT. Umin(i)) THEN
    Umin(i) = U(i)
    TFL(i) = TPP
  END IF
  IF (U(i) .GT. Umax(i)) THEN
    Umax(i) = U(i)
    TEB(i) = TPP
  END IF
  IF (Ql(i) .GT. 0.0 .AND. Q2(i) .LE. 0.0) THEN
    TSF(i) = TPP
    SSF(i) = S2(i)
  END IF
  IF (Ql(i) .LT. 0.0 .AND. Q2(i) .GE. 0.0) THEN
    TSE(i) = TPP
    SSE(i) = S2(i)
  END IF
80 CONTINUE
RETURN
END

C***************
SUBROUTINE Output(iTPsl)
C******************
INCLUDE 'COM-HYO.INC'
Common/Mean/Ymax(iX),Umax(iX),Ymin(iX),Umin(iX),
* TLO(iX),THI(iX),TFL(iX),TEB(iX),TSF(iX),TSE(iX),SSF(iX),SSE(iX)

WRITE(6,'(//,A9,F13.8,A44)')'***** At ', TOUT(IncP),* ' tidal cycles after computation begins *****'
WRITE(6,802)
WRITE(6,803) (i, DistT(i),Y2(i),Q2(i),U(i),S2(i),E(i), i=ML,MU)
802 FORMAT(/,'No. km from Sfc elev. Discharge Tidal vel. ' * 'Salinity Disp. coeff.',/,* mouth (m**3/s) (m/s) * ' (ppt) (m**2/s)',/)
803 FORMAT('No. km from Sfc elev. Discharge Tidal vel. ',* 'No. km from Sfc elev. Discharge Tidal vel. ',* 'No. km from Sfc elev. Discharge Tidal vel. ',/)
WRITE(7,804) '** Tidal range & time of HW/LW at ', TOUT(IncP),
* 'TCs after model starts ' WRITE(7,7801)'No., Dist(km), Tidal range(m), Time(h) of HW & LW'
WRITE(7,7,8) ('I6,4F15.4)') (i, DistS(i),Ymax(i)-Ymin(i),THI(i),
* 'mouth ' TLO(i), i=ML,MU)
WRITE(10,804) '** Time & Sal at slackwater ', TOUT(IncP),
* 'TCs after model starts'
WRITE(10,801) 'No., Distance(km), TSF, SSF, TSE, SSE

A6-20
WRITE(10,('(I3,5F10.4)')) (i, DistT(i), TSF(i), SSF(i), TSE(i),
SSF(i), i=ML,MU)

* DO 120 i=ML,MU
  Ymax(i) = -1.0E4
  Umax(i) = -1.0E4
  Ymin(i) = 1.0E4
  Umin(i) = 1.0E4
120 CONTINUE
END IF

**FORMAT(A49)
**FORMAT(I3, F10.2, F10.5, F10.2, F10.5, F10.2, F15.3)
**FORMAT(/, A34, F14.7, A23, /)
RETURN
END

C***************
BLOCK DATA HFirst
C************************************************************************
INCLUDER'BLKD-HYD.INC'
END
A6-2. HYDPLT.FOR

C***********************************************************
SUBROUTINE AvgPLT
C***********************************************************
INCLUDE 'COM-HYO.INC'
Common/tPLT/tY
DO 80 i=ML,MU
   tAvgN = tAvgN + 1.0
   tYavg(i) = tYavg(i) + Y2(i)
   tQavg(i) = tQavg(i) + Q2(i)
   tSavg(i) = tSavg(i) + S2(i)
   tUavg(i) = tUavg(i) + U(i)
   tEavg(i) = tEavg(i) + E(i)
   tDavg(i) = tDavg(i) + D2(i)
   IF (Q2(i) .LT. tQmin(i)) tQmin(i) = Q2(i)
   IF (Q2(i) .GT. tQmax(i)) tQmax(i) = Q2(i)
   IF (S2(i) .LT. tSmin(i)) tSmin(i) = S2(i)
   IF (S2(i) .GT. tSmax(i)) tSmax(i) = S2(i)
   IF (E(i) .LT. tEmin(i)) tEmin(i) = E(i)
   IF (E(i) .GT. tEmax(i)) tEmax(i) = E(i)
   IF (Y2(i) .LT. tYmin(i)) tYmin(i) = Y2(i)
   IF (Y2(i) .GT. tYmax(i)) tYmax(i) = Y2(i)
   IF (U(i) .LT. tUmin(i)) tUmin(i) = U(i)
   IF (U(i) .GT. tUmax(i)) tUmax(i) = U(i)
   IF (D2(i) .LT. tDmin(i)) tDmin(i) = D2(i)
   IF (D2(i) .GT. tDmax(i)) tDmax(i) = D2(i)
80 CONTINUE
RETURN
END

C***********************************************************
SUBROUTINE OutPLT(TinTC,iPLT)
C***********************************************************
INCLUDE 'COM-HYO.INC'
Common/tPLT/tY
DO 100 i=ML,MU
   YavgPLT(i) = tYavg(i) / tAvgN
   QavgPLT(i) = tQavg(i) / tAvgN
   SavgPLT(i) = tSavg(i) / tAvgN
   UavgPLT(i) = tUavg(i) / tAvgN
   EavgPLT(i) = tEavg(i) / tAvgN
   DavgPLT(i) = tDavg(i) / tAvgN
   YmaxPLT(i) = tYmax(i)
   QmaxPLT(i) = tQmax(i)
   SmaxPLT(i) = tSmax(i)
   UmaxPLT(i) = tUmax(i)
   EmaxPLT(i) = tEmax(i)
   DmaxPLT(i) = tDmax(i)
   YminPLT(i) = tYmin(i)
   QminPLT(i) = tQmin(i)
   SminPLT(i) = tSmin(i)
100 CONTINUE
UminPLT(i)  tUmin(i)
EminPLT(i)  tEmin(i)
DminPLT(i)  tDmin(i)

100 CONTINUE

IF (iPLT.EQ.1 .AND. TinTC.GT.2.5) THEN
  TS = TinTC - 1.0
  WRITE(14,801)'** Cycle Average between ', TS, ' to ', TinTC
  WRITE(14,802) (*, Dist(i), YavgPLT(i), QavgPLT(i), UavgPLT(i),
  * SavgPLT(i), EavgPLT(i), DavgPLT(i), i=ML,MU)
  WRITE(14,801)'** Cycle Maximum between ', TS, ' to ', TinTC
  WRITE(14,802) (*, Dist(i), YmaxPLT(i), QmaxPLT(i), UmaxPLT(i),
  * SmaxPLT(i), EmaxPLT(i), DmaxPLT(i), i=ML,MU)
  WRITE(14,801)'** Cycle Minimum between ', TS, ' to ', TinTC
  WRITE(14,802) (*, Dist(i), YminPLT(i), QminPLT(i), UminPLT(i),
  * SminPLT(i), EminPLT(i), DminPLT(i), i=ML,MU)
END IF

801 FORMAT(/, A25, F7.2, A4, f7.2)
802 FORMAT(/, 'No. km from, Sfc elev, Discharge, Tidal vel, Salinity,
  * Disp coeff, Dye', '/',
  * (m**2/s) (ppb)', '/)

 tAvgN = 0.0
 DO 120 i=ML,MU
   tYmax(i) = -1.0E4
   tQmax(i) = -1.0E4
   tSmax(i) = -1.0E4
   tUmax(i) = -1.0E4
   tEmax(i) = -1.0E4
   tDmax(i) = -1.0E4
   tYmin(i) =  1.0E4
   tQmin(i) =  1.0E4
   tSmin(i) =  1.0E4
   tUmin(i) =  1.0E4
   tEmin(i) =  1.0E4
   tDmin(i) =  1.0E4
   tYavg(i) =  0.0
   tQavg(i) =  0.0
   tSavg(i) =  0.0
   tUavg(i) =  0.0
   tEavg(i) =  0.0
   tDavg(i) =  0.0
120 CONTINUE
RETURN
END
B6-3. COM-HYD.INC

Parameter (iX=70)
Common/HydV/Y1(iX), Y2(iX), Q1(iX), Q2(iX), S1(iX), S2(iX), rMan(iX),
* QLat(iX), PSQ(iX), ALPHA(iX), E(iX), U(iX), HR(iX), StS(iX),
* DistT(iX), DX(iX), StH(iX), BcT(iX), ARD(iX), DistS(iX), XA(iX),
* Vol1(iX), Vol2(iX), DTX(iX), BCM(iX), XAM(iX), SAM(iX), VolM(iX),
* SS(iX), SIDES(iX), DCM(iX), StSAM(iX), StH(iX), StVol1(iX),
* StVol2(iX), DIc(iX), DL(iX), D2(iX), StD(iX), PS(iX), BBS(iX),
* PODIVS(iX), DIVS(iX), Dif(iX), DareA,
* TOUT(30), ML, MU, ML1, MLs1, MUs1, DT, IncP, Wind, Dcay

B6-4. BLKD-HYD.INC

INCLUDE 'COM-HYD.INC'
Common/Ecal/UA(iX,220), TavgU(220), UT(iX), UTrms(iX), Ebase, VS, TS,
* FEXP, CRI, FET, GRVCR
Common/Mean/Ymax(iX), Umax(iX), Ymin(iX), Umin(iX),
* TLO(iX), THI(iX), TFL(iX), TEB(iX), TSF(iX), TSE(iX), SSF(iX), SSE(iX)

C+++
Common/tPLT/tYmax(iX), tQmax(iX), tSmax(iX), tUmax(iX), tEmax(iX),
* tDmax(iX), tYmin(iX), tQmin(iX), tSmin(iX), tUmin(iX), tEmin(iX),
* tDmin(iX), tYavg(iX), tQavg(iX), tSavg(iX), tUavg(iX), tEavg(iX),
* tAvg(iX), tAvgN

C+++
Data Voll, Vol2, SAM, StSAM, StVol1, StVol2/420*0.0/
Data Q2, QLat, PSQ/210*0.0./, E/iX*1.0./, U/iX*0.0./, IncP/1/
Data UA, TavgU/15620*0.0/
Data Ymax, Umax/140*-1.0E4/, Ymin, Umin/140*1.0E4/
Data TSF, TSE, SSF, SSE/280*0.0/
Data tYmax, tQmax, tSmax, tUmax, tEmax, tDmax/420*-1.0E4/
Data tYmin, tQmin, tSmin, tUmin, tEmin, tDmin/420*1.0E4/
Data tYavg, tQavg, tSavg, tUavg, tEavg, tAvg, tAvgN/421*0.0/

