A DYNAMIC RIVER BASIN WATER QUALITY MODEL

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John Yearsley
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MODEL DEVELOPMENT

1.1 Introduction

Knowledge of the physical, chemical and biological processes, acquired from laboratory and field studies, has greatly increased our understanding of aquatic ecosystems. In the case of some state variables which characterize these ecosystems, the knowledge has reached a level at which it is possible to describe important features of the ecosystem in terms of mathematical relationships. For those processes which can be described in these terms, simulation of water quality with mathematical models can be a useful tool for water resource planning. These relationships are developed by combining the empirical results and concepts from the field and laboratory with the fundamental laws of conservation of energy, momentum and mass. Formulation of these relationships leads to the equations for a mathematical model.

In their most general form, the equations developed to describe aquatic ecosystems are extremely difficult to solve. However, by limiting the range of the analysis to certain time and length scales and by using numerical methods, it is possible to obtain approximate solutions to such equations . The limitations in the model are invoked by making certain assumptions. While invoking assumptions may make the solution of the equations more tractable, it will also limit the range of applications of the model. It is, therefore, important for those using the model to understand both the capabilities and the limitations of an ecosystem model.

The model described in this report makes use of ecosystem concepts which have been used in other modelling efforts (e.g., Thomann et al., 1975;

Patten et al., 1975., DiToro et al., 1975; Chen and Orlob, 1975; Scavia, 1980). Based upon these concepts, the mathematical model described in this report has been developed to simulate the following state variables:

(1) Carbonaceous biological oxygendemand
(2) Dissolved oxygen
(3) Algal biomass
(4) Organic nitrogen
(5) Ammonia nitrogen
(6) Nitrite + nitrate nitrogen
(7) Organic phosphorus
(8) Orthophosphorus
(9) Temperature
(10) Coliform bacteria
(11) Conservative constituent #1
(12) Conservative constituent #2

The hydrologic setting is that of a river basin within which there can be free-flowing river segments, river-run reservoirs and stratified reservoirs (Figure 1.1). The model simulates the time history of the ecologic state variables dynamically for time scales of hours and greater. Length scales of computational segments can be of the order of 100's of feet longitudinally and 5-10 feet vertically. The ability of the model to resolve changes at these time and length scales depends, of course, on the availability of appropriate data, as well as on the structural accuracy of the model.

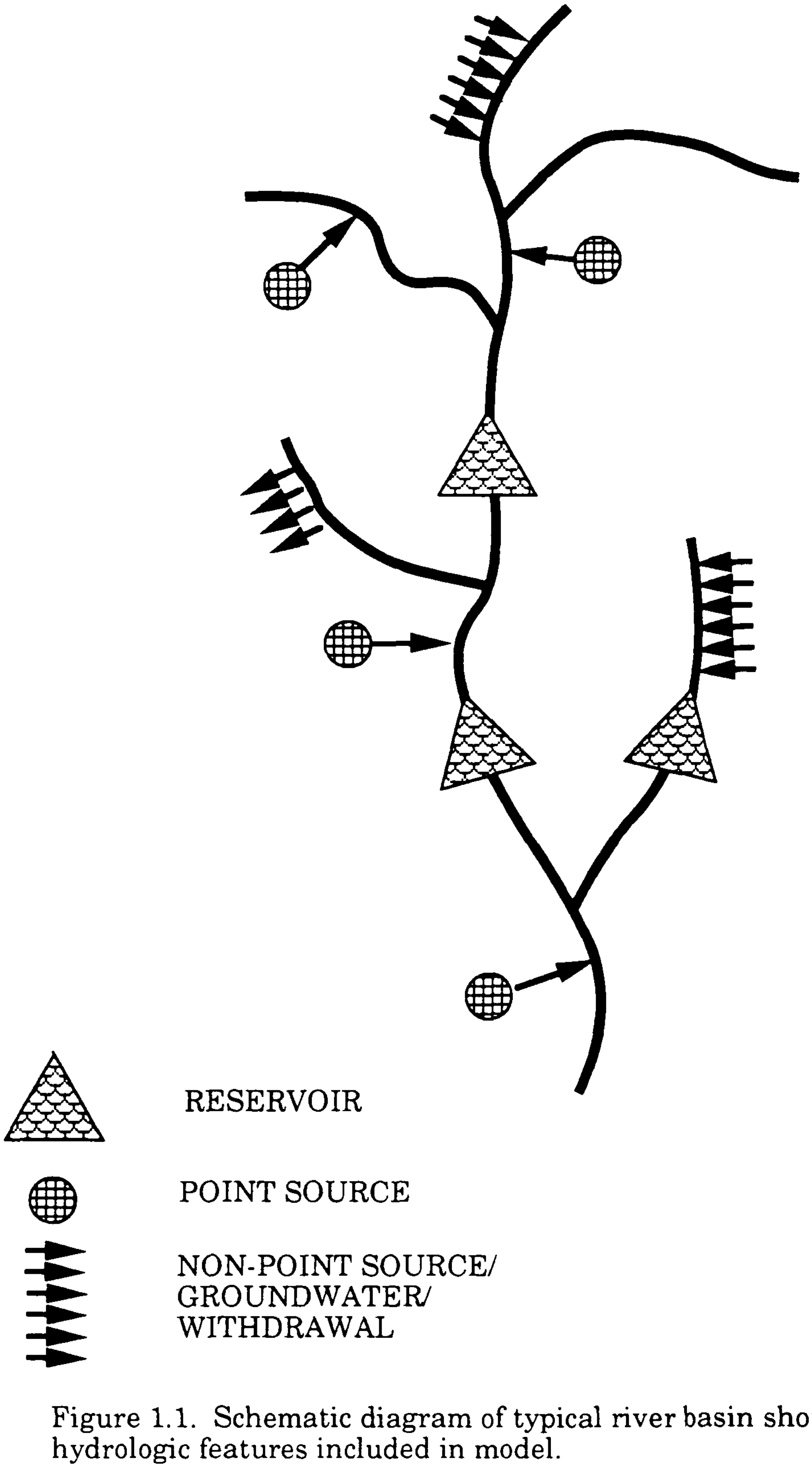

Figure 1.1. Schematic diagram of typical river basin shown major hydrologic features included in model.

1.2 Mathematical Development

The proper application of a mathematical model requires a knowledge of the model's capabilities and limitations. These limitations are determined by the assumptions upon which the model has been based. The general assumptions associated with this model are:

- Horizontal and vertical advection and vertical eddy diffusion are the primary physical processes for water and mass transport

- The vertical eddy diffusivity is the same for all state variables

- The lateral variations of properties in the waterbodies are negligible compared to longitudinal and vertical variations of the properties

- Rate constants for the various reactions do not change over a given length segment

- Hydrodynamic characteristics are a function of the stream , river, or reservoir geometry, only

- The river system can be divided into a finite number of segments within which hydrodynamic characteristics are constant

- Hydrodynamic characteristics of free-flowing river segments and river-run reservoirs can be expressed as a simple function of the flow in any segment

- Hydrodynamic characteristics of stratified reservoir segments are a function of the density structure of the reservoir

- The time required for flow in a reach to adjust to changes in elevation is small compared to the travel time of some constituent. Another way of viewing this is in terms of the speed of the gravity wave carrying elevation information compared to the average river velocity.

- Simulated state variables of the ecosystem are averages over a given computational element (Figure 1.2 for free-flowing rivers or river-run reservoirs and Figure 1.3 for stratified reservoirs) and a finite time interval