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**B6-5. HEM-WQ.FOR**

```fortran
PROGRAM HEM_WQ
C: This program solves 1-D Mass Balance Eqsns for Organic Nitrogen (N1),
C Ammonia N (N2), Nitrite-Nitrate N (N3), Organic Phosphorus (P1), Inorganic
C P (P2), Chlorophyll 'a' (Chl), Carbonaceous Biochemical Oxygen Demand
C (CBOD) and Dissolved Oxygen (DOC).
C: Written in FORTRAN 77 (ANSI x3.9-1978) except DO WHILE & END DO.
INCLUDE 'COM-WQ.INC'
INCLUDE 'SPINATTR.HDR'

Common/PtMeanWQ/PtN1Min(iX),PtN2Min(iX),PtN3Min(iX),PtP1Min(iX),
* PtP2Min(iX),PtChlMin(iX),PtBODMin(iX),PtDOMin(iX),PtN1Max(iX),
* PtN2Max(iX),PtN3Max(iX),PtP1Max(iX),PtP2Max(iX),PtChlMax(iX),
* PtBODMax(iX),PtDOMax(iX),PtAvgN1(iX),PtAvgN2(iX),PtAvgN3(iX),
* PtAvgP1(iX),PtAvgP2(iX),PtAvgChl(iX),PtAvgBOD(iX),PtAvgDO(iX),
* PtTNMin(iX),PtTPMin(iX),PtTNMax(iX),PtTPMax(iX),PtAvgTN(iX),
* PtAvgTP(iX)
Character titlel*20,title2*20, yunit1*14,yunit2*14
Character*2 pltdata1,pltdata2, VK*l
Logical hydplt,firstl,first2,newclock,kpress,ISKEY,cancel,redrawl,
* redraw2, LFile,FEXIST
Integer*2 iCL,iRL
Data keyval/1/
Character*30 Win

CALL Wheading

5111 CONTINUE
CALL SETATTR(BLKBKG+LBLUCHR+BRITE)
CALL LOCATE(3,10)
CALL PRINTS('* General water quality input data file = *)
CALL CURON
CALL GETPOS(iRL,iCL)
CALL SETATTR(WHITECHR)
CALL LOCATE(iRL,iCL+1)
CALL PRINTS('wq-def.in')
CALL LOCATE(S,7)
CALL PRINTS(': press ENTER to use the default file (wq-def.in) ')
CALL LOCATE(iRL,iCL+2)
READ ( *, ' (a) ' ) Win
Win = VK // Win
END IF
LFile = FEXIST(Win)
IF (.NOT.LFile) THEN
    CALL CUROFF
    CALL SETATTR(BLKBKG+REDCHR+BRITE)
    CALL LOCATE(9,5)
    CALL PRI::TS('WARNING !!!')

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```
CALL LOCATE(11,2)
CALL PRINTS(  
"Specified file does not exist in the current directory")
CALL LOCATE(12,2)
CALL PRINTS("Press (Y)es to try again or ANY OTHER KEY to exit")
iTMP = IXKEY()
CALL SETATTR(BLKBKG+WHITECHR)
CALL CLS
IF (iTMP.EQ.121 .OR. iTMP.EQ.89) THEN
   GOTO 5111
ELSE
   STOP
END IF
END IF

CONTINUE
TinDay=0.0
IterN=0

OPEN(5,FILE=\'Win\',STATUS=\'OLD\')
OPEN(7,FILE=\'WQ.HYD\',STATUS=\'OLD\',FORM=\'UNFORMATTED\')
OPEN(6,FILE=\'WQ.OUT\')

READ(5, \'(6i5)\') iTdep, iUBC, iBC, iNPS, iPS, iSolar
READ(5, \'\(i5\)\') iPLTWQ
IF (iTdep .EQ. 1) THEN
   WRITE(6,802) * Time-varying conditions are used.
ELSE
   WRITE(6,802) * Steady conditions are used.
END IF
IF (iUBC .EQ. 1) THEN
   WRITE(6,802) * Only mass input from freshwater discharge.
ELSE
   WRITE(6,802) * Both momentum & mass flux from f.w. discharge.
END IF
IF (iBC .EQ. 1) THEN
   OPEN(11,FILE=\'BC.IN\',STATUS=\'OLD\')
   WRITE(6,802) * Time-varying boundary conditions.
ELSE
   WRITE(6,802) * Constant boundary condition.
END IF
IF (iNPS .EQ. 1) THEN
   OPEN(8,FILE=\'NPS.IN\',STATUS=\'OLD\')
   WRITE(6,802) * Time-varying non-point source input.
ELSE
   WRITE(6,802) * Constant non-point source input.
END IF
IF (iPS .EQ. 1) THEN
   OPEN(9,FILE=\'PS.IN\',STATUS=\'OLD\')
   WRITE(6,802) * Time-varying point source input.
ELSE
   WRITE(6,802) * Constant point source input.
END IF
IF (iSolar .EQ. 1) THEN
   OPEN(10,FILE=\'SOLAR.IN\',STATUS=\'OLD\')
   WRITE(6,802) * Time-varying solar radiation parameters.
ELSE
   WRITE(6,802) * Constant solar radiation parameters.
END IF
IF (iPLTWQ .EQ. 1) THEN
   OPEN(14,FILE=\'WQ-PLT.DAT\')
   WRITE(6,802) * Generate daily max, mean & min output.
ELSE
   WRITE(6,802) * No daily max, mean & min output.

5001 CONTINUE

IF (iBC.EQ.1 .OR. iNPS.EQ.1 .OR. iPS.EQ.1 .OR. iSolar.EQ.1) THEN
  IF (iTdep .NE. 1) STOP '** iTdep should be 1 (time-varying)'
END IF

CALL ReadHYDC(NTSiD,iTMAX,iTPrw,iTPslW,DTH,TfM,MUH,TMAX)
CALL ReadWQC
CALL Init(MUH)
CALL Input(iBC,inPS,iPS,iSolar)
CALL InitWLoad
IF (iPLTWQ.EQ.1) THEN
  WRITE(14,9999)'* Upstream boundary segment number = ML,
  WRITE(14,9998)'* Downstream boundary segment number = MU
END IF

NTSfM = NINT(TfM / DTH)
IterN = NTSfM
TinDay = TfM / 24.0
Hour = TfM

DO WHILE (IterN .LE. iTMAX)
  IF (pltdatal.EQ.'mp') CALL mappltl(titlel,firstl,redrawl)
  IF (pltdatal.EQ.'nl') CALL mdpltl(Nl,titlel,yunitl,ML,MU,nseg,
       yminl,ymaxl,TinDay,firstl,redrawl,hydplt,DistS)
  IF (pltdatal.EQ.'n2') CALL mdpltl(N2,titlel,yunitl,ML,MU,nseg,
       yminl,ymaxl,TinDay,firstl,redrawl,hydplt,Dists)
  IF (pltdatal.EQ.'n3') CALL mdpltl(N3,titlel,yunitl,ML,MU,nseg,
       yminl,ymaxl,TinDay,firstl,redrawl,hydplt,DistS)
  IF (pltdatal.EQ.'tn') CALL mdpltl(TN,titlel,yunitl,ML,MU,nseg,
       yminl,ymaxl,TinDay,firstl,redrawl,hydplt,DistS)
  CALL PLOT(0.0,0.0,-999)
END DO WHILE

CALL GTEXT(29,0,'(P)ause (R)esume re(S)tart (O)ther-plots (Y)cale-change (Q)uit-or-ESC')
IF (pltdata1.EQ.'pl') CALL mdlplt1(P1,title1,yunit1,ML,MU,nseg,
  ymin1,ymax1,TinDay,first1,redraw1,hydplt,DistS)
* IF (pltdata1.EQ.'p2') CALL mdlplt1(P2,title1,yunit1,ML,MU,nseg,
  ymin1,ymax1,TinDay,first1,redraw1,hydplt,DistS)
* IF (pltdata1.EQ.'tp') CALL mdlplt1(TP,title1,yunit1,ML,MU,nseg,
  ymin1,ymax1,TinDay,first1,redraw1,hydplt,DistS)
* IF (pltdata1.EQ.'ch') CALL mdlplt1(Chl,title1,yunit1,ML,MU,nseg,
  ymin1,ymax1,TinDay,first1,redraw1,hydplt,DistS)
* IF (pltdata1.EQ.'cb') CALL mdlplt1(CBOD,title1,yunit1,ML,MU,
  nseg,ymin1,ymax1,TinDay,first1,redraw1,hydplt,DistS)
* IF (pltdata1.EQ.'do') CALL mdlplt1(DOC,title1,yunit1,ML,MU,nseg,
  ymin1,ymax1,TinDay,first1,redraw1,hydplt,DistS)
 IF (pltdata1.NE. 'no') CALL PLOT(-1.0,-4.75,-3)

IF (pltdata2.EQ.'mp') CALL mapplt2(title2,first2,redraw2)
IF (pltdata2.EQ.'nl') CALL mdlplt2(Nl,PtN1Min,PtN1Max,PtAvgN1,
  title2,yunit2,ML,MU,nseg,ymin2,ymax2,TinDay,first2,redraw2,
  hydplt,DistS)
* IF (pltdata2.EQ.'n2') CALL mdlplt2(N2,PtN2Min,PtN2Max,PtAvgN2,
  title2,yunit2,ML,MU,nseg,ymin2,ymax2,TinDay,first2,redraw2,
  hydplt,DistS)
* IF (pltdata2.EQ.'n3') CALL mdlplt2(N3,PtN3Min,PtN3Max,PtAvgN3,
  title2,yunit2,ML,MU,nseg,ymin2,ymax2,TinDay,first2,redraw2,
  hydplt,DistS)
* IF (pltdata2.EQ.'tn') CALL mdlplt2(TN,PtTNMin,PtTNMax,PtAvgTN,
  title2,yunit2,ML,MU,nseg,ymin2,ymax2,TinDay,first2,redraw2,
  hydplt,DistS)
* IF (pltdata2.EQ.'pl') CALL mdlplt2(Pl,PtP1Min,PtP1Max,PtAvgPl,
  title2,yunit2,ML,MU,nseg,ymin2,ymax2,TinDay,first2,redraw2,
  hydplt,DistS)
* IF (pltdata2.EQ.'p2') CALL mdlplt2(P2,PtP2Min,PtP2Max,PtAvgP2,
  title2,yunit2,ML,MU,nseg,ymin2,ymax2,TinDay,first2,redraw2,
  hydplt,DistS)
* IF (pltdata2.EQ.'tp') CALL mdlplt2(TP,PtTPMin,PtTPMax,PtAvgTP,
  title2,yunit2,ML,MU,nseg,ymin2,ymax2,TinDay,first2,redraw2,
  hydplt,DistS)
* IF (pltdata2.EQ.'ch') CALL mdlplt2(Chl,PtChlMin,PtChlMax,
  PtAvChl,title2,yunit2,ML,MU,nseg,ymin2,ymax2,TinDay,first2,
  redraw2,hydplt,DistS)
* IF (pltdata2.EQ.'cb') CALL mdlplt2(CBOD,PtBODMin,PtBODMax,
  PtAvgBOD,title2,yunit2,ML,MU,nseg,ymin2,ymax2,TinDay,first2,
  redraw2,hydplt,DistS)
* IF (pltdata2.EQ.'do') CALL mdlplt2(DOC,PtDOMin,PtDOMax,PtAvgDO,
  title2,yunit2,ML,MU,nseg,ymin2,ymax2,TinDay,first2,redraw2,
  hydplt,DistS)
* IF (pltdata2.NE.'no') CALL PLOT(-1.0,-0.8,-3)
CALL pltclock(hydplt,IterN,iTMAX,TinDay,newclock)
CALL PTime(TinDay,hydplt)

keyval=0
kpress=ISKEY() 
5100 CONTINUE
IF (kpress) keyval=IXKEY()
IF (keyval.EQ.27 .OR. keyval.EQ.81 .OR. keyval.EQ.113) *
  cancel=.TRUE.
IF (cancel) GOTO 5999
IF (keyval.EQ.80 .OR. keyval.EQ.112) GOTO 5100
IF (keyval.EQ.82 .OR. keyval.EQ.114) GOTO 5200
IF (keyval.EQ.83 .OR. keyval.EQ.115) THEN
  CLOSE(5)
  CLOSE(6)
  CLOSE(7)
  CLOSE(8)
  CLOSE(9)
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CLOSE(10)
CLOSE(11)
CLOSE(14)
CALL PLOT(0.0,0.0,-999)
GOTO 5001
END IF
IF (keyval.EQ.79 .OR. keyval.EQ.111) THEN
    CALL PLOT(0.0,0.0,-999)
    ipltnum1 = 1
    CALL AskPLTW(ipltnum1,pltdatal,title1,yunit1,ymin1,ymax1)
    redraw1 = .TRUE.
    newclock = .TRUE.
    ipltnum2 = 2
    CALL AskPLTW(ipltnum2,pltdatal2,title2,yunit2,ymin2,ymax2)
    redraw2 = .TRUE.
    newclock = .TRUE.
    CALL PLOT(0.0,0.0,-999)
    CALL NEWPEN(11)
    CALL GTEXT(29,0,'(P)ause (R)esume re(S)tart (O)ther-plots
*(Y)scale-change (Q)uit-or-ESC'
END IF
IF (keyval.EQ.89 .OR. keyval.EQ.121) THEN
    IF (pltdatal.NE.'mp' .AND. pltdatal.NE.'no') THEN
        CALL SETATTR(LBLUCHR+BRITE)
        CALL LOCATE(5,15)
        CALL PRINTS(')
        CALL LOCATE(6,15)
        CALL PRINTS(')
        CALL LOCATE(7,15)
        CALL PRINTS(')
        CALL LOCATE(8,15)
        CALL PRINTS(')
        CALL LOCATE(9,15)
        CALL PRINTS(')
        CALL SETATTR(YELLOCHR+BRITE)
        CALL LOCATE(6,18)
        CALL PRINTS('press ESC for no change or ANY OTHER KEY'
        CALL LOCATE(7,18)
        CALL PRINTS('to proceed')
        Kvall = IXKEY()
        IF (Kvall.NE.27) THEN
            CALL SETATTR(LBLUCHR+BRITE)
            CALL LOCATE(6,15)
            CALL PRINTS(')
            CALL LOCATE(7,15)
            CALL PRINTS(')
            CALL LOCATE(8,15)
            CALL PRINTS(')
            CALL SETATTR(WHITECHR+BRIGHT)
            CALL LOCATE(8,16)
            CALL PRINTS(': type 2 values separated by comma, and ENTER')
            CALL SETATTR(YELLOCHR+BRITE)
            CALL LOCATE(6,18)
            CALL PRINTS('Type Y-min & Y-max for PLOT 1: ')
            CALL GETPOS(iRL,iCL)
            CALL LOCATE(iRL,iCL+1)
            READ(*,*) ymin1,ymax1
        END IF
    END IF
    IF (pltdatal2.NE.'mp' .AND. pltdatal2.NE.'no') THEN
        CALL SETATTR(LBLUCHR+BRITE)
        CALL LOCATE(19,15)
        CALL PRINTS(')
        CALL LOCATE(20,15)
        CALL PRINTS(')
CALL PRINTS('')
CALL LOCATE(21,15)
CALL PRINTS('')
CALL LOCATE(22,15)
CALL PRINTS('')
CALL LOCATE(23,15)
CALL PRINTS('')
CALL SETATTR(YELLOWCHR+BRITE)
CALL LOCATE(20,18)
CALL PRINTS(''press ESC for no change or ANY OTHER KEY'')
CALL LOCATE(21,18)
CALL PRINTS('to proceed')
Kval2=IXKEY()
IF (Kval2.NE.27) THEN
   CALL SETATTR(LBLUCHR+BRITE)
   CALL LOCATE(20,15)
   CALL PRINTS('')
   CALL LOCATE(21,15)
   CALL PRINTS('')
   CALL LOCATE(22,15)
   CALL PRINTS('')
   CALL SETATTR(WHITECHR+BRIGHT)
   CALL LOCATE(22,16)
   CALL PRINTS(': type 2 values separated by comma, and ENTER')
   CALL SETATTR(YELLOWCHR+BRITE)
   CALL LOCATE(20,18)
   CALL PRINTS('Type Y-min & Y-max for PLOT 2: ')
   CALL GETPOS(iRL,iCL)
   CALL LOCATE(iRL,iCL+1)
   READ(*,*) ymin2,ymax2
END IF
END IF
newclock=.TRUE.
redraw1=.TRUE.
redraw2=.TRUE.
first1=.TRUE.
first2=.TRUE.
CALL PLOT(0.0,0.0,-999)
CALL NEWPEN(11)
CALL GTEXT(29,0,'(P)ause (R)esume re(S)tart (O)ther-plots
*(Y)scale-change (Q)uit-or-ESC')
END IF
C+++e
5200
CONTINUE
IF (IterN .EQ. iTprnW) THEN
   CALL Output
   IncPW = IncPW + 1
   iTprnW = NINT( TOUT(IncPW)/DTD )
   iTPs1W = NINT( (TOUT(IncPW)-1.0)/DTD)
END IF
TinDay = TinDay + DTD
IterN = IterN + 1
NTSfM = NTSfM + 1
Hour = Hour + DTH
IF (MOD(NTSfM,NTSiD) .EQ. 0) THEN
   CALL OutPLTWQ(TinDay,iPLTWQ)
C+++s
   CALL OutPLTWQ(TinDay,iPLTWQ)
C+++e
   IF (ITdep .EQ. 1) CALL Input(iBC,iNPS,iPS,iSolar)
   NTSfM = NTSfM - NTSiD
   Hour = Hour - 24.0
END IF
CALL CalcAll(Hour,NTSfM,iNPS,iPS)

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CALL AvgPLTWQ
* IF (iTpslW .GE. 0 .AND. IterN .GT. iTpslW) CALL GetMean
END DO
5999 CONTINUE
CALL PLOT(0.0,0.0,999)

IF (keyval.EQ.27 .OR. keyval.EQ.81 .OR. keyval.EQ.113) THEN
CLOSE(5)
CLOSE(6,STATUS='DELETE')
CLOSE(7)
CLOSE(8)
CLOSE(9)
CLOSE(10)
CLOSE(11)
CLOSE(14,STATUS='DELETE')
STOP '** Aborted! **'
ELSE
CLOSE(5)
CLOSE(6)
CLOSE(7)
CLOSE(8)
CLOSE(9)
CLOSE(10)
CLOSE(11)
CLOSE(14)
STOP '** Successful Run !!!!! **'
END IF

C***************
SUBROUTINE ReadHYDC(NTSiD,iTMAX,iTprnW,iTPslW,DTH,TfM,MUH,TMAX)
C**********************************************************************C
INCLUDE 'COM-WQ.INC'
READ(7) MLH,MUH,DistT,StSAM,ARD,Darea
READ(S, '(2I5)') ML,MU
WRITE(6,801)'* Upstream boundary transect number = ', ML,
* Downstream boundary transect number = ', MU
WRITE(6,'(/A48,F15.5)')
* ' Drainage area (km**2) upstream of fall line = ', Darea
WRITE(6,801)'* Drainage area (km**2) at each segment ' WRITE(6,'(10F7.2)') (ARD(i), i=ML,MU)
MLl = ML + 1
MLsl = ML - 1
MUsl = MU - 1
IF (ML .LT. MLH) STOP '** ML for WQ model < ML for HYD model.'
IF (MU .GT. MUH) STOP '** MU for WQ model > MU for HYD model.'
READ(5,'(3F10.0,I10)') TMAX,DTD,TfM,NTprn
READ(S, '(10F8.0)') (TOUT(m), m=1,NTprn)
READ(5,'(2F8.0)') TOFH,FDTL
WRITE(6,802)'* Number of days for model to be run = ', TMAX,
* Time increment in days = ', DTD,
** Hours from midnight to model start = ', TfM
WRITE(6,801)'* Number of times to print the output = ', NTprn
WRITE(6,802)'* Times (in days) to print the output;
WRITE(6,801)'* Hours to reach the DB conditions from SBF = ', TOFH,
** Time lag (days) to adjust fw discharge = ', FDTL
801 FORMAT(/, (A40, I5))
802 FORMAT(/, (A45, F15.6))

A6-31
C DTD/DTH/DT = time step in days/hrs/sec
C iTMAX = total number of iteration time steps.
C NTSID = number of time steps in one day.

DT = DTD * 86400.0
DTH = DTD * 24.0
NTSID = NINT(1.0/DTD)
ITMAX = NINT(ITMAX/DTD)
iFDTL = NINT(FTDL/DT)
iTPrnW = NINT(TOUT(INcPW)/DT)
iTPs1W = NINT((TOUT(INcPW)-1.0)/DT)
MST = NINT(TOFH/DTH)
IF (MST .EQ. 0) MST = 1
RETURN
END

C***************
SUBROUTINE ReadWQC
C**********************************************************************C
C Read in the parameters related to nutrient transfer.
C**********************************************************************C
INCLUDE 'COM-WQ.INC'
Parameter (aco=2.67)
WRITE(6,803)'* Exp.base for temp. dependence of rate constants '
WRITE(6,802)' of nitrogen hydrolysis =',TheN12
WRITE(6,802)' of nitrification =',TheN23
WRITE(6,802)' of organic phosphorous mineralization =',TheP12
READ(5,9002) NS2
READ(5,9001) (xKn12(i), i=2,NS2)
READ(5,9001) (xKn23(i), i=2,NS2)
READ(5,9001) (xKp12(i), i=2,NS2)
IF (NS2 .LE. 2) THEN
  DO 151 i=ML,MU
    xKn12(i) = xKn12(2)
    xKn23(i) = xKn23(2)
    xKp12(i) = xKp12(2)
  151 CONTINUE
END IF
WRITE(6,803)'* Rate constant (mg/L/day) at 20C of Hydrolysis Nitrification P mineralization'
WRITE(6,'(I3,Al,F13.5)') (i, ':', xKn12(i),xKn23(i),xKp12(i),
  i=ML,MU)
READ(5,9001) rKh12,rKh23,rKhp12
WRITE(6,802)'* Half-saturation concentration (mg/L) of nitrogen hydrolysis of nitrification of organic phosphorous mineralization =',rKh12,rKh23,rKhp12
READ(5,9002) NS2
READ(5,9001) (xKc(i), i=2,NS2)
IF (NS2 .EQ. 2) THEN
  DO 111 i=ML,MU
    xKc(i) = xKc(2)
  111 CONTINUE
END IF
WRITE(6,803)'* CBOD decay rate (/day) at 20C of'
WRITE(6,'(I3,Al,F13.5)') (i, ':', xKc(i), i=ML,MU)
READ(5,9001) TheKc
WRITE(6,802)': Exp.base for temp. depend. for CBOD decay =', TheKc
READ(5,9001) TheDOaer
WRITE(6,802)': Exp.base for temp.depend. of DO reaeration=’, TheDOaer
READ(5,9002) NS2
READ(5,9001) (rKni(i), i=2,NS2)
READ(5,9001) (rKn33(i), i=2,NS2)
READ(5,9001) (rKpi1(i), i=2,NS2)
READ(5,9001) (rKp22(i), i=2,NS2)
READ(5,9001) (rKbod(i), i=2,NS2)
IF (NS2 .LE. 2) THEN
  DO 232 i = ML, MU
    rKni(i) = rKni(2)
    rKn33(i) = rKn33(2)
    rKpi1(i) = rKpi1(2)
    rKp22(i) = rKp22(2)
    rKbod(i) = rKbod(2)
  CONTINUE
END IF
WRITE(6,803) ' Settling and loss rate (m/d) in main channel of '
WRITE(6,805) N1 N3 P1 P2 CBOD
WRITE(6,‘(I3,Al,5F10.5)’) (i, ‘:’, rKni(i),rKn33(i),rKpi1(i),
  rKp22(i),rKbod(i), i=ML,MU)
C3-2
READ(5,9002) NS2
READ(5,9001) (StKni(i), i=2,NS2)
READ(5,9001) (StKn33(i), i=2,NS2)
READ(5,9001) (StKpi1(i), i=2,NS2)
READ(5,9001) (StKp22(i), i=2,NS2)
READ(5,9001) (StKbod(i), i=2,NS2)
IF (NS2 .LE. 2) THEN
  DO 233 i = ML, MU
    StKni(i) = StKni(2)
    StKn33(i) = StKn33(2)
    StKpi1(i) = StKpi1(2)
    StKp22(i) = StKp22(2)
    StKbod(i) = StKbod(2)
  CONTINUE
END IF
WRITE(6,803) ' Settling and loss rate (m/d) in storage area of '
WRITE ( 6, 805) ' N1 N3 P1 P2 CBOD
WRITE(6, ‘(I3,Al,5F10.5)’) (i, ‘:’, StKni(i),StKn33(i),StKpi1(i),
  StKp22(i),StKbod(i), i=ML,MU)
C4
READ(5,9001) ac,an,ap,ar,PQ,RQ,rKmn,rKmp,xKgr,ris,rKchl,StKchl,
  Resp20,Graz20,Fn,Fp,ThetaG,ThetaR,ThetaD,EH
WRITE(6,803) ' Phytoplankton (pp) related coefficients
WRITE(6,804) ': Carbon/Chl ratio (mgC to ugChl) in pp =', ac
*: N/Chl ratio (mgN to ugChl) in pp =', an
*: Org.P/Chl ratio (mgP to ugChl) in pp =', ap
*: Proportion of consumed pp recycled by zp =', ar
*: Photosynthesis quotient (moles O2/mole C) =', PQ
*: Respiration quotient (moles CO2/mole O2) =', RQ
*: Half-sat. conc. (mg/L) for inorg.N uptake =', rKmn
*: for orthophosphorus uptake =', rKmp
*: Optimum growth rate of pp (/day) at 20C =', xKgr
*: Optimum solar radiation rate (langley/d) =', ris
*: Endogenous respiration rate (/day) at 20C =', Resp20
*: Grazing & other mortality rate (/d) at 20C =', Graz20
*: Settling rate (m/s) of pp in main channel =', rkChl
*: in side storage area =', rkChl
*: Fraction of made N recycled to org. pool =', Fn
*: of metabolically produced P recycled to =', Fp
*: Exp. base for temp. dependency of growth =', ThetaG
*: of respiration =', ThetaR
*: of grazing & other mortality =', ThetaD
*: Euphotic depth (m) for pp growth =', EH
ac = ac * aco
PQ = PQ * ac

9001 FORMAT(10F8.0)
9002 FORMAT(I5)
9003 FORMAT(/, (A45, F15.6))
9004 FORMAT(/, A50)
9005 FORMAT(2X, A45, F15.5))

RETURN
END

C***************
SUBROUTINE Init(MUH)
C**********************************************************************C

INCLUDE 'COM-WQ.INC'

READ(5,9001) (N1(i), i=ML,MU)
READ(5,9001) (N2(i), i=ML,MU)
READ(5,9001) (N3(i), i=ML,MU)
READ(5,9001) (P1(i), i=ML,MU)
READ(5,9001) (P2(i), i=ML,MU)
READ(5,9001) (Chl(i), i=ML,MU)
READ(5,9001) (CBOD(i), i=ML,MU)
READ(5,9001) (DOC(i), i=ML,MU)
WRITE(6,801)'* Initial conditions'
WRITE(6,'(A43,A31)')' N1 N2 NJ Pl P2 Chl CBOD DOC'
DO 22 i=ML,MU
   StN1(i) = N1(i)
   StN2(i) = N2(i)
   StN3(i) = N3(i)
   StP1(i) = P1(i)
   StP2(i) = P2(i)
   StChl(i) = Chl(i)
   StCBOD(i) = CBOD(i)
   StDOC(i) = DOC(i)
22 CONTINUE

READ(5,9001) (Alpha(i), i=ML,MU)
DO 23 i=ML,MU
   CAlpha(i) = 1.0 - Alpha(i)
23 CONTINUE

CALL GetHYD
WRITE(6,801)'* Initial conditions of Hydrodynamic variables'
WRITE(6,801)' DistT ARCO HR HA VOL'
WRITE(6,801)'  StSAM U E Alpha'
DO 17 i=ML,MU
   WRITE(6,'(I3,Al,2F9.3,2F7.3,2E12.4,3F6.2) •) (i, ': ', DistT(i),
   XA(i),HR(i),HA(i),Vol(i),StSAM(i), U(i),E(i),Alpha(i), i=ML,MU)
17 CONTINUE

IF (iUBC .EQ. 1 .AND. U(ML) .NE. 0.0)
   STOP '** Momentum flux from f.w. input; U(ML) is not 0.'
IF (iUBC .NE. 1 .AND. Alpha(ML) .NE. 1.0)
   STOP '** Alpha(ML)=1 if there is mom input from f.w.'

9001 FORMAT(10F8.0)
801 FORMAT(/, (A51, A27))

C DX(i) = distance (m) bet/ the center of segment i-1 & i.
C To get DX(ML), assumed that DistS(MLsl)-DistT(ML) = DistT(ML)-DistS(ML).
C DistS(i) = distance (km) from the center of segment i to the mouth.

DX(ML) = (DistT(ML) - DistT(ML1)) * 1.0E3
DO 17 i=ML1,MUSl
DX(i) = (DistT(i-1) - DistT(i+1))/2.0 * 1.0E3

CONTINUE
IF (MU .EQ. MUH) THEN
  DX(MU) = (DistT(MUsl) + DistT(MU))/2.0 * 1.0E3
ELSE
  DX(MU) = (DistT(MUsl) - DistT(MU+1))/2.0 * 1.0E3
END IF
DTXatDB = DT / DX(MU)
DO 16 i=ML,MUsl
  DistS(i) = (DistT(i) + DistT(i+1)) / 2.0
16 CONTINUE
IF (MU .EQ. MUH) THEN
  DistS(MU) = 0.0
ELSE
  DistS(MU) = (DistT(MU) + DistT(MU+1)) / 2.0
END IF
RETURN
END

C**************
SUBROUTINE InitWLoad
C******************************************
C Since, for now, we know only Q & conc at fall line (i=ML) are known, it is
C assumed (conc in lateral inflow into segment i) = (conc at the fall line).
C******************************************
INCLUDE 'COM-WQ.INC'
Data QLat/0.0/
QLaatUB = DSQ / Darea
DO 10 i=ML,MUsl
  IF (i .EQ. ML) THEN
    IF (iUBC .EQ. 1) THEN
      QLat = DSQ + QLaatUB*ARD(ML)
    ELSE
      QLat = QLaatUB*ARD(ML)
    END IF
  ELSE
    QLat = QLaatUB*ARD(i)
  END IF
  WN1(i) = PSWN1(i) + QLat*DSN1
  WN2(i) = PSWN2(i) + QLat*DSN2
  WN3(i) = PSWN3(i) + QLat*DSN3
  WP1(i) = PSWP1(i) + QLat*DSP1
  WP2(i) = PSWP2(i) + QLat*DSP2
  WChl(i) = QLat*DSChl
  WBOD(i) = PSWBOD(i) + QLat*DSBOD
  WDO(i) = PSWDO(i) + QLat*DSDO
  OQ = DSQ
  ON1 = DSN1
  ON2 = DSN2
  ON3 = DSN3
  OP1 = DSP1
  OP2 = DSP2
  OChl = DSChl
  OBOD = DSBOD
  ODO = DSDO
10 CONTINUE
RETURN
END

C**************
SUBROUTINE GetHYD
C******************************************
C: Depending upon iUBC, model can take care of 2 kinds of upstream BC.
C: HR = hydraulic radius and HA = segment mean depth
C******************************************
INCLUDE 'COM-WQ.INC'

DO 14 i=ML,MUS1
   VolO(i) = Vol(i)
   StVolO(i) = StVol(i)
14 CONTINUE

READ(7) XA, Vol, U, E, HR, SAT, StVol, DSQ
DSQ=DSQ*8.64E4
DO 12 i=ML,MUS1
   HA(i) = Vol(i) / SAT(i)
   IF (StSAM(i) .NE. 0.0) StH(i) = StVol(i) / StSAM(i)
12 CONTINUE

E(ML) = 0.0
IF (UBC .EQ. 1 .AND. U(ML) .NE. 0.0)
* STOP '** Momentum flux from f.w. input; U(ML) is not 0.'
RETURN
END

C***************
SUBROUTINE Input(IBC,INPS,IPS,ISolar)
C**********************************************************************C
INCLUDE 'COM-WQ.INC'
Dimension xBenN1(iX), xBenN2(iX), xBenN3(iX), xBenPl(iX), xBenP2(iX),
* xBenBOD(iX), xBenDO(iX)
Character Title*SO
Save/Local/, xBenN1, xBenN2, xBenN3, xBenPl, xBenP2, xBenBOD, xBenDO,
* TBN1, TBN2, TBN3, TBP1, TBP2, TBOD, TBBOD
Data PSN1, PSN2, PSN3, PSP1, PSP2, PSBOD, PSDO/7*0.0/
Data xBenN1, xBenN2, xBenN3, xBenPl, xBenP2, xBenBOD, xBenDO/490*0.0/
READ(5, '(A50)') Title
WRITE(6, 801) Title
READ(5, 9002) NDG, NS2
DO WHILE (NDG .NE. 99)

C2 ELSE IF (NDG .EQ. 2) THEN
IF (IPS .EQ. 1) THEN
   WRITE(6, 803)' Down:', DnN1, DnN2, DnN3, DnP1, DnP2, DnChl, DnBOD, DnDO
WRITE(6, 803)' CBO',
   WRITE(6, 802)' N1 N2 N3 P1 P2 ',
*   WRITE(6, 803)' Up :', UpN1, UpN2, UpN3, UpP1, UpP2, UpChl, UpBOD, UpDO
   WRITE(6, 803)' D D D D D D D D D D
C2 ELSE IF (NDG .EQ. 2) THEN
IF (IPS .EQ. 1) THEN
   WRITE(6, 805)'*2 Constant point source input in kg/day'
ELSE
   WRITE(6, 805)'*2 Daily point source input in kg/day'
END IF
WRITE(6, 802)'
A6-36
IF (iPS .EQ. 1) THEN
READ(9,9003) i, PSN1,PSN2,PSN3, PSP1,PSP2, PSBOD,PSDO
ELSE
READ(5,9003) i, PSN1,PSN2,PSN3, PSP1,PSP2, PSBOD,PSDO
END IF
WRITE(6,'(I3,A1,7F8.3)') i, ': ', PSN1,PSN2,PSN3, PSP1,PSP2, PSBOD,PSDO
PSWN1(i) = PSN1 * 1000.0
PSWN2(i) = PSN2 * 1000.0
PSWN3(i) = PSN3 * 1000.0
PSWP1(i) = PSP1 * 1000.0
PSWP2(i) = PSP2 * 1000.0
PSWBOD(i) = PSBOD * 1000.0
PSWDO(i) = PSDO * 1000.0
CONTINUE

ELSE IF (NDG .EQ. 3) THEN
IF (iNPS .EQ. 1) THEN
WRITE(6,805)'*3 Daily non-point source input in mg/L'
OQ = DSQ
ON1 = DSN1
ON2 = DSN2
ON3 = DSN3
OP1 = DSP1
OP2 = DSP2
OCChl = DSChl
0800 = DSBOD
ODO = DSDO
ELSE
WRITE(6,805)'*3 Constant non-point source input in mg/L'
END IF
WRITE(6,802)' Q(m**3/s) N1 N2 N3 P1 P2',
* Chl(ug/L) CBOD DO
IF (iNPS .EQ. 1) THEN
READ(S,9004) xDSQ,DSN1,DSN2,DSN3,DSP1,DSP2,DSChl,DSBOD,DSDO
ELSE
READ(S,9004) xDSQ,DSN1,DSN2,DSN3,DSP1,DSP2,DSChl,DSBOD,DSDO
END IF
WRITE(6,9001) xDSQ,DSN1,DSN2,DSN3,DSP1,DSP2,DSChl,DSBOD,DSDO
DSQ = DSQ * 8.64E4

C Negative values, including BenDO (i.e., SOD), indicate loss to sediment.
ELSE IF (NDG .EQ. 4) THEN
WRITE(6,801)'*4 Benthic fluxes: release rate (g/m**2/d) at 20C'
READ(5,9001) (xBenN1(i), i=ML,MU)
READ(5,9001) (xBenN2(i), i=ML,MU)
READ(5,9001) (xBenN3(i), i=ML,MU)
READ(5,9001) (xBenP1(i), i=ML,MU)
READ(5,9001) (xBenP2(i), i=ML,MU)
READ(5,9001) (xBenBOD(i), i=ML,MU)
READ(5,9001) (xBenDO(i), i=ML,MU)
WRITE(6,802)' N1 N2 N3 P1 P2 ',
* CBOD DO
WRITE(6,'(I3,A1,7F9.3)') i, ': ', xBenN1(i),xBenN2(i),xBenN3(i),
* xBenP1(i),xBenP2(i), xBenBOD(i),xBenDO(i), i=ML,MU)
READ(5,9001) TBN1,TBN2,TBN3,TBP1,TBP2,TBBOD,TBDO
WRITE(6,802)' : Exp. bases for temp. correction for the above
WRITE(6,'(4X,7F9.3)') TBN1,TBN2,TBN3,TBP1,TBP2,TBBOD,TBDO

ELSE IF (NDG .EQ. 5) THEN
READ(5,9001) (Turb(i), i=ML,MU)
WRITE(6,804) (i, ': ', Turb(i), i=ML,MU)
ELSE IF (NDG .EQ. 6) THEN
READ(5,9001) (WREA(i), i=ML,MU)
WRITE(6,801) '6 Wind-induced reaeration of DO (m/day)'
WRITE(6,804) (i, ':', WREA(i), i=ML,MU)
END IF

C Always read Temp after benthic fluxes and CBOD decay rate.
C TDOs = 14.6244 - 0.367134*Temp + 4.497E-3*Temp*Temp
ELSE IF (NDG .EQ. 7) THEN
READ(5,9001) Temp
WRITE(6,805) '7 Temperature (deg C) = ', Temp
TDOs = 14.62 - 0.367*Temp + 0.0045*Temp*Temp
STOOS = -9.66E-2 + 2.05E-3*Temp
DO 11 i=ML,MU
 rKn12(i) = xKn12(i) * TheN12**Temp20
 rKn23(i) = xKn23(i) * TheN23**Temp20
 rKp12(i) = xKp12(i) * TheP12**Temp20
 BenN1(i) = xBenN1(i) * TBN1**Temp20
 BenN2(i) = xBenN2(i) * TBN2**Temp20
 BenN3(i) = xBenN3(i) * TBN3**Temp20
 BenP1(i) = xBenP1(i) * TBP1**Temp20
 BenP2(i) = xBenP2(i) * TBP2**Temp20
 BenBOD(i) = xBenBOD(i) * TBBD**Temp20
 BenDO(i) = xBenDO(i) * TBDO**Temp20
 rKc(i) = xKc(i) * TheKc**Temp20
11 CONTINUE

TDOaer = TheDOaer**Temp20
rKgr = 2.718 * xKgr * ThetaG**Temp20
RespR = Resp20 * ThetaR**Temp20
GrazR = Graz20 * ThetaD**Temp20
Cndie = (RespR + ar*GrazR) * an
Cndie1 = Cndie * Fn
Cndie2 = Cndie * (1.0 - Fn)
Cpdie = (RespR + ar*GrazR) * ap
Cpdie1 = Cpdie * Fp
Cpdie2 = Cpdie * (1.0 - Fp)
EODdie = ac * ar * GrazR
L0resp = RespR * ac / RQ

ENDIF

C When first calling SUBR Input, NS2 for this group should be 1.
ELSE IF (NDG .EQ. 8) THEN
IF (iSolar .EQ. 1) THEN
WRITE(6,805) '8 Daily-varying solar radiation data'
WRITE(6,805) ': Hours from midnight to sun rise = ', TU
WRITE(6,805) ': Hours from midnight to sun set = ', TD
WRITE(6,805) ': Total daily radiation (angleys/day) = ', ria
ELSE
READ(10,'(9X,3Fl0.0)') ria,TU,TD
WRITE(6,805) ': Total daily radiation (angleys/day) = ', ria
ENDIF
ELSE
WRITE(6,805) '8 Constant solar radiation parameters'
READ(5,'(9X,3Fl0.0)') ria,TU,TD
WRITE(6,805) ': Hours from midnight to sun rise = ', TU,
WRITE(6,805) ': Hours from midnight to sun set = ', TD,
WRITE(6,805) ': Total daily radiation (angleys/day) = ', ria
ENDIF

PTT = 3.1416 / (TD-TU)
rIn = -12.0 * PTT * (ria/ris)
END IF
READ(5,9002) NDG, NS2
END DO
SUBROUTINE CalcAll(Hour,NTsFm,INPs,IPS)
C**********************************************************************

INCLUDE 'COM-WQ.INC'
CALL GetHYD
CALL AdvDif
IF (INPs .EQ. 1 .OR. IPS .EQ. 1) THEN
   IF (NTsFm .LE. IFDTL) CALL GetWLoad(NTsFm)
END IF
CALL Phyto(Hour)
CALL WDNBDry
CALL EqnDO
CALL EqnCBOD
CALL EqnN3
CALL EqnN2
CALL EqnN1
DO 10 i=ML,MU
   TN(i) = N1(i) + N2(i) + N3(i)
10 CONTINUE
CALL EqnP2
CALL EqnP1
DO 20 i=ML,MU
   TP(i) = P1(i) + P2(i)
20 CONTINUE
CALL EqnChl
C Negative predicted values screened out.
* CALL Rneg
RETURN
END

SUBROUTINE AdvDif
C**********************************************************************

INCLUDE 'COM-WQ.INC'
P(MLs1) = 0.0
Gam1 = Alpha(ML)
IF (U(ML) .LT. 0.0) Gam1 = CAlpha(ML)
Del1 = 1.0 - Gam1
EAD1 = E(ML) * XA(ML) / DX(ML)
UA1 = U(ML) * XA(ML)
DO 100 i=ML,MUs1
   Gam2 = Alpha(i+1)
   IF (U(i+1) .LT. 0.0) Gam2 = CAlpha(i+1)
   Del2 = 1.0 - Gam2
   EAD2 = E(i+1) * XA(i+1) / DX(i+1)
   DV = DT / Vol(i)
   Dif1(i) = DV * EAD1
   Dif2(i) = DV * EAD2
   UA2 = U(i+1) * XA(i+1)
   Div(i) = 1.0 + DV * (Gam2*UA2 - Del1*UA1)
   AA(i) = - DV * Del2*UA2 / Div(i)
   BB(i) = DV * Gam1*UA1 / Div(i)

PODiv(i) = 1.0 - BB(i)*P(i-1)
P(i) = AA(i) / PODiv(i)
Gam1 = Gam2 
Del1 = Del2 
EAD1 = EAD2 
UA1 = UA2

100 CONTINUE 
RETURN 
END 

C*************** 
SUBROUTINE GetWLoad(NTSfM) 
C******************************************************************************C 
C Since, for now, we know only Q & conc at fall line (i=ML) are known, it is 
C assumed (conc in lateral inflow into segment i) = (conc at the fall line). 
C******************************************************************************C 
INCLUDE 'COM-WQ.INC' 
Data QLat,rN1Lat,rN2Lat,rN3Lat,P1Lat,P2Lat,ChlLat,BODLat, 
* DOLat/9*0.0/ 

Tmp = REAL(NTSfM) / REAL(iFDTL) 
rN1Lat = (DSN1 - ON1)*Tmp + ON1 
rN2Lat = (DSN2 - ON2)*Tmp + ON2 
rN3Lat = (DSN3 - ON3)*Tmp + ON3 
P1Lat = (DSP1 - OP1)*Tmp + OP1 
P2Lat = (DSP2 - OP2)*Tmp + OP2 
ChlLat = (DSChl - OChl)*Tmp + OChl 
BODLat = (DSBOD - OBOD)*Tmp + OBOD 
DOLat = (DSO - OD)*Tmp + OD 
QQ = (DSQ - OQ)*Tmp + OQ 
QLaatUB = QQ / Darea 
DO 10 i=ML,MUL 
IF (i .EQ. ML) THEN 
IF (IUBC .EQ. 1) THEN 
QLat = QQ + QLaatUB*ARD(ML) 
ELSE 
QLat = QLaatUB*ARD(ML) 
END IF 
ELSE 
QLat = QLaatUB*ARD(ML) 
END IF 
WN1(i) = WSN1(i) + QLat*rN1Lat 
WN2(i) = WSN2(i) + QLat*rN2Lat 
WN3(i) = WSN3(i) + QLat*rN3Lat 
WP1(i) = WSPN1(i) + QLat*P1Lat 
WP2(i) = WSPN2(i) + QLat*P2Lat 
WChl(i) = QLat*ChlLat 
WBOD(i) = WSNBOD(i) + QLat*BODLat 
WDO(i) = WSNDO(i) + QLat*DOLat 
10 CONTINUE 
RETURN 
END 

C*************** 
SUBROUTINE WDnBdry 
C******************************************************************************C 
INCLUDE 'COM-WQ.INC' 
Save/OpBdry/, DN1,DN2,DN3,DP1,DP2,DChl,DBOD,DDO,Ncount 
Data Ncount/10000/ 

IF (U(MU) .GE. 0.0) THEN 
NCOUNT = 0 
Change = DTXatDB * U(MU) 
Tmp = 1.0 - Change 
N1(MU) = N1(MU)*Tmp + N1(MUsl)*Change 
N2(MU) = N2(MU)*Tmp + N2(MUsl)*Change 

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\[ N_3(MU) = N_3(MU) \times Tmp + N_3(MUsl) \times \text{Change} \]
\[ P_1(MU) = P_1(MU) \times Tmp + P_1(MUsl) \times \text{Change} \]
\[ P_2(MU) = P_2(MU) \times Tmp + P_2(MUsl) \times \text{Change} \]
\[ Chl(MU) = Chl(MU) \times Tmp + Chl(MUsl) \times \text{Change} \]
\[ CBOD(MU) = CBOD(MU) \times Tmp + CBOD(MUsl) \times \text{Change} \]
\[ DOC(MU) = DOC(MU) \times Tmp + DOC(MUsl) \times \text{Change} \]

ELSE

IF (NCOUNT .GE. MST) THEN
\[ N_1(MU) = DnN_1 \]
\[ N_2(MU) = DnN_2 \]
\[ N_3(MU) = DnN_3 \]
\[ P_1(MU) = DnP_1 \]
\[ P_2(MU) = DnP_2 \]
\[ Chl(MU) = DnChl \]
\[ CBOD(MU) = DnBOD \]
\[ DOC(MU) = DnDO \]
ELSE

IF (NCOUNT .EQ. 0) THEN
\[ DN_1 = (DnN_1 - N_1(MU)) / MST \]
\[ DN_2 = (DnN_2 - N_2(MU)) / MST \]
\[ DN_3 = (DnN_3 - N_3(MU)) / MST \]
\[ DP_1 = (DnP_1 - P_1(MU)) / MST \]
\[ DP_2 = (DnP_2 - P_2(MU)) / MST \]
\[ DChl = (DnChl - Chl(MU)) / MST \]
\[ DBOD = (DnBOD - CBOD(MU)) / MST \]
\[ DDO = (DnDO - DOC(MU)) / MST \]
END IF
ELSE
NCOUNT = NCOUNT + 1
N_1(MU) = N_1(MU) + DN_1
N_2(MU) = N_2(MU) + DN_2
N_3(MU) = N_3(MU) + DN_3
P_1(MU) = P_1(MU) + DP_1
P_2(MU) = P_2(MU) + DP_2
Chl(MU) = Chl(MU) + DChl
CBOD(MU) = CBOD(MU) + DBOD
DOC(MU) = DOC(MU) + DDO
END IF
ENDIF
RETURN
END

C*****

SUBROUTINE Phyto(Hour)
C**********************************************************************
C Calculate growth of phytoplankton, light inhibition, nutrient limiting
C terms and preference for various species of N.
C**********************************************************************
INCLUDE 'COM-WQ.INC'
Data rLite/0.0/
IF (Hour .GT. TU .AND. Hour .LT. TD) THEN
rLite = rIn * SIN( PTT*(Hour-TU) )
DO 750 i=ML,MUsl
IF (N_2(i) .LE. 0.0) THEN
PR_2(i) = 0.0
ELSE
IF (N_3(i) .LE. 0.0) THEN
rNutN = 0.0
ELSE
rNutN = N_3(i) / (N_3(i)+rKmn)
ELSE
IF (N_3(i) .LE. 0.0) THEN
PR_2(i) = 1.0
rNutN = N_2(i) / (N_2(i)+rKmn)
ELSE
ENDIF
ENDIF
ENDIF
ENDIF
\[
PR2(i) = \frac{N2(i) \cdot N3(i)}{(rKmn+N2(i))(rKmn+N3(i))} + \frac{N2(i) \cdot rKmn}{(N2(i)+N3(i))(rKmn+N3(i))}
\]
\[
rNutN = \frac{(N2(i)+N3(i))}{(N2(i)+N3(i)+rKmn)}
\]

END IF
END IF
PR3(i) = 1.0 - PR2(i)
IF (P2(i) \leq 0.0) THEN
rNutP = 0.0
ELSE
rNutP = P2(i) / (P2(i)+rKmp)
END IF
IF (HA(i) > EH) THEN
Depth = EH
ELSE
Depth = HA(i)
END IF
\]
\[
rKe = Turb(i) \cdot Depth
\]
\[
IF (Chl(i) \geq 0.0) rKe = rKe + 0.018 \cdot Chl(i) \cdot Depth
\]
\[
TmpL = rLite \cdot EXP(rKe)
\]
\[
GC(i) = AMIN1(rNutN, rNutP) \cdot \frac{rKgr}{rKe} \cdot (EXP(TmpL) - EXP(rLite))
\]

END IF
END IF
StPR2(i) = 1.0 - StPR2(i)
IF (StP2(i) \leq 0.0) THEN
StNutP = 0.0
ELSE
StNutP = StP2(i) / (StP2(i)+rKmp)
END IF
IF (StH(i) > EH) THEN
Depth = EH
ELSE
Depth = StH(i)
END IF
\]
\[
StKe = Turb(i) \cdot Depth
\]
\[
IF (StChl(i) \geq 0.0) StKe = StKe + 0.018 \cdot StChl(i) \cdot Depth
\]
\[
TmpL = rLite \cdot EXP(StKe)
\]
\[
StGC(i) = AMIN1(StNutN, StNutP) \cdot \frac{rKgr}{StKe} \cdot (EXP(TmpL) - EXP(rLite))
\]

END IF
750 CONTINUE
ELSE
DO 770 i=ML, MUSL
GC(i) = 0.0
StGC(i) = 0.0
770 CONTINUE
END IF
SUBROUTINE EqnDO
C**********************************************************************C
INCLUDE 'COM-WQ.INC'
Parameter (rKro=3.933, ano=4.57)
Dimension O(iX)
Data O/iX*0.0/
C For estuarine part, pass Sal from HYD and use
C : DOS = TDOs + (2.739E-4*S + STDOs)*S
O(MLsl) = UpDO
DOs = TDOs
UH1 = 0.5 * ABS(U(ML)) / HR(ML)
DO 100 i=ML,MUsl
  IF (StSAM(i) .NE. 0.0) THEN
    StKr = TDOaer * WREA(i) / StH(i)
    StNit(i) = rKn23(i) * StN2(i) / (rKh23 + StN2(i))
    StSO = ( (PQ*StGC(i) - DOresp)*StChl(i) - rKc(i)*StBOD(i)
            - ano*StNit(i) + StKr*(DOs-StDO(i)) + BenDO(i)/StH(i) ) * OTO
    DelStVol = StVol(i) - StVolO(i)
    IF (Vol(i) .GT. VolO(i)) THEN
      Sink = DOC(i) * DelStVol
      StDO(i)=StSO+(StDO(i)*StVolO(i)+DOC(i)*DelStVol)/StVol(i)
    ELSE
      Sink = StDO(i) * DelStVol
      StDO(i) = StSO + StDO(i)
    END IF
  ELSE
    Sink = 0.0
  END IF
  UH2 = 0.5 * ABS(U(i+l)) / HR(i+l)
  rKr = TDOaer * (rKro*SQRT(UH1+UH2) + WREA(i))/HA(i)
  UH1 = UH2
  rNit(i) = rKn23(i) * N2(i) / (rKh23 + N2(i))
  SO = ( (PQ*GC(i) - DOresp)*Chl(i) - rKc(i)*CBOD(i) - ano*rNit(i)
        + rKr*(DOs-CBOD(i)) + BenBOD(i)/HA(i) ) * OTO
  CC = ( Dif2(i)*(DOC(i+l)-DOC(i)) - Difl(i)*(DOC(i)-DOC(i-1))*+VolO(i)*StBOD(i)/Vol(i) ) * Div(i)
  StBOD(i)=StSO+(StBOD(i)*StVolO(i)+CBOD(i)*StDO(i)+CC)/Div(i)
100 CONTINUE
DO 200 i=MUsl,ML,-1
  DOC(i) = P(i)*DOC(i+l) + O(i)
200 CONTINUE
RETURN
END
C*************************************************************
SUBROUTINE EqnCBOD
C**********************************************************************C
INCLUDE 'COM-WQ.INC'
Dimension O(iX)
Data O/iX*0.0/
O(MLsl) = UpBOD
DO 100 i=ML,MUsl
  IF (StSAM(i) .NE. 0.0) THEN
    StSO = ( BODdie*StChl(i) - rKc(i)*StBOD(i)
             + (BenBOD(i) - StKbod(i)*StBOD(i))/StH(i) ) * OTO
    DelStVol = StVol(i) - StVolO(i)
    IF (Vol(i) .GT. VolO(i)) THEN
      Sink = CBOD(i) * DelStVol
      StBOD(i)=StSO+(StBOD(i)*StVolO(i)+CBOD(i)*DelStVol)/StVol(i)
    ELSE
      Sink = StBOD(i) * DelStVol
      StBOD(i) = StSO + StBOD(i)
    END IF
  ELSE
    Sink = 0.0
  END IF
100 CONTINUE
DO 200 i=MUsl,ML,-1
  DOC(i) = P(i)*DOC(i+l) + O(i)
200 CONTINUE
RETURN
END
A6-43
ELSE
    Sink = StBOD(i) * DelStVol
    StBOD(i) = StSO + StBOD(i)
END IF
ELSE
    Sink = 0.0
END IF

SO = ( BODdie*Chl(i) + (BenBOD(i) - rKbod(i)*CBOD(i))/HA(i) * rkC(i)*CBOD(i) + WBOD(i)/VolO(i) ) * DTD
CC = ( Dif2(i)*(CBOD(i+1)-CBOD(i)) - Dif1(i)*(CBOD(i)-CBOD(i-1)) * (VolO(i)*SO + CBOD(i) - Sink)/Vol(i) ) / Div(i)
O(i) = (CC + BB(i)*O(i-1)) / PODiv(i)
100 CONTINUE
DO 200 i=MUsl,ML,-1
    CBOD(i) = P(i)*CBOD(i+1) + O(i)
200 CONTINUE
RETURN
END
C***************
SUBROUTINE EqnN3
C**********************************************************************C
INCLUDE 'COM-WQ.INC'
Dimension O(iX)
Data 0/iX*O.O/
O(MLsl) = UpN3
DO 100 i=ML,MUsl
  IF (StSAM(i) .NE. 0.0) THEN
    StSO = ( StNit(i) + (BenN3(i) - StKn33(i)*StN3(i))/StH(i) - an*StPR3(i)*StGC(i)*StChl(i) ) * DTD
    DelStVol = StVol(i) - StVolO(i)
    IF (Vol(i) .GT. VolO(i)) THEN
      Sink = N3(i) * DelStVol
      StN3(i) = StSO + (StN3(i)*StVolO(i)+N3(i)*DelStVol)/StVol(i)
    ELSE
      Sink = StN3(i) * DelStVol
      StN3(i) = StSO + (StN3(i)*StVolO(i)+N3(i)*DelStVol)/StVol(i)
    END IF
  ELSE
    Sink = 0.0
  END IF
100 CONTINUE
DO 200 i=MUsl,ML,-1
    N3(i) = P(i)*N3(i+1) + O(i)
200 CONTINUE
RETURN
END
C***************
SUBROUTINE EqnN2
C**********************************************************************C
INCLUDE 'COM-WQ.INC'
Dimension O(iX)
Data 0/iX*O.O/
O(MLsl) = UpN2
DO 100 i=ML,MUsl
  IF (StSAM(i) .NE. 0.0) THEN
    StSO = ( StNit(i) + (BenN2(i) - StKn33(i)*StN2(i))/StH(i) - an*StPR3(i)*StGC(i)*StChl(i) ) * DTD
    DelStVol = StVol(i) - StVolO(i)
    IF (Vol(i) .GT. VolO(i)) THEN
      Sink = N2(i) * DelStVol
      StN2(i) = StSO + (StN2(i)*StVolO(i)+N2(i)*DelStVol)/StVol(i)
    ELSE
      Sink = StN2(i) * DelStVol
      StN2(i) = StSO + (StN2(i)*StVolO(i)+N2(i)*DelStVol)/StVol(i)
    END IF
  ELSE
    Sink = 0.0
  END IF
100 CONTINUE
DO 200 i=MUsl,ML,-1
    N2(i) = P(i)*N2(i+1) + O(i)
200 CONTINUE
RETURN
END
StHydN(i) = rKn12(i) * StNl(i) / (rKh12 + StNl(i))
StSO = ( StHydN(i) - StNit(i) + BenN2(i)/StH(i) + (CNdie2 - an*StPR2(i)*StGC(i)) * StChl(i) ) * DTD
DelStVol = StVol(i) - StVolO(i)
IF (Vol(i) .GT. VolO(i)) THEN
  Sink = N2(i) * DelStVol
  StN2(i) = StSO + (StN2(i)*StVolO(i)+N2(i)*DelStVol)/StVol(i)
ELSE
  Sink = StN2(i) * DelStVol
  StN2(i) = StSO + StN2(i)
END IF
ELSE
  Sink = 0.0
END IF
HydN(i) = rKn12(i) * N1(i) / (rKh12 + N1(i))
SO = ( HydN(i) - rNit(i) + (CNdie2 - an*PR2(i)*GC(i))*Chl(i) * DTD
     + BenN2(i)/HA(i) + WN2(i)/VolO(i) )
CC = ( Dif2(i)*(N2(i+1)-N2(i)) - Dif1(i)*(N2(i)-N2(i-1))
     + VolO(i)*(SO + N2(i)) - Sink)/Vol(i) ) / Div(i)
O(i) = (CC + BB(i)*O(i-1)) / PODiv(i)
CONTINUE
DO 200 i=MUsl,ML,-1
  N2(i) = P(i)*N2(i+1) + O(i)
CONTINUE
RETURN
END
INCLUDE 'COM-WQ.INC'
Dimension O(ix)
Data O/ix*0.0/

O(MLsl) = UpP2
DO 100 i=ML,MUsl
   IF (StSAM(i) .NE. 0.0) THEN
      StHydP(i) = rKp12(i) * StP1(i) / (rKhpl2 + StP1(i))
      StSO = ( StHydP(i) + (BenP2(i) - StKp22(i)*StP2(i))/StH(i) ) * DTD
      DelStVol = StVol(i) - StVolO(i)
      IF (Vol(i) .GT. VolO(i)) THEN
         Sink = P2(i) * DelStVol
         StP2(i) = StSO + (StP2(i)*StVolO(i)+P2(i)*DelStVol)/StVol(i)
      ELSE
         Sink = StP2(i) * DelStVol
         StP2(i) = StSO + StP2(i)
      END IF
   ELSE
      Sink = 0.0
   END IF
   HydP(i) = rKp12(i) * P1(i) / (rKhpl2 + P1(i))
   SO = ( HydP(i) + (BenP2(i) - rKp22(i)*P2(i))/HA(i) ) * DTD
   CC = ( Dif2(i)*(P2(i+l)-P2(i)) - Difl(i)*(P2(i)-P2(i-1)) ) * DTD
   O(i) = (CC + BB(i)*O(i-1)) / PODiv(i)
   CONTINUE
DO 200 i=MUsl,ML,-1
   P2(i) = P(i)*P2(i+l) + O(i)
200 CONTINUE
RETURN
END

SUBROUTINE EqnPl
*C*******************************************************
INCLUDE 'COM-WQ.INC'
Dimension O(ix)
Data O/ix*0.0/

O(MLsl) = UpPl
DO 100 i=ML,MUsl
   IF (StSAM(i) .NE. 0.0) THEN
      StHydP(i) = rKp12(i) * StPl(i) / (rKhpl2 + StPl(i))
      StSO = ( StHydP(i) + (BenPl(i) - StKp22(i)*StP2(i))/StH(i) ) * DTD
      DelStVol = StVol(i) - StVolO(i)
      IF (Vol(i) .GT. VolO(i)) THEN
         Sink = Pl(i) * DelStVol
         StPl(i) = StSO + (StPl(i)*StVolO(i)+Pl(i)*DelStVol)/StVol(i)
      ELSE
         Sink = StPl(i) * DelStVol
         StPl(i) = StSO + StPl(i)
      END IF
   ELSE
      Sink = 0.0
   END IF
   HydP(i) = rKp12(i) * Pl(i) / (rKhpl2 + P1(i))
   SO = ( HydP(i) + (BenPl(i) - rKp22(i)*P2(i))/HA(i) ) * DTD
   CC = ( Dif2(i)*(Pl(i+l)-Pl(i)) - Difl(i)*(Pl(i)-Pl(i-1)) ) * DTD
   O(i) = (CC + BB(i)*O(i-1)) / PODiv(i)
100 CONTINUE
DO 200 i=MUsl,ML,-1
   P2(i) = P(i)*P2(i+l) + O(i)
200 CONTINUE
RETURN
END
100 CONTINUE
   DO 200 i=MUSl,ML,-1
      Pl(i) = P(i)*Pl(i+1) + O(i)
200 CONTINUE
RETURN
END

C***************
SUBROUTINE EqnChl
C**********************************************************************C
INCLUDE 'COM-WQ.INC'
Dimension O(iX)
Data 0/iX*0.0/

O(MLsl) = UpChl
DO 100 i=ML,MUSl
   IF (StSAM(i) .NE. 0.0) THEN
      stso = (StGC(i) - RespR - GrazR - StKchl/StH(i))*Chl(i) * DTD
      DelStVol = StVol(i) - StVolO(i)
      IF (Vol(i) .GT. VolO(i)) THEN
         Sink = Chl(i) * DelStVol
         StChl(i)=StSO+ (StChl(i)*StVolO(i)+Chl(i)*DelStVol)/StVol(i)
      ELSE
         Sink = StChl(i) * DelStVol
         StChl(i) = StSO + StChl(i)
      END IF
   ELSE
      Sink = 0.0
   END IF
   SO = ( (GC(i) - RespR - GrazR - rKchl/HA(i))*Chl(i) 
      + WChl(i)/VolO(i) ) * DTD
   CC = ( Dif2(i)*(Chl(i+l)-Chl(i)) - Difl(i)*(Chl(i)-Chl(i-1)) 
      + (VolO(i)*(SO + Chl(i)) - Sink)/Vol(i) ) / Div(i)
   O(i) = (CC + BB(i)*O(i-1)) / PODiv(i)
100 CONTINUE
   DO 200 i=MUSl,ML,-1
      Chl(i) = P(i)*Chl(i+1) + O(i)
200 CONTINUE
RETURN
END

C***************
SUBROUTINE Rneg
C**********************************************************************C
INCLUDE 'COM-WQ.INC'

DO 100 i=ML,MU
   IF (Nl(i) .LT. 0.0) THEN
      Nl(i) = 0.0
   END IF
   IF (N2(i) .LT. 0.0) THEN
      N2(i) = 0.0
   END IF
   IF (N3(i) .LT. 0.0) THEN
      N3(i) = 0.0
   END IF
   IF (Pl(i) .LT. 0.0) THEN
      Pl(i) = 0.0
   END IF
   IF (P2(i) .LT. 0.0) THEN
      P2(i) = 0.0
   END IF
   IF (Chl(i) .LT. 0.0) THEN
      Chl(i) = 0.0
   END IF
   IF (CBOD(i) .LT. 0.0) THEN
      CBOD(i) = 0.0
   END IF
   IF (DOC(i) .LT. 0.0) THEN
      DOC(i) = 0.0
   END IF
100 CONTINUE
RETURN
END

C***************
SUBROUTINE Output
C**********************************************************************C
INCLUDE 'COM-WQ.INC'

WRITE(6,('+A30,F13.8,A36')+'***** Concentration (mg/L) at ', 
* TOUT(IncPW), ' days after computation begins *****')
WRITE(6,850)
WRITE(6,840) (i, DistS(i), N1(i), N2(i), N3(i), TN(i), P1(i), P2(i),
* TP(i), Chl(i), CBOD(i), DOC(i), i=ML, MU)
850 FORMAT(/, ' Seg Dist Org-N NH4-N NO3-N Total-N Org-P PO4-P '
* 'Total-P Chl(ug/L) CBOD DO')
840 FORMAT(I2,F8.3,F7.3,F7.4,F7.3,3F7.2)
RETURN
END
C***************
BLOCK DATA Wfirst
C*****************************************************************************C
INCLUDE 'BLKD-WQ.INC'
END
**B6-6. WQPLT.FOR**

```fortran
C******************************************************************************
C SUBROUTINE AvgPLTWQ
C******************************************************************************
C Compute average, max and min over a day.
C******************************************************************************
C INCLUDE 'COM-WQ.INC'
C******************************************************************************
C+++s
Common/WQMM/rN1Min(iX),rN2Min(iX),rN3Min(iX),P1Min(iX),P2Min(iX),
 * Ch1Min(iX),BODMin(iX),DOMin(iX),rN1Max(iX),rN2Max(iX),rN3Max(iX)
 * ,P1Max(iX),P2Max(iX),ChlMax(iX),BODMax(iX),DOMax(iX),AvgN1(iX),
 * AvgN2(iX),AvgN3(iX),AvgP1(iX),AvgP2(iX),AvgChl(iX),AvgBOD(iX),
 * AvgDO(iX),TNMin(iX),TPMin(iX),TNMax(iX),TPMax(iX),AvgTN(iX),
 * AvgTP(iX),AvgNWQ
C+++e
AvgNWQ = AvgNWQ + 1.0
DO 790 i=ML,MU
   AvgN1(i) = AvgN1(i) + N1(i)
   AvgN2(i) = AvgN2(i) + N2(i)
   AvgN3(i) = AvgN3(i) + N3(i)
   AvgTN(i) = AvgTN(i) + TN(i)
   AvgP1(i) = AvgP1(i) + P1(i)
   AvgP2(i) = AvgP2(i) + P2(i)
   AvgTP(i) = AvgTP(i) + TP(i)
   AvgCh1(i) = AvgCh1(i) + Chl(i)
   AvgBOD(i) = AvgBOD(i) + CBOD(i)
   AvgDO(i) = AvgDO(i) + DOC(i)
   IF (N1(i) .LT. rN1Min(i)) rN1Min(i) = N1(i)
   IF (N2(i) .LT. rN2Min(i)) rN2Min(i) = N2(i)
   IF (N3(i) .LT. rN3Min(i)) rN3Min(i) = N3(i)
   IF (TN(i) .LT. TNMin(i)) TNMin(i) = TN(i)
   IF (P1(i) .LT. P1Min(i)) P1Min(i) = P1(i)
   IF (P2(i) .LT. P2Min(i)) P2Min(i) = P2(i)
   IF (TP(i) .LT. TPMin(i)) TPMin(i) = TP(i)
   IF (Chl(i) .LT. ChlMin(i)) ChlMin(i) = Chl(i)
   IF (CBOD(i) .LT. BODMin(i)) BODMin(i) = CBOD(i)
   IF (DO(i) .LT. DOMin(i)) DOMin(i) = DOC(i)
   IF (N1(i) .GT. rN1Max(i)) rN1Max(i) = N1(i)
   IF (N2(i) .GT. rN2Max(i)) rN2Max(i) = N2(i)
   IF (N3(i) .GT. rN3Max(i)) rN3Max(i) = N3(i)
   IF (TN(i) .GT. TNMax(i)) TNMax(i) = TN(i)
   IF (P1(i) .GT. P1Max(i)) P1Max(i) = P1(i)
   IF (P2(i) .GT. P2Max(i)) P2Max(i) = P2(i)
   IF (TP(i) .GT. TPMax(i)) TPMax(i) = TP(i)
   IF (Chl(i) .GT. ChlMax(i)) ChlMax(i) = Chl(i)
   IF (CBOD(i) .GT. BODMax(i)) BODMax(i) = CBOD(i)
   IF (DO(i) .GT. DOMax(i)) DOMax(i) = DOC(i)
790 CONTINUE
RETURN
END
C******************************************************************************
C SUBROUTINE OutPLTWQ(TinDay,iPLTWQ)
C******************************************************************************
C INCLUDE 'COM-WQ.INC'
Common/WQMM/rN1Min(iX),rN2Min(iX),rN3Min(iX),P1Min(iX),P2Min(iX),
 * Ch1Min(iX),BODMin(iX),DOMin(iX),rN1Max(iX),rN2Max(iX),rN3Max(iX)
 * ,P1Max(iX),P2Max(iX),ChlMax(iX),BODMax(iX),DOMax(iX),AvgN1(iX),
 * AvgN2(iX),AvgN3(iX),AvgP1(iX),AvgP2(iX),AvgChl(iX),AvgBOD(iX),
 * AvgDO(iX),TNMin(iX),TPMin(iX),TNMax(iX),TPMax(iX),AvgTN(iX),
 * AvgTP(iX),AvgNWQ
C+++s
Common/PtMeanWQ/PtN1Min(iX),PtN2Min(iX),PtN3Min(iX),PtP1Min(iX),
```
DO 100 i = ML, MU
   PtAvgN1(i) = AvgN1(i) / AvgNWQ
   PtAvgN2(i) = AvgN2(i) / AvgNWQ
   PtAvgN3(i) = AvgN3(i) / AvgNWQ
   PtAvgTN(i) = AvgTN(i) / AvgNWQ
   PtAvgP1(i) = AvgP1(i) / AvgNWQ
   PtAvgP2(i) = AvgP2(i) / AvgNWQ
   PtAvgTP(i) = AvgTP(i) / AvgNWQ
   PtAvgChl(i) = AvgChl(i) / AvgNWQ
   PtAvgBOD(i) = AvgBOD(i) / AvgNWQ
   PtAvgDO(i) = AvgDO(i) / AvgNWQ
   PtN1Max(i) = rN1Max(i)
   PtN2Max(i) = rN2Max(i)
   PtN3Max(i) = rN3Max(i)
   PtTNMax(i) = TNMax(i)
   PtP1Max(i) = P1Max(i)
   PtP2Max(i) = P2Max(i)
   PtTPMax(i) = TPMax(i)
   PtChlMax(i) = ChlMax(i)
   PtBODMax(i) = BODMax(i)
   PtDOMax(i) = DOMax(i)
   PtN1Min(i) = rN1Min(i)
   PtN2Min(i) = rN2Min(i)
   PtN3Min(i) = rN3Min(i)
   PtTNMin(i) = TNMin(i)
   PtP1Min(i) = P1Min(i)
   PtP2Min(i) = P2Min(i)
   PtTPMin(i) = TPMin(i)
   PtChlMin(i) = ChlMin(i)
   PtBODMin(i) = BODMin(i)
   PtDOMin(i) = DOMin(i)
CONTINUE

IF (iPLTWQ.EQ.1 .AND. TinDay.GT.1.5) THEN
   TSWQ = TinDay - 1.0
   WRITE(14,890)*** Daily Average (mg/L) between ' TSWQ, ' to ' ,
   TinDay
   WRITE(14,860)
   WRITE(14,870) (i, DistS(i), PtAvgN1(i), PtAvgN2(i), PtAvgN3(i),
   PtAvgTN(i), PtAvgP1(i), PtAvgP2(i), PtAvgTP(i), PtAvgChl(i),
   PtAvgBOD(i), PtAvgDO(i), i = ML, MU)
   WRITE(14,890)*** Daily Maximum (mg/L) between ', TSWQ, ' to ',
   TinDay
   WRITE(14,860)
   WRITE(14,870) (i, DistS(i), PtN1Max(i), PtN2Max(i), PtN3Max(i),
   PtTNMax(i), PtP1Max(i), PtP2Max(i), PtTPMax(i), PtChlMax(i),
   PtBODMax(i), PtDOMax(i), i = ML, MU)
   WRITE(14,890)*** Daily Minimum (mg/L) between ', TSWQ, ' to ',
   TinDay
   WRITE(14,860)
   WRITE(14,870) (i, DistS(i), PtN1Min(i), PtN2Min(i), PtN3Min(i),
   PtTNMin(i), PtP1Min(i), PtP2Min(i), PtTPMin(i), PtChlMin(i),
   PtBODMin(i), PtDOMin(i), i = ML, MU)
END IF
890 FORMAT(/, A32, F7.2, A4, F7.2)
860 FORMAT(/, ' Seg Dist Org-N NH4-N NO3-N Total-N Org-P PO4-P ',
   'Total-P Chl(ug/L) CBOD DO')
870 FORMAT(I2, F8.3, 5F7.3, F7.4, F7.3, 3F7.2)

AvgNWQ = 0.0
DO 110 i=ML,MU
    AvgN1(i) = 0.0
    AvgN2(i) = 0.0
    AvgN3(i) = 0.0
    AvgTN(i) = 0.0
    AvgP1(i) = 0.0
    AvgP2(i) = 0.0
    AvgTP(i) = 0.0
    AvgChl(i) = 0.0
    AvgBOD(i) = 0.0
    AvgDO(i) = 0.0
    rN1Max(i) = -1.0E4
    rN2Max(i) = -1.0E4
    rN3Max(i) = -1.0E4
    TNMax(i) = -1.0E4
    P1Max(i) = -1.0E4
    P2Max(i) = -1.0E4
    TПMax(i) = -1.0E4
    ChlMax(i) = -1.0E4
    BODMax(i) = -1.0E4
    DOMax(i) = -1.0E4
    rN1Min(i) = 1.0E4
    rN2Min(i) = 1.0E4
    rN3Min(i) = 1.0E4
    TNMin(i) = 1.0E4
    P1Min(i) = 1.0E4
    P2Min(i) = 1.0E4
    TPMin(i) = 1.0E4
    ChlMin(i) = 1.0E4
    BODMin(i) = 1.0E4
    DOMin(i) = 1.0E4
110 CONTINUE
RETURN
END
B6-7. COM-WQ.INC

Parameter (iX=70)
Common/WQV/XA(iX), Vol(iX), VolO(iX), HA(iX), StSAM(iX), DistT(iX), DistS(iX), DX(iX), StVol(iX),
* HA(iX), StSAM(iX), DistT(iX), DistS(iX), DX(iX), StVol(iX),
* StVol0(iX), StH(iX), ARD(iX), Darea,
* Div(iX), AA(iX), BB(iX), Dif1(iX), Dif2(iX), Alpha(iX), CAlpha(iX),
* P(iX), PDiv(iX),
* TOUT(30), ML, MU, ML1, MLS1, MU1, DT, DTD, IncPW, iFDTL, uBEC,
* N1(iX), Stn1(iX), BenN1(iX), WN1(iX), rKn12(iX), xKn12(iX),
* rKn11(iX), StKn11(iX), Upn1, rKh12, TheN12,
* N2(iX), Stn2(iX), PR2(iX), StPr2(iX), BenN2(iX), WN2(iX), rKn23(iX),
* xKn23(iX), Upn2, rKh23, TheN23,
* N3(iX), Stn3(iX), PR3(iX), StPr3(iX), BenN3(iX), WN3(iX), rKn33(iX),
* StKn33(iX), TN(iX), Upn3,
* P1(iX), StP1(iX), BenP1(iX), WP1(iX), rKp12(iX), xKp12(iX), rKp11(iX),
* StKp11(iX), UpP1, rKhP12, TheP12,
* P2(iX), StP2(iX), BenP2(iX), WP2(iX), rKp22(iX), StKp22(iX), TP(iX),
* UpP2,
* Chl(iX), StChl(iX), GC(iX), StGC(iX), WChl(iX), Turb(iX), StNit(iX),
* StHydn(iX), StHydp(iX), rH(iX), Hydn(iX), Hydp(iX), UpChl, rChl,
* StChl, rG, xGr, CDie1, CDie2, CPdie1, CPdie2, ThetaG, ThetaD,
* ThetaR, Resp10, ReepR, Graz20, GrazR, Fp, rFp, rU, rTu, rIn, PTT, rKmn,
* rKsp, rNH,
* CBOD(iX), StBOD(iX), BenBOD(iX), WBOD(iX), rKc(iX), xKc(iX), rKbod(iX),
* StKbod(iX), UpBod, TheBod, BODdie,
* DOC(iX), StDO(iX), BenDO(iX), WDO(iX), WREA(iX), UpDO, Pq, Rq, DOresp,
* TDOae, TheDOae, TDOs, StDOs,
* PSWN1(iX), PSWN2(iX), PSWN3(iX), PSWP1(iX), PSWP2(iX), PSWBOD(iX),
* PSWD(iX), DSQ, DSN1, DSN2, DSN3, DSP1, DSP2, DSCh1, DSbod, DSdo, Oq, On1,
* ON2, ON3, Op1, Op2, OChl, OBOd, OdO,
* ac, ar, an, SkpP, SkpNP, SkpNPC,
* DnN1, DnN2, DnN3, DnP1, DnP2, DnChl, DnBOD, DnDO, DTXatDB, MST
Real N1, N2, N3

B6-8. BLKD-WQ.INC

INCLUDE 'COM-WQ.INC'
Common/WQMM/rN1Min(iX), rN2Min(iX), rN3Min(iX), P1Min(iX), P2Min(iX),
* Ch1Min(iX), BODMin(iX), DOMin(iX), rN1Max(iX), rN2Max(iX), rN3Max(iX)
* , P1Max(iX), P2Max(iX), Ch1Max(iX), BODMax(iX), DOMax(iX), AvgN1(iX),
* AvgN2(iX), AvgN3(iX), AvgP1(iX), AvgP2(iX), AvgChl(iX), AvgBOD(iX),
* AvgDO(iX), AvgNWq
Data Vol, VolO, HA, StSAM, StVol, StVolO, StH, ARD/560*0.0/
Data Div, AA, BB/210*1.0/, Dif1, Dif2/140*0.0/, P/iX*0.0/, IncPW/1/
Data N1/iX*0.1/, Stn1, BenN1, WN1, rKn12/280*0.0/, rKh12/1.0/
Data N2/iX*0.1/, Stn2, BenN2, WP2/210*1.0/
* BenN2, WN2, rKn23/210*0.0/, rKh23/1.0/
Data N3/iX*0.1/, Stn3, BenN3, WN3/350*0.0/, TN/iX*0.0/
Data P1/iX*0.1/, StP1, WP1, rKp12/280*0.0/, rKhP12/1.0/
Data P2/iX*0.1/, StP2, WP2/210*0.0/, TP/iX*0.0/
Data Chl/iX*10.0/, StChl, GC, StCC, WChl/280*0.0/, Turb/iX*1.0/
* StNit, StHydn, StHydp, rNit, Hydn, Hydp/420*0.0/
Data CBOD/iX*2.0/, StBOD, BenBOD, WBOD, rKc, xKc/350*0.0/
Data DOC/iX*7.0/, StDO, BenDO, WDO, WREA/280*0.0/
Data PSWN1, PSWN2, PSWN3, PSWP1, PSWP2, PSWBOD, PSWD/490*0.0/
Data DSQ, DSN1, DSN2, DSN3, DSP1, DSP2, DSCh1, DSbod, DSdo, Oq, ON1, ON2, ON3,
* OP1, OP2, OChl, OBOD, OD0/18*0.0/
Data rN1Min, rN2Min, rN3Min, P1Min, P2Min, Ch1Min, BODMin,
* DOMin/560*1.0E4/, rN1Max, rN2Max, rN3Max, P1Max, P2Max, Ch1Max,
* BODMax, DOMax/560*1.0E4/, AvgN1, AvgN2, AvgN3, AvgP1, AvgP2,
* AvgChl, AvgBOD, AvgDO, AvgNWq/561*0.0/
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Appendix 7.

Model User’s Manual, Include Instructions for Graphic Interface, Preprocessor, and Postprocessor
I. Introduction

The one-dimensional Hydrodynamic-Eutrophication Model (HEM-1D) consists of a hydrodynamic model and a water quality model linked externally. To facilitate its use, a graphic interface has been incorporated into HEM-1D. A Pre-Processor and a Post-Processor were also created for easy editing of some input data and viewing of the model results. The Pre-Processor is applicable only to the steady state application. It provides a menu-driven editing of the most frequently-changed parameters in mode applications.

A model package was created for limited distribution. The package includes four executable files and 12 sample input data files. They are listed in the following:

1) Hydrodynamic Model (HEM-HYD.EXE), which calculates surface elevation, tidal velocity, volume discharge, dispersion coefficient, salinity and dye, and show them in real-time on the screen as the model progresses.

2) Water Quality Model (HEM-WQ.EXE), which calculates ten water quality parameters (dissolved oxygen, carbonaceous biochemical oxygen demand, chlorophyll 'a', organic nitrogen, ammonia nitrogen, nitrite-nitrate nitrogen, total nitrogen, organic phosphorus, inorganic (ortho) phosphorus and total phosphorus), and show them in real-time on the screen as the model progresses.

3) Pre-Processor (HEM-PRE.EXE), which allows limited editing of the input data files for both hydrodynamic and water quality models.

4) Post-Processor (HEM-POST.EXE), which shows the selected model outputs saved from the model runs of hydrodynamic or water quality model on the screen, either in longitudinal or time-series plot.

5) HYD-DEF.IN and WQ-DEF.IN, which are default input data files for hydrodynamic and water quality models, respectively.

6) Eight input data files for time-varying conditions: HYD-CAL.IN, FLOW.IN, TIDE.IN and PSQ.IN for HEM-HYD.EXE and WQ-CAL.IN, NPS.IN, PS.IN and SOLAR.IN for HEM-WQ.EXE.

7) HYD-DI.IN, which is the same as HYD-DEF.IN except for instantaneous dye release while HYD-DEF.IN contains information for continuous release of dye.

8) HYD-DCU.IN, which is the same as HYD-DEF.IN except for ALPHA(i) = 1.0 while HYD-DEF.IN has ALPHA(i) of 0.7: i.e., HYD-DCU.IN contains...
information for continuous dye release with fully upwind difference scheme.
This report explains the new features; graphic interface in both hydrodynamic and water quality models, and Pre- and Post-Processors.

II. Hardware/Software Description

The HEM-1D package is coded in FORTRAN 77, and compiled using Lahey F77L-EM/32. The following three FORTRAN Libraries are used for the user interface; Lahey Graphoria Library, Lahey Spindrift Utility Library and Lahey Spindrift Windows Library.

The HEM-1D package runs on IBM compatible personal computers with 80386 (with math-coprocessor) or with higher CPUs. You must have VGA (or higher resolution) monitor, at least 2 MB of memory, a hard disk with ca. 2 MB for execution files and input data files. The hard disk space required for output files depends upon the model running time and number of segments. For example, output files for 30 day simulation with 62 segments require ca. 13 MB, of which the intermediate binary file (WQ.HYD) uses ca. 11.5 MB.

Note that, because of disk space requirement, you cannot run the HEM-1D package from floppy drives. You should run hydrodynamic model before water quality model to generate WQ.HYD, which water quality model requires as input. You should also run hydrodynamic and water quality models before Post-Processor because the enclosed disk does not contain the output files that Post-Processor requires as input.

III. Hydrodynamic Model (HEM-HYD.EXE)

Hydrodynamic model run may require several data files: for timewise constant conditions, you need only one input file (e.g., HYD-DEF.IN). Each file is specified in the program by a logical unit number as listed in Table A7-1. Input data file organization is explained in detail in Attachment A. The graphic interface of HEM-HYD.EXE is self-explanatory, and a brief description is given in the following.

When you execute HEM-HYD.EXE, you will be first asked to specify the input data file for hydrodynamic model: press ENTER key to use the default input file (HYD-DEF.IN) or type another file name. The conditions used in HYD-DEF.IN, which should
be in the current directory with HEM-HYD.EXE, are listed in Table A7-2. Like HYD-
DEF.IN, the input files, HYD-DI.IN and HYD-DCU.IN, use timewise constant
conditions. However, if you use HYD-CAL.IN for a simulation with time-varying
conditions, the remaining input files, FLOW.IN, TIDE.IN and PSQ.IN, should be in the
current directory with HEM-HYD.EXE. Note that once you specify the input data file,
the existing output files from previous model run in the same directory will be lost,
including the intermediate binary output file (WQ.HYD). This is so whether you
complete the new model run or not. If you want to save the existing output files, you
should move these files to another directory or rename them.

After you specify the input data file, then you will be asked to choose a parameter
for the top plot (Plot #1). The present implementation has 9 choices:

F1: Map (not implemented yet)
F2: Surface Elevation
F3: Discharge
F4: Tidal Velocity
F5: Salinity
F6: Dye Concentration
F7: Dispersion Coefficient
F8: none
ESC: Exit the program

You will be asked one more time with the same menu for the bottom plot (Plot #2). For
graphic interface, the screen is divided into top and bottom parts so that you can examine
two parameters at the same time. If you choose any key between F2 to F6, Plot #1
shows the longitudinal plot of the parameter of your choice at each time step with
different color for each tidal cycle. The bottom plot (Plot #2) shows the longitudinal plot
of the parameter of your choice at each time step with 3 lines of cycle maximum, mean
and minimum for the previous tidal cycle. These cycle mean and range at each tidal
cycle also are written to unit 14 (HYD-PLT.DAT), if iPLT = 1, for later use in Post-
Processor. For the first 3 tidal cycles, both Plot #1 and #2 show the real-time model
calculation only because it takes ca. 3 tidal cycles for the hydrodynamic model to
overcome the effect of initial condition.

In addition to two plots that you choose, the graphic screen shows 1) a clock
showing the progress, 2) time in tidal cycles and 3) a line of menu at the bottom, which
is

(P)ause (R)esume (S)tart (O)ther-plots (Y)scale-change (Q)uit-or-ESC

Pressing P will pause the model run until you press R or any other key. Pressing s
restarts the mode run from the beginning. Pressing o brings you to the previous menu to let you select other parameters to plot. The model continues its run after new selection. Pressing v allows you to change the y-axis scale for both Plot #1 and #2 at any time. You can abort the model run by pressing either q or ESCAPE key. Note that the current output files will be deleted if you abort the model run before its normal termination.

IV. Water Quality Model (HEM-WQ.EXE)

Water quality model run may require several data files: for timewise constant conditions, you need only one input file (e.g., WQ-DEF.IN). Each file is specified in the program by a logical unit number as listed in Table A7-3. Input data file organization is explained in detail in Attachment B. The graphic interface of HEM-WQ.EXE is self-explanatory, and a brief description is given in the following.

When you execute HEM-WQ.EXE, you will be first asked to specify the input data file for water quality model: press ENTER key to use the default input file (WQ-DEF.IN) or type another file name. The conditions used in HYD-DEF.IN, which should be in the current directory with HEM-WQ.EXE, are listed in Table A7-4. If you use WQ-CAL.IN for a simulation with time-varying conditions, the remaining input files, NPS.IN, PS.IN and SOLAR.IN, should be in the current directory with HEM-WQ.EXE. As in the hydrodynamic model, once you specify the input data file, the existing output files from previous model run in the same directory will be lost whether you complete the new model run or not. If you want to save the existing output files, you should move these files to another directory or rename them.

After you specify the input data file, then you will be asked to choose a parameter for the top plot (Plot #1). The present implementation has 13 choices:

- F1: Map (not implemented yet)
- F2: Organic Nitrogen
- F3: Ammonia Nitrogen
- F4: NO2+NO3 Nitrogen
- F5: Total Nitrogen
- F6: Organic Phosphorus
- ESC: Exit the program
- F7: Inorganic Phosphorus
- F8: Total Phosphorus
- F9: Chlorophyll ‘a’
- F10: CBOD
- F11: Dissolved Oxygen
- F12: none

You will be asked one more time with the same menu for the bottom plot (Plot #2). For graphic interface, the screen is divided into top and bottom parts so that you can examine two parameters at the same time. If you choose any key between F2 to F11, Plot #1

A7-4
shows the longitudinal plot of the parameter of your choice at each time step with
different color for each day. The bottom plot (Plot #2) shows the longitudinal plot of the
parameter of your choice at each time step with 3 lines of daily maximum, mean and
minimum for the previous day. These daily mean and range at each day also are written
to unit 14 (WQ-PLT.DAT), if _iPLTWQ_ = 1, for later use in Post-Processor. Once you
choose two parameters for Plot #1 and #2, the screen layout is the same as the
hydrometric model. Both Plot #1 and #2, not to show the unrealistic initial fluctuation
for the first 2 days, show the real-time model calculation only for the first 2 days.

V. Pre-Processor (HEM-PRE.EXE)

The HEM Pre-Processor allows limited editing of the input data files to let you
change some input parameters for both hydrodynamic and water quality models. When
you execute HEM-PRE.EXE, you will be first asked to choose either hydrodynamic or
water quality model, and then to specify the input data file for the chosen model.

If you choose the hydrodynamic model, you will see the following menu:

A) Write WQ.HYD
B) Write HYD-PLT.DAT
C) TMAX
E) NP
F) : TOUT(m)
G) Simulate dye
H) : _IDS_
I) : TDIC
J) : DIC(_IDS_)
K) SPLDM
L) QML2
M) NSPSQ
N) : _IPSQ(n)_
O) : _PSQ_(n)
S) (S)ave changes
D) (D)efault values
P) go to (P)revious menu
Q) (Q)uit program

You can choose each item either by moving cursor key followed by ENTER or by
pressing the first character. The one-line help for each item at the bottom of the screen
explains the meaning of above 18 items. For example, if you choose item D), it will
read and display the values for each of the first 14 items from the default input data file
(HYD-DEF.IN), which should be in the current directory with HEM-PRE.EXE. If you
choose item P), it will bring you back to the model-selection menu.
It should be noted that the Pre-Processor allows limited editing of the input data file: 1) only 14 parameters can be edited here (see Attachment A for the full list of parameters) and 2) only timewise constant conditions (e.g., HYD-DEF.IN) can be edited here. Although the hydrodynamic model can handle both time-varying (e.g., HYD-CAL.IN) and constant boundary conditions for downstream salinity (SFLDM), freshwater discharge (QML2) and point source discharge (PSQ), the Pre-Processor can edit only the timewise constant cases. The program therefore will stop if it finds any one of isatDB, iuatub, iTide and iPSQ equal to 1 (i.e., time-varying conditions). Another limitation is that the Pre-Processor can edit the point dye release only by specifying idye = 1 (instantaneous release) or 2 (continuous release) and by providing values for TDIC and DIC(iDS). The model, however, can handle any dye release, point or distributed. You can edit the input parameters that the Pre-Processor cannot modify using any ASCII editor: the input data file organization for hydrodynamic model is described in detail in Attachment A.

If you choose the water quality model, you will see the following menu:

A) Write WQ-PLT.DAT
B) TMAXWQ
C) NPWQ
E) : TOUTWQ(m)
F) Temperature
G) Ta
H) : TD
I) : TD
J) Downstream BCs
K) Nonpoint source
L) NSPS, iPS(n)
M) : PSL(n), iPS(n)
S) (S)ave changes
D) (D)efault values
P) (P)revious menu
Q) (Q)uit program

Again, the one-line help for each item at the bottom of the screen explains the meaning of above 16 items.

As in the hydrodynamic model, the Pre-Processor allows limited editing of the input data file for water quality model: 1) only 12 parameters can be edited here (see Attachment B for the full list of parameters) and 2) only timewise constant conditions (e.g., WQ-DEF.IN) can be edited here. Although the water quality model can handle both time-varying (e.g., WQ-CAL.IN) and constant conditions for temperature, solar
radiation (Ia, tu and td), downstream boundary conditions, nonpoint source input and point source loading (PsL), the Pre-Processor can edit only the timewise constant cases. The program therefore will stop if it finds any one of iTdep, iSolar, iBC, iNPs and iPs equal to 1 (i.e., time-varying conditions). You can edit the input parameters that the Pre-Processor cannot modify using any ASCII editor: the input data file organization for water quality model is described in detail in Attachment B.

VI. Post-Processor (HEM-POST.EXE)

The Post-Processor lets you examine the model output graphically upon normal completion of model run. The hydrodynamic model generates, if iPLT = 1, a file (HYD-PLT.DAT) containing tidal cycle mean and range throughout the model run. If iPLT=WQ = 1, the water quality model generates WQ-PLT.DAT with daily mean and range throughout the model run. The HEM Post-Processor shows on the screen the model output in HYD-PLT.DAT or WQ-PLT.DAT, in either longitudinal or time-series plot. When you execute HEM-POST.EXE, you will be first asked to choose either hydrodynamic or water quality model, and then to specify the input data file for the chosen model. You can press ENTER key to use the default data files (HYD-PLT.DAT or WQ-PLT.DAT) or type another file name. Whenever you run the hydrodynamic (or water quality) model, if iPLT (or iPLT=WQ) = 1, you have HYD-PLT.DAT (or WQ-PLT.DAT) as an output. If you want to prevent the next model run from overwriting them, you should move the files to another directory or rename them.

If you choose the hydrodynamic model, you will see the following parameter-selection menu:

F1: Surface Elevation
F2: Discharge
F3: Tidal Velocity
F4: Salinity
F5: Dye Concentration
F6: Dispersion Coefficient
ESC: Exit the program

If you choose any key between F1 and F6, the next screen shows a 3-D plot of the parameter of your choice; tidal cycle mean values as functions of distance from mouth and time. As explained at the bottom of the screen, you can move the arrow keys to change segment (or transect) or time. Now, if you press L, a longitudinal plot of tidal
cycle mean and range at the selected time will be shown in the next screen. If you press T, a time-series plot of tidal cycle mean and range at the selected segment will be shown. Pressing o brings you back to the parameter-selection menu, and pressing m brings you back to the model-selection menu. In either longitudinal or time-series plot, there is a line of menu at the bottom, which is

(Y)scale-change (P)revious-screen (O)ther-plots another-(M)odel
ESC-to-quit

Pressing y allows you to change the y-axis scale. Pressing p will bring you back to the previous screen of 3-D plot, and pressing o brings you back to the parameter-selection menu. Pressing m brings you to the model-selection menu. You can exit the Post-Processor by pressing ESCAPE key.

If you choose the water quality model, you will see the following parameter-selection menu:

F1: Organic Nitrogen
F2: Ammonia Nitrogen
F3: NO2+NO3 Nitrogen
F4: Total Nitrogen
F5: Organic Phosphorus
F6: Inorganic Phosphorus
F7: Total Phosphorus
F8: Chlorophyll ‘a’
F9: CBOD
F10: Dissolved Oxygen
ESC: Exit the program

The remaining part is analogous to the hydrodynamic model case.
Table A7-1. Data file organization for hydrodynamic model.

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>LOGICAL UNIT</th>
<th>READ or WRITE</th>
<th>EXAMPLE (REMARK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>general input including geometry, program control parameters and hydrodynamic data</td>
<td>8</td>
<td>read</td>
<td>HYD-DEF.IN or HYD-CAL.IN</td>
</tr>
<tr>
<td>time-varying salinity conditions at the downstream boundary segment</td>
<td>5</td>
<td>read</td>
<td>SALTBC.IN (optional)</td>
</tr>
<tr>
<td>time-varying freshwater discharges at the upstream boundary transect</td>
<td>11</td>
<td>read</td>
<td>FLOW.IN (optional)</td>
</tr>
<tr>
<td>time-varying tidal heights at the downstream boundary segment</td>
<td>12</td>
<td>read</td>
<td>TIDE.IN (optional)</td>
</tr>
<tr>
<td>time-varying point source discharges</td>
<td>13</td>
<td>read</td>
<td>PSQ.IN (optional)</td>
</tr>
<tr>
<td>general model output</td>
<td>6</td>
<td>write</td>
<td>HYD.OUT</td>
</tr>
<tr>
<td>output having tidal range, and time of high water and low water</td>
<td>7</td>
<td>write</td>
<td>TRANGE.OUT</td>
</tr>
<tr>
<td>output having time and salinity at slackwater</td>
<td>10</td>
<td>write</td>
<td>SALT.OUT</td>
</tr>
<tr>
<td>output having tidal cycle maximum, mean and minimum for the entire model run</td>
<td>14</td>
<td>write</td>
<td>HYD-PLT.DAT (optional)</td>
</tr>
<tr>
<td>binary output of hydraulic information used as input for water quality model</td>
<td>9</td>
<td>write</td>
<td>WQ.HYD (optional)</td>
</tr>
</tbody>
</table>

A7-9
Table A7-2. Conditions used in HYD-DEF.IN*.

- The real geometry of the tidal Rappahannock River from the mouth to the fall line (see Table 4-1).
  * ML = 2 and MU = 63

- iSalt = iWQ = iPLT = 1

- Timewise constant boundary conditions
  * iSatDB = 0: SFLDM = 18 psu
  * iUatUB = 0: QML2 = 45.3 m³ sec⁻¹
  * iTide = 0: harmonic M2 tide (Ampl = 18.3 cm and Phase = π/2 radian)
  * iPSQ = 0: point source discharge in m³ sec⁻¹ of (0.0550, 0.0633, 0.134, 0.0888) into 4 segments (3, 4, 5, 9)

- Cold start (i.e., arbitrary initial conditions)

- TMAX = 64.1 tidal cycles
  \( \Delta T = 0.0100644 \) tidal cycles = 7.5 minutes
  \( NP = 1 \)
  \( TOUT = 64.0 \) tidal cycles

- \( Ebase = 1.0 \text{ m}^2 \text{ sec}^{-1} \)
  \( (Vs, Ts, GRVCR, CRi, FEXP) = (63.2, 10^{-5}, 10.0, 4.0, 0.65) \)

- ALPHA(i) = 0.7

- \( rk = 7.5 \cdot 10^{-4} \)

- NS2Sal = 0

- idye = 2 and tDIC = 3.0 day: continuous dye release of 10.0 kg day⁻¹ into km 139 (segment # = 25) starting from 3 days after mode start

* The meaning of parameters are explained in detail in Attachment A.
Table A7-3. Data file organization for water quality model.

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>LOGICAL UNIT</th>
<th>READ or WRITE</th>
<th>EXAMPLE (REMARK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>general input including program control parameters and water quality data</td>
<td>5</td>
<td>read</td>
<td>WQ-DEF.IN or WQ-CAL.IN</td>
</tr>
<tr>
<td>daily varying nonpoint source data</td>
<td>8</td>
<td>read</td>
<td>NPS.IN (optional)</td>
</tr>
<tr>
<td>daily varying point source data</td>
<td>9</td>
<td>read</td>
<td>PS.IN (optional)</td>
</tr>
<tr>
<td>daily varying solar radiation, and time of sunrise and sunset</td>
<td>10</td>
<td>read</td>
<td>SOLAR.IN (optional)</td>
</tr>
<tr>
<td>daily varying boundary conditions for water quality parameters</td>
<td>11</td>
<td>read</td>
<td>BC.IN (optional)</td>
</tr>
<tr>
<td>general model output</td>
<td>6</td>
<td>write</td>
<td>WQ.OUT</td>
</tr>
<tr>
<td>output having daily maximum, mean and minimum for the entire model run</td>
<td>14</td>
<td>write</td>
<td>WQ-PLT.DAT (optional)</td>
</tr>
<tr>
<td>binary input of hydraulic information from hydrodynamic model</td>
<td>7</td>
<td>read</td>
<td>WQ.HYD</td>
</tr>
</tbody>
</table>
Table A7-4. Conditions used in WQ-DEF.IN*.

- The water quality model has been calibrated and verified for the upper 60 km of the tidal Rappahannock River (see Kuo et al. 1991)
  * \( ML = 2 \) and \( MU = 33 \)

- \( \text{iPLTWQ} = 1 \)

- Timewise constant boundary conditions (\( \text{iTdep} = 0 \))
  * \( \text{iBC} = 0: \) (\( \text{DnN}_1, \text{DnN}_2, \text{DnN}_3, \text{DnP}_1, \text{DnP}_2, \text{DnChl}, \text{DnBOD}, \text{DnDO} \)) = (0.492, 0.005, 0.306, 0.039, 0.009, 10.0, 2.0, 7.0) in mg L\(^{-1} \) except \( \text{DnChl} \) in \( \mu g \) L\(^{-1} \)
  * \( \text{iNPS} = 0: \) (\( \text{DSN}_1, \text{DSN}_2, \text{DSN}_3, \text{DSP}_1, \text{DSP}_2, \text{DSChl}, \text{DSBOD}, \text{DSDO} \)) = (0.168, 0.019, 0.183, 0.014, 6.30, 1.88, 8.11) in mg L\(^{-1} \) except \( \text{DSChl} \) in \( \mu g \) L\(^{-1} \)
  * \( \text{iSolar} = 0: \) (\( \text{TRa}, \text{TU}, \text{TD} \)) = (548.4 langleys day\(^{-1} \), 5.5 hr, 19.3 hr)
  * \( \text{iPs} = 0: \) point source input in kg day\(^{-1} \) into 4 segments (3, 4, 5, 9)

<table>
<thead>
<tr>
<th>No.</th>
<th>PSN1</th>
<th>PSN2</th>
<th>PSN3</th>
<th>PSP1</th>
<th>PSP2</th>
<th>PSBOD</th>
<th>PSDO</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>12.66</td>
<td>90.3</td>
<td>3.50</td>
<td>3.31</td>
<td>10.57</td>
<td>125.9</td>
<td>35.5</td>
</tr>
<tr>
<td>4</td>
<td>3.48</td>
<td>44.3</td>
<td>8.13</td>
<td>1.29</td>
<td>0.39</td>
<td>42.2</td>
<td>22.9</td>
</tr>
<tr>
<td>5</td>
<td>10.69</td>
<td>67.0</td>
<td>54.75</td>
<td>6.84</td>
<td>23.04</td>
<td>114.2</td>
<td>103.6</td>
</tr>
<tr>
<td>9</td>
<td>18.23</td>
<td>150.3</td>
<td>7.03</td>
<td>3.22</td>
<td>13.46</td>
<td>208.5</td>
<td>70.3</td>
</tr>
</tbody>
</table>

- Initial conditions = slackwater survey data in 7/5/1990 (see Kuo et al. 1991)

- \( \text{TMAXWQ} = 30.05 \) days
  \( \text{DTD} = 0.0052083 \) days = 7.5 minutes
  \( \text{NTprn} = 1 \)
  \( \text{TOUT} = 30.0 \) days

- Temp = 30.0°C

- All the other coefficients are the calibrated coefficients in Tables 5-2, 5-3, 5-4 and 5-5

* The meaning of parameters are explained in detail in Attachment B.
A-1. Main input data file (logical unit 8)

VARIABLE (FORMAT)
  iSalt, iWQ, iSatDB, iUatUB, iTide, iUBC, iPSQ, iDye (8I5)
iPLT (I5)
  : iSalt = 1 if salinity is to be modeled, otherwise salinity not modeled.
  : iWQ = 1 causes hydrodynamic output to be written in binary format to logical unit 9
    and to be passed to water quality model. Otherwise it is not output.
  : iSatDB = 1 if daily varying salinities are used for the downstream boundary
    conditions (read from unit 5). Otherwise a constant value is read from unit 8
    and kept throughout the model run.
  : iUatUB = 1 if daily varying values are used for the freshwater inflow through the
    upstream boundary (read from unit 11). Otherwise a constant value is read from unit 8
    and kept throughout the model run.
  : iTide = 1 if hourly observation of tidal heights at the mouth are used for the
    downstream boundary conditions (read from unit 12). Otherwise nine tidal amplitudes
    and phases are read in from unit 8 to generate tidal heights by harmonics.
  : iUBC = 1 means that only mass (no momentum) is input from freshwater discharges
    at the upstream boundary; this is so, when the fall line is well developed to create
    supercritical flow at the upstream boundary. Otherwise both mass and momentum are
    input from freshwater discharges.
  : iPSQ = 1 if daily varying values are used for the point source discharges (read from
    unit 13). Otherwise timewise constant values are read in from unit 8 to kept throughout
    the model run.
  : iDye = 1 or 2 simulates a conservative substance (e.g., dye) concentration with
    iDye = 1 for instantaneous release and iDye = 2 for continuous release. Otherwise no
dye simulation.
  : iPLT = 1 opens logical unit 14 and writes tidal cycle maximum, mean and minimum
    every tidal cycle for the entire model run. Otherwise no output to unit 14.
At this point, control passes to subroutine ReadGH.

**ML, MU (2I5)**
- ML = upstream boundary transect number. For proper operation, \( ML \geq 2 \).
- MU = downstream boundary transect number.

Note that **COMMON** and **DIMENSION** statements presently implemented limit \( MU \) to a maximum value of 70.

**Darea (F8.0)**
- drainage area (km²) upstream of the fall line, i.e., at the gauging station at the upstream boundary.

**DistT(i), i=ML,MU (10F8.0)**
- distance (km) from the transect \( i \) to the center of segment \( MU \), i.e., river mouth.

**BCM(i), i=ML,MU (10F8.0)**
- width (m) at mean tide at the transect \( i \).

**XAM(i), i=ML,MU (10F8.0)**
- cross-sectional area in \( 10^3 \) m² at mean tide at the transect \( i \).

**SAM(i), i=ML,MU (10F8.0)**
- surface area (km²) of the main conveyance channel at mean tide at the segment \( i \).

Since \( SAM \) is defined at the center of each segment, we don't need \( SAM(MU) \) which can be set to any number, e.g., 0.

**StSAM(i), i=ML,MU (10F8.0)**
- surface area (km²) of the side storage area at mean tide at the segment \( i \); so,

\[ StSAM(MU) = 0. \]

**VolM(i), i=ML,MU (10F8.0)**
- volume of the main conveyance channel in \( 10^6 \) m³ at mean tide at the segment \( i \);

\[ VolM(MU) = 0. \]

**ARD(i), i=ML,MU (10F8.0)**
- land drainage area (km²) feeding into the segment \( i \), i.e., between the transect \( i \) and \( i+1 \); \( ARD(MU) = 0 \).

**SS(i), i=ML,MU (10F8.0)**
- increase in total width (in m) for each meter increase in surface elevation at the transect \( i \).

**SIDES(i), i=ML,MU (10F8.0)**
- increase in surface area (in m²) for each meter increase in surface elevation at the transect \( i \).
segment i; SIDES(MU) = 0.

DCM(i), i=ML,MU (10F8.0)  
: centroid depth (m) at mean tide at the transect i.

StH(i), i=ML,MU (10F8.0)  
: mean depth (m) of the side storage area at mean tide at the segment i.

Q2(i), i=ML,MU (10F8.0)  
Y2(i), i=ML,MU (10F8.0)  
S2(i), i=ML,MU (10F8.0)  
: initial conditions for volume flow (m$^3$ sec$^{-1}$) through the transect i, and surface
elevation (m) and salinity (psu) at the segment i.

rMan(i), i=ML,MU (10F8.0)  
: Manning's friction coefficient at the transect i.

ALPHA(i), i=ML,MU (10F8.0)  
: weighting factor for advective mass transport at the transect i.

At this point, control comes back to the main program.

TMAX, DTT, NP (2F10.0, I10)  
: TMAX = duration of model run in tidal cycles.
 : DTT = time increment in tidal cycles.
 : NP = number of times during model run to print out the results.

Note that if iPLT = 1, the SUBROUTINE outPLT writes the tidal cycle maximum, mean
and minimum from the beginning till the end of model run (TMAX) to the unit 14, which
the Post-Processor uses to plot either longitudinal or time-series plot.

TOUT(m), m=1,NP (8F10.0)  
: At the time of TOUT(m) tidal cycles from model start, the SUBROUTINE output prints
out,
to unit 6,
 - results at TOUT(m) tidal cycles,
 - time of maximum flood and ebb between TOUT(m)-1 and TOUT(m) tidal cycles,
to unit 7,
 - tidal range, and time of HW and LW between TOUT(m)-1 and TOUT(m) tidal cycles,
and to unit 10,
 - time of, and salinity at, slackwater between TOUT(m)-1 and TOUT(m).
Note that the present model implementation allows the maximum of 30 times of output printing, and that \(0 \leq \text{TOUT}(m) \leq \text{TMAX}\).

**SPT, EPT, iNTS** (2F10.0, I10)
- Start to write binary output (to unit 9) for water quality model from \(\text{SPT}\) (days) till \(\text{EPT}\) (days), every \(\text{iNTS}\) time steps. These may be arbitrarily specified if \(\text{iWQ} \neq 1\).

**Alp, Beta** (2F8.0)
- Implicit weighting factors for surface gradient term in momentum equation and for velocity gradient term in continuity equation, respectively. If \(\text{Alp} = \text{Beta} = 1\), it is a fully implicit scheme.

**WIND** (F8.0)
- Uniform wind stress in dynes cm\(^{-2}\).

**Ebase, Vs, Ts, GRVCR, CRi, FEXP** (6F8.0)
**UT(i), i=ML,MU** (10F8.0)
- Parameters used in the equation for dispersion coefficient (Wilber & Kuo 1987):

\[
E = E_{\text{base}} + \text{Vs} \cdot n \cdot U \cdot R^{5/6} \left[1 + Ts \left(\frac{UT \cdot T}{b}\right)^2\right] + \text{GRVCR} \left[1 + CRi \cdot S \left(\frac{Q_i}{Q}\right)^{FEXP}\right]^4 \left(\frac{\delta S}{\delta x}\right)^2
\]

\[= E_{\text{base}} + E_{\text{shear}} + E_{\text{grav}}\]

where

- \(E_{\text{base}}\) = minimum dispersion coefficient (m\(^2\) sec\(^{-1}\)) at slack tide (ca. 1),
- \(n, R\) = Manning’s friction coefficient and hydraulic radius (m), respectively,
- \(u, s\) = cross-sectionally averaged tidal current velocity (m sec\(^{-1}\)) and salinity (psu), respectively,
- \(Q_i/Q\) = ratio of freshwater inflow to average tidal flow at the mouth.

Note that
- The present model implementation uses the tidal velocity averaged over two tidal
cycles to get the residual flow ($Q_r$). To use averaging period longer than two tidal cycles or to use time step smaller than 0.01 tidal cycles, increase the dimension of $UA$ and $TAVO$ accordingly in the program.

: At the fresh portion of the river, $E_{\text{grav}}$ is always 0 due to the absence of the gravitational circulation. For the project described in Kuo et al. (1991), therefore, $GRVCR$ is set to 0, and only $E_{\text{base}}$, $v_s$ and $T_s$ are calibrated with the field data.

: For stability consideration, $E_{\text{grav}}$ is set to 0 for the first 4 tidal cycles.

$rk$, $Dcay$ (2F8.0)
: $rk$ (proportionality constant relating water density to salinity) = $7.5 \times 10^{-4}$.
: $Dcay$ = first-order decay rate (day$^{-1}$) for dye.

$SatUB$, $DatUB$, $TOFH$ (3F8.0)
: $SatUB$ = salinity (psu) at the upstream boundary.
: $DatUB$ = concentration of dye (ppb) at the upstream boundary. The read-in $DatUB$ will be used only when $iDye = 1$ or 2.
: $TOFH$ = time (hr) required for the salinity at the downstream boundary to reach $SFLDM$ after SBF.

$AMPL(m)$, $PHASE(m)$, $m=1,9$ (2F8.3)
: amplitudes (cm) and phases (radian) for the nine most important tidal components, in the following order: M2, S2, N2, K1, M4, O1, MM, SSA, SA. Regardless of $iTide$, these nine lines of data are read in from unit 8, but if $iTide = 1$, these will not be used in the model calculation.

At this point, control passes to SUBROUTINE $ReadTD$ if $iTide = 1$.

$NS2Sal$ (I5)
$TSIC$ (F8.0)
$SIC(i)$, $i=ML,MU$ (10F8.0)
: $NS2Sal \neq 0$ means that $SIC(i)$ will be used to override the previously specified initial conditions for salinity at $TSIC$ days.
: $TSIC$ = time (in days) to specify the salinity.
: $SIC(i)$ = salinity (psu) at the segment $i$.

Note that these 3 variables are for specifying salinity after the model starts. Regardless of $NS2Sal$, the subsequent 2 variables ($TSIC$ and $SIC(i)$) are read in from unit 8, but if
NS2Sal = 0, these will not be used in the model calculation.

TDIC (F8.0)
DIC(i), i=ML,MU (10F8.0)

: TDIC = time (in days) to start to release dye.

: DIC(i) = amount of dye to be released into the segment i.

DIC(i) is in kg day\(^{-1}\) for continuous release (iDye = 1) or in kg for instantaneous release (iDye = 2). Note that these 2 variables are for dye release after the model starts. Regardless of iDye, the 2 variables are read in from unit 8, but these will be used only when iDye = 1 or 2.

SFLDM, DFLDM, QML2 (3F8.0)

: SFLDM = maximum salinity (psu) at the downstream boundary.

: DFLDM = concentration of dye (ppb) at the downstream boundary.

: QML2 = freshwater discharge (m\(^3\) sec\(^{-1}\)) through the transect ML (i.e., through the upstream boundary transect). Regardless of isatDB, iDye and iUatUB, this line is read in from unit 8, but if isatDB = 1, the read-in SFLDM will not be used. Neither will DFLDM unless iDye = 1 or 2, nor will be QML2 if iUatUB = 1.

NS2 (I5)

: number of segments into which the point source discharges feed.

i, PSQ(i), m=1,NS2 (9X, I5, F10.4) if IPSQ ≠ 1

: i = segment number; ML ≤ i < MU.

: PSQ(i) = time-constant point source discharge (m\(^3\) sec\(^{-1}\)) feeding into segment i.

End of logical unit 8.

A-2. Time-varying point source discharges (logical unit 13)

i, PSQ(i), m=1,NS2 (9X, I5, F10.4)

: If IPSQ = 1, the daily-varying point source discharges, PSQ(i)'s, are read in from a separate file (unit 13). The format is that the first 9 columns are used for the sampling date and ignored when being read, and the next 5 columns are for i (segment number) and the next 10 columns for PSQ(i). NS2 lines are read in everyday.

End of logical unit 13.
A-3. Observed tide input file (logical unit 12)

\[ T_{\text{data}}(n), \; n=1,24 \; \text{(7X, 12F6.2)} \]

: If \( \text{iTide} = 1 \), the subroutine \( \text{ReadTD} \) reads in \( T_{\text{data}}(n) \), for the boundary tidal heights at the segment \( \mu \), from a separate file (unit 12), which contains hourly-measured tidal heights (in ft). The format is that the first 7 columns are used for the sampling date and ignored when reading in \( T_{\text{data}}(n) \), and every line has 12 values \( (12F6.2) \). Two lines are read in everyday. The read-in \( T_{\text{data}}(n) \) is converted into cm and used in the subroutine \( \text{OTide} \) to calculate the tidal heights at the downstream boundary.

End of logical unit 12.

A-4. Time-varying salinity at downstream boundary (logical unit 5)

\[ \text{SFLDM} \; \text{(10X, F10.2)} \]

: If \( \text{iSatDB} = 1 \), the daily-varying SFLDM is read in from a separate file (unit 5). The format is that the first 10 columns are used for identifying the date and ignored when reading in SFLDM, and the next 10 columns for SFLDM. One line is read in everyday.

End of logical unit 5.

A-5. Time-varying freshwater inflow through upstream boundary (logical unit 11)

\[ \text{FDTL} \; \text{(F8.0)} \]
\[ \text{QML2} \; \text{(10X, F10.2)} \]

: If \( \text{iSatUB} = 1 \), the daily-varying QML2 is read in from another separate file (unit 11). FDTL, which is the time lag (in days) to adjust for varying freshwater discharge, occupies 8 columns of the first line, and the rest of the file is for QML2, the format of which is the same as that of logical unit 5.

End of logical unit 11.
VARIABLE (FORMAT)
iTdep, iUBC, iBC, iNPS, iPS, iSolar (6I5)
iPLTWQ (15)

: iTdep = 1 means time-varying water quality input conditions, so that the
SUBROUTINE Input will be called every midnight; If any of iBC, iNPS, iPS, iSolar
equals 1, then iTdep must be 1. Otherwise time constant water quality conditions.

: iUBC = 1 means that only mass is input from freshwater discharge at the upstream
boundary. Otherwise, both momentum and mass fluxes are input from freshwater
discharges.

: iBC = 1 causes the daily-varying boundary conditions for water quality parameters
to be read from logical unit 11. Otherwise constant conditions are read from unit 5 and
kept throughout the model run.

: iNPS = 1 causes the daily-varying nonpoint source data to be read from logical unit
8. Otherwise timewise constant values are read from unit 5 and kept throughout the
model run.

: iPS = 1 causes the daily-varying point source data to be read from logical unit 9.
Otherwise time-constant values are read from unit 5 and kept throughout the model run.

: iSolar = 1 if daily varying values are used for the parameters related to the solar
radiation (from logical unit 10). Otherwise constant values are read from unit 5 and kept
throughout the model run.

: iPLTWQ = 1 opens logical unit 14 and writes daily maximum, mean and minimum
every day for the entire model run. Otherwise no output to unit 14.

At this point, control passes to SUBROUTINE ReadHYDC.

MLH, MUH, DistT, StSAM, ARD, Darea (no format) from unit 7

: MLH = upstream boundary transect number used in hydrodynamic model.
: MUH = downstream boundary transect number in hydrodynamic model.
: DistT = distance (km) from the mouth to each transect.
: StSAM = surface area (m²) of the side storage area at mean tide at each segment.
ARD = land drainage area (km²) feeding into each segment.
Darea = drainage area (km²) upstream of the fall line.

In both hydrodynamic and water quality models, \( \text{stsAM} \) is assumed not to vary with respect to rising and falling tide.

ML, MU (2I5)
upstream (ML) and downstream (MU) boundary transect numbers are re-defined, i.e., read in from unit 5, since the water quality model can be used, depending upon the spatial extent of the area of interest, for any part of the river. The region, however, should be encompassed by the one over which the hydrodynamic model was run (i.e., \( MLH \leq ML < MU \leq MUH \)) since we need the hydrodynamic informations for the physical transport calculations in water quality model.

TMAX, DTD, TfM, NTprn (3F10.0, I10)
TMAX = number of days to run the model.
DTD = time increment in days.
TfM = hours from midnight to model start, which allows us to start the model any time of the day.
NTprn = number of times to print out the results.

Note that if iPLTWQ = 1, the SUBROUTINE OutPLTWQ writes the daily maximum, mean and minimum from the beginning till the end of model run (TMAX) to the unit 14, which the Post-Processor uses to plot either longitudinal or time-series plot.

TOUT(m), m=1,NTprn (10F8.0)
At the time of TOUT(m) days from the midnight of the day of model start, the SUBROUTINE output writes the model results at TOUT(m) days to "WQ.OUT" (unit 6). Note that the clock in the model is the time since the midnight (0000) of the day of model start. Therefore, TMAX is the time duration of model run from 0000 of starting day, not from TfM, and so is TOUT(m), thus, TfM/24 \( \leq \) TOUT(m) \( \leq \) TMAX. The present model implementation allows the maximum of 30 times of output printing.

TOFH, FDTL (2F8.0)
TOFH = time lag (in hours) from SBF to recover downstream boundary conditions.
FDTL = time lag (in days) to adjust for varying freshwater discharge.

Control comes back to the main program and thence to SUBROUTINE ReadWQC.
The N12, The N23, The P12 (3F8.0)
: exponential bases for temperature dependence of rate constants of nitrogen
hydrolysis, nitrification and organic phosphorus mineralization, respectively.

NS2 (I5)
: number of segments for which nutrient transfer coefficients will be read. Setting NS2
= 2 establishes uniform values, otherwise NS2 ≥ MU.

xKn12(i), i=2,NS2 (10F8.0)
xKn23(i), i=2,NS2 (10F8.0)
xKp12(i), i=2,NS2 (10F8.0)
: rates in mg L⁻¹ day⁻¹ for nitrogen hydrolysis, nitrification and organic phosphorus
mineralization rate at 20°C, respectively.

rKh12, rKh23, rKhp12 (3F8.0)
: half-saturation concentrations for nitrogen hydrolysis, nitrification and organic
phosphorus mineralization, respectively, in mg L⁻¹.

NS2 (I5)
: number of segments for which CBOD decay rate(s) will be read. Setting NS2 = 2
establishes uniform values, otherwise NS2 ≥ MU.

xKc(i), i=2,NS2 (10F8.0)
: CBOD decay rate at 20°C in day⁻¹.

The Kc (F8.0)
The DO aer (F8.0)
: exponential bases for temperature correction of CBOD decay rate and DO reaeration,
respectively.

NS2 (I5)
: number of segments for which settling and loss rates in the main conveyance channel
will be specified. Setting NS2 = 2 establishes uniform values, otherwise NS2 ≥ MU.

rKn11(i), i=2,NS2 (10F8.0)
rKn33(i), i=2,NS2 (10F8.0)
rKp11(i), i=2,NS2 (10F8.0)
rKp22(i), i=2,NS2 (10F8.0)
rKbod(i), i=2,NS2 (10F8.0)
: organic nitrogen settling rate, denitrification rate (nitrate loss coefficient), and
settling rates of organic phosphorus, inorganic phosphorus and CBOD in the main
channel, respectively, in m day⁻¹.

NS2 (I5)
: number of segments for which settling and loss rates in the side storage area will be
specified. Setting NS2 = 2 establishes uniform values, otherwise NS2 ≥ MU.
: organic nitrogen settling rate, denitrification rate (nitrate loss coefficient), and settling rates of organic phosphorus, inorganic phosphorus and CBOD in the side storage area, respectively, in m day\(^{-1}\).

\[
\begin{align*}
ac, an, ap, ar, PQ, RQ, rKmn, rKmp, xKgr, rIs, rKchl, StKchl, Resp20, Graz20, Fn, Fp, \text{ThetaG, ThetaR, ThetaD, EH} (10F8.0) \\
\end{align*}
\]

: \(ac, an, ap\) = carbon/chlorophyll (mg C per µg Chl), nitrogen/chlorophyll (mg N per µg Chl), phosphorus/chlorophyll (mg P per µg Chl) ratios, respectively, in algal biomass (typically 0.05, 0.007 and 0.001, respectively).

: \(ar\) = proportion of consumed phytoplankton recycled by zooplankton.

: \(PQ\) = ratio of oxygen produced to carbon fixed (moles O\(_2\) per mole C).

: \(RQ\) = ratio of CO\(_2\) liberated to oxygen consumed (moles CO\(_2\) per mole O\(_2\))

: \(rKmn, rKmp\) = half-saturation constants for growth limitation due to nitrogen and phosphorus, respectively, in mg L\(^{-1}\).

: \(xKgr\) = optimum growth rate at 20\(^\circ\)C in day\(^{-1}\).

: \(rIs\) = saturation light intensity in langley\(s\) day\(^{-1}\).

: \(rKchl, StKchl\) = phytoplankton settling rates (in m day\(^{-1}\)) in the main conveyance channel and in the side storage area, respectively.

: \(Resp20\) = endogenous respiration rate at 20\(^\circ\)C in day\(^{-1}\).

: \(Graz20\) = grazing and other mortality rate at 20\(^\circ\)C in day\(^{-1}\).

: \(Fn, Fp\) = fraction of metabolically produced nitrogen and phosphorus, respectively, recycled to the organic pool.

: \(\text{ThetaG, ThetaR, ThetaD}\) = exponential bases for temperature adjustment of growth rate, respiration rate, and grazing and other mortality rate, respectively.

: \(EH\) = euphotic depth (m). The algal growth is assumed to occur only at the surface layer and EH, which needs to be calibrated, specifies the depth of the surface layer.

At this point, control comes back to the main program and thence to SUBROUTINE Init.

\[
N1(i), \ i=ML,MU (10F8.0)
\]
N2(i), i=ML,MU (10F8.0)
N3(i), i=ML,MU (10F8.0)
P1(i), i=ML,MU (10F8.0)
P2(i), i=ML,MU (10F8.0)
Chl(i), i=ML,MU (10F8.0)
CBOD(i), i=ML,MU (10F8.0)
DOC(i), i=ML,MU (10F8.0)

: initial conditions (in mg L\(^{-1}\) except Chl in \(\mu g\) L\(^{-1}\)) for organic nitrogen (N1), ammonia nitrogen (N2), nitrate-nitrate nitrogen (N3), organic phosphorus (P1), ortho-phosphorus (P2), chlorophyll 'a' (Chl), carbonaceous biochemical oxygen demand (CBOD) and dissolved oxygen (DOC), respectively.

Alpha(i), i=ML,MU (10F8.0)
: interpolation factors for weighting of upstream flow in mass transport calculations.
Note that Alpha(ML) is always 1 (see the boundary conditions in subroutine Input for detailed explanation).

Control, at this point, passes to subroutine GetHYD.

XA, Vol, U, E, HR, Sat, StVol, DSQ (no format) from unit 7
: XA = cross-sectional area (m\(^2\)) at each transect.
: Vol = volume (m\(^3\)) of the main conveyance channel at each segment.
: U = current velocity (m sec\(^{-1}\)) at each transect.
: E = dispersion coefficient (m\(^2\) sec\(^{-1}\)) at each transect.
: HR = hydraulic radius (m) at each transect.
: Sat = surface area (m\(^2\)) of the main conveyance channel at each segment.
: StVol = volume of the side storage area (m\(^3\)) at each segment.
: DSQ = freshwater discharge (m\(^3\) sec\(^{-1}\)) through the transect ML (i.e., through the upstream boundary transect).

Control comes back to the main program and thence to subroutine Input.

Title (A50)
: alpha information describing the input data that follow. The date at which the data are read in, can be an example of Title.
NDG, NS2 (2I5)
: $\text{NDG} =$ integer identifying a particular data group. There are 8 possible data groups.
: $\text{NS2} =$ number of values to be read.

1) If $\text{NDG} = 1$, then boundary conditions

$\text{UpN1, UpN2, UpN3, UpP1, UpP2, UpCh1, UpBOD, UpDO}$
$\text{DnN1, DnN2, DnN3, DnP1, DnP2, DnCh1, DnBOD, DnDO}$

- format is $(11X, 8F8.0)$ if $\text{iBC} = 1$ (daily-varying conditions), from unit 11
- format is $(10F8.0)$ if $\text{iBC} \neq 1$ (timewise constant conditions), from unit 5

: upstream and downstream boundary conditions in mg L$^{-1}$ (except Chl in µg L$^{-1}$). $\text{NS2}$ for this group can be any arbitrary number.

Note that

: Even if $\text{iBC} = 1$, the general input file (unit 5) should have a line containing $\text{NDG}$ and $\text{NS2}$ whenever boundary conditions need to be updated. Actual values are read from a separate file (unit 11). The format is that the first 11 columns are used for the sampling date and ignored when being read in, and then every line has 8 values ($8F8.0$). Two lines are read in everyday, one line for each upstream and downstream conditions.

: For the freshwater discharge through the upstream boundary, the present model implementation can take care of two different cases; only the mass input ($\text{iUBC} = 1$) or both momentum and mass fluxes ($\text{iUBC} \neq 1$) from discharge. When $\text{iUBC} = 1$, the mass input from freshwater discharge will be incorporated by being treated as nonpoint source and by not including the advective transport through the upstream boundary transect. This can be done by setting the upstream boundary conditions to zero, and $\text{Alpha(ML)}$ can be any value. When $\text{iUBC} \neq 1$, the freshwater discharge will be treated as the advective flux through the upstream boundary, and thus $\text{Alpha(ML)}$ should be 1.

2) If $\text{NDG} = 2$, then point source input from unit 9 if $\text{iPS} = 1$, or

from unit 5 if $\text{iPS} \neq 1$

$i, \text{PSN1, PSN2, PSN3, PSP1, PSP2, PSBOD, PSDO, m=1, NS2} \ (9X, I5, 7F7.3)$
: \( i \) = segment number; \( ML \leq i < MU \).

: \( PSN1 \) to \( PSDO \) = waste loads (in kg day\(^{-1}\)) from point source(s).

Even if \( iPS = 1 \), the general input file (unit 5) should have a line containing \( NDG \) and \( NS2 \) whenever point source data need to be updated. Actual values are read from unit 9. The format in both unit 5 (\( iPS \neq 1 \)) and unit 9 (\( iPS = 1 \)) is that the first 9 columns are used for the identifying alpha information (the sampling date, for example, when \( iPS = 1 \)) and ignored when being read in. Then, every line has 7 values (7F7.3) preceded by an integer (I5) denoting the segment number into which the point source waste load feeds. \( NS2 \) lines are read in everyday.

3) If \( NDG = 3 \), then nonpoint source input from unit 8 if \( INPS = 1 \), or from unit 5 if \( INPS \neq 1 \)

\( xDSQ, DSN1, DSN2, DSN3, DSP1, DSP2, DSChl, DSCBOD, DSDO \) (9X, 8F7.3)

: \( xDSQ \) = freshwater discharge (\( m^3 \) sec\(^{-1}\)) through the transect \( ML \).

: \( DSN1 \) to \( DSDO \) = concentrations in mg L\(^{-1}\) (except DSChl in \( \mu g \) L\(^{-1}\)).

Note that

: \( NS2 \) for this group can be any arbitrary number.

: Even if \( INPS = 1 \), the general input file (unit 5) should have a line containing \( NDG \) and \( NS2 \) whenever nonpoint source data need to be updated. Actual values are read from unit 8. The format in both unit 5 (\( INPS \neq 1 \)) and unit 8 (\( INPS = 1 \)) is that the first 9 columns are used for the identifying alpha information (the sampling date, for example, when \( INPS = 1 \)) and ignored when being read in. Every line has 8 values (8F7.3).

: The values passed from the hydrodynamic model (from unit 7) are used for freshwater discharges to avoid potential inconsistency. The discharges (\( xDSQ \)) read in here are for information purpose only, and not used in model calculation.
4) If \( \text{NDG} = 4 \), then benthic fluxes

\[
\begin{align*}
\text{xBenN}_1(i), \ i = \text{ML}, \text{MU} & \quad (10F8.0) \\
\text{xBenN}_2(i), \ i = \text{ML}, \text{MU} & \quad (10F8.0) \\
\text{xBenN}_3(i), \ i = \text{ML}, \text{MU} & \quad (10F8.0) \\
\text{xBenP}_1(i), \ i = \text{ML}, \text{MU} & \quad (10F8.0) \\
\text{xBenP}_2(i), \ i = \text{ML}, \text{MU} & \quad (10F8.0) \\
\text{xBenBOD}(i), \ i = \text{ML}, \text{MU} & \quad (10F8.0) \\
\text{xBenDO}(i), \ i = \text{ML}, \text{MU} & \quad (10F8.0) \\
\text{TBN}_1, \text{TBN}_2, \text{TBN}_3, \text{TB}_1, \text{TB}_2, \text{TBOD}, \text{TBDO} & \quad (10F8.0)
\end{align*}
\]

: \( \text{xBenN}_1 \) to \( \text{xBenDO} \) = benthic exchange rates at 20°C in g m\(^{-2}\) day\(^{-1}\).

: \( \text{TBN}_1 \) to \( \text{TBDO} \) = exponential bases for temperature adjustment.

Note that negative values are losses to sediment and positive values are sources from sediment. Whenever updating the benthic exchange rates, since they need to be adjusted for temperature, the data group 7 (temperature) should also be read in. \( \text{NS}_2 \) for this group can be any arbitrary number.

5) If \( \text{NDG} = 5 \), then turbidity

\[
\begin{align*}
\text{Turb}(i), \ i = \text{ML}, \text{MU} & \quad (10F8.0)
\end{align*}
\]

: light extinction coefficient (m\(^{-1}\)). \( \text{NS}_2 \) for this group is arbitrary.

6) If \( \text{NDG} = 6 \), then wind reaeration

\[
\begin{align*}
\text{WREA}(i), \ i = \text{ML}, \text{MU} & \quad (10F8.0)
\end{align*}
\]

: coefficient for wind reaeration (m day\(^{-1}\)). \( \text{NS}_2 \) for this group is arbitrary.

7) If \( \text{NDG} = 7 \), then temperature

\[
\text{Temp} \quad (F8.0)
\]

: Note that this data group must be read after data group 4 (bottom exchanges, including sediment oxygen demand) and CBOD decay rate in subroutine \text{ReadwQc}, since these parameters must be temperature-adjusted. \( \text{NS}_2 \) for this group can be any arbitrary number.

8) If \( \text{NDG} = 8 \), then sunlight parameters

from unit 10 if \( \text{iSolar} = 1 \), or
from unit 5 if \( \text{iSolar} \neq 1 \)

\[
\begin{align*}
\text{rI}_a, \text{TU}, \text{TD} & \quad (9X, 3F10.0) \quad \text{if NS}_2 = 1, \\
\text{rI}_a & \quad (9X, F10.0) \quad \text{if NS}_2 \neq 1,
\end{align*}
\]

: \( \text{rI}_a \) = total solar radiation over one day (langleys day\(^{-1}\)).
\( \text{TU, TD} = \text{hours from midnight to sunrise and sunset, respectively.} \)

Note that

\( i_{\text{Solar}} \neq 1, \) since this data group is executed only once and we need \( \text{TU} \) and \( \text{TD} \) as well as \( r_{\text{IA}} \), \( \text{NS2} \) should be 1. The format is that the first 9 columns are used for the identifying alpha information and ignored when being read in, and followed by 3 values \((3F10.0)\).

\( i_{\text{Solar}} = 1, \) the general input file (unit 5) should have a line containing \( NDG \) and \( NS2 \) whenever solar parameters need to be updated. Actual values are read from unit 10. \( NS2 = 1 \) means that all 3 parameters will be updated, whereas only \( r_{\text{IA}} \) will be read in if \( NS2 
eq 1 \). The format is that the first 9 columns are used for the sampling date and ignored when being read in, and every line has 3 values \((3F10.0)\) if \( NS2 = 1 \), or 1 value \((F10.0)\) if \( NS2 
eq 1 \). One line is read in everyday. Even when \( i_{\text{Solar}} = 1, \text{NS2} \) should be 1 at the first call of SUBROUTINE Input.

If \( NDG = 99, \) exit from SUBROUTINE Input.

Note that if \( iT_{\text{dep}} = 1, \) SUBROUTINE Input will be called every midnight.
Appendix 8.

Sample Input Data File
This appendix lists 2 sample input data files: HYD-DEF.IN and WQ-DEF.IN.

A8-1. HYD-DEF.IN

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| 151.739 | 150.711 | 149.683 | 148.656 | 147.628 | 146.599 | 145.571 | 144.543 |
| 143.515 | 142.487 | 141.459 | 140.431 | 139.403 | 138.375 | 137.347 | 136.319 |
| 135.291 | 134.263 | 133.235 | 132.207 | 131.179 | 130.151 | 129.123 | 128.095 |
| 127.067 | 126.039 | 125.011 | 123.983 | 122.955 | 121.927 | 120.899 | 119.871 |
| 118.843 | 117.815 | 116.787 | 115.759 | 114.731 | 113.703 | 112.675 | 111.647 |
| 102.395 | 101.367 | 100.339 | 99.311 | 98.283 | 97.255 | 96.227 | 95.199 |
| 94.171 | 93.143 | 92.115 | 91.087 | 90.059 | 89.031 | 88.003 | 86.975 |
| 85.947 | 84.919 | 83.891 | 82.863 | 81.835 | 80.807 | 79.779 | 78.751 |
| 77.723 | 76.695 | 75.667 | 74.639 | 73.611 | 72.583 | 71.555 | 70.527 |
| 69.499 | 68.471 | 67.443 | 66.415 | 65.387 | 64.359 | 63.331 | 62.303 |
| 61.275 | 60.247 | 59.219 | 58.191 | 57.163 | 56.135 | 55.107 | 54.079 |
| 53.051 | 52.023 | 51.995 | 50.967 | 49.939 | 48.911 | 47.883 | 46.855 |
| 45.827 | 44.799 | 43.771 | 42.743 | 41.715 | 40.687 | 39.659 | 38.631 |
| 37.603 | 36.575 | 35.547 | 34.519 | 33.491 | 32.463 | 31.435 | 30.407 |
| 4.708 | 3.680 | 2.652 | 1.624 | 0.696 | 0.668 | 0.640 | 0.612 |
| 0.584 | 0.556 | 0.528 | 0.500 | 0.472 | 0.444 | 0.416 | 0.388 |
| 0.360 | 0.332 | 0.304 | 0.276 | 0.248 | 0.220 | 0.192 | 0.164 |
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*** Constant Inputs for Design Flow ***
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Point sources
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Design
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5 10.687 67.00 54.750 6.837 23.041 114.16 103.60
9 18.233 150.32 7.027 3.218 13.464 208.49 70.30
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Design
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18 : Benthic and aerial fluxes
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6  1: Wind-induced reaeration

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7  1: Temperature

30.0

8  1: Solar radiation parameters

Design:  548.392  5.5  19.3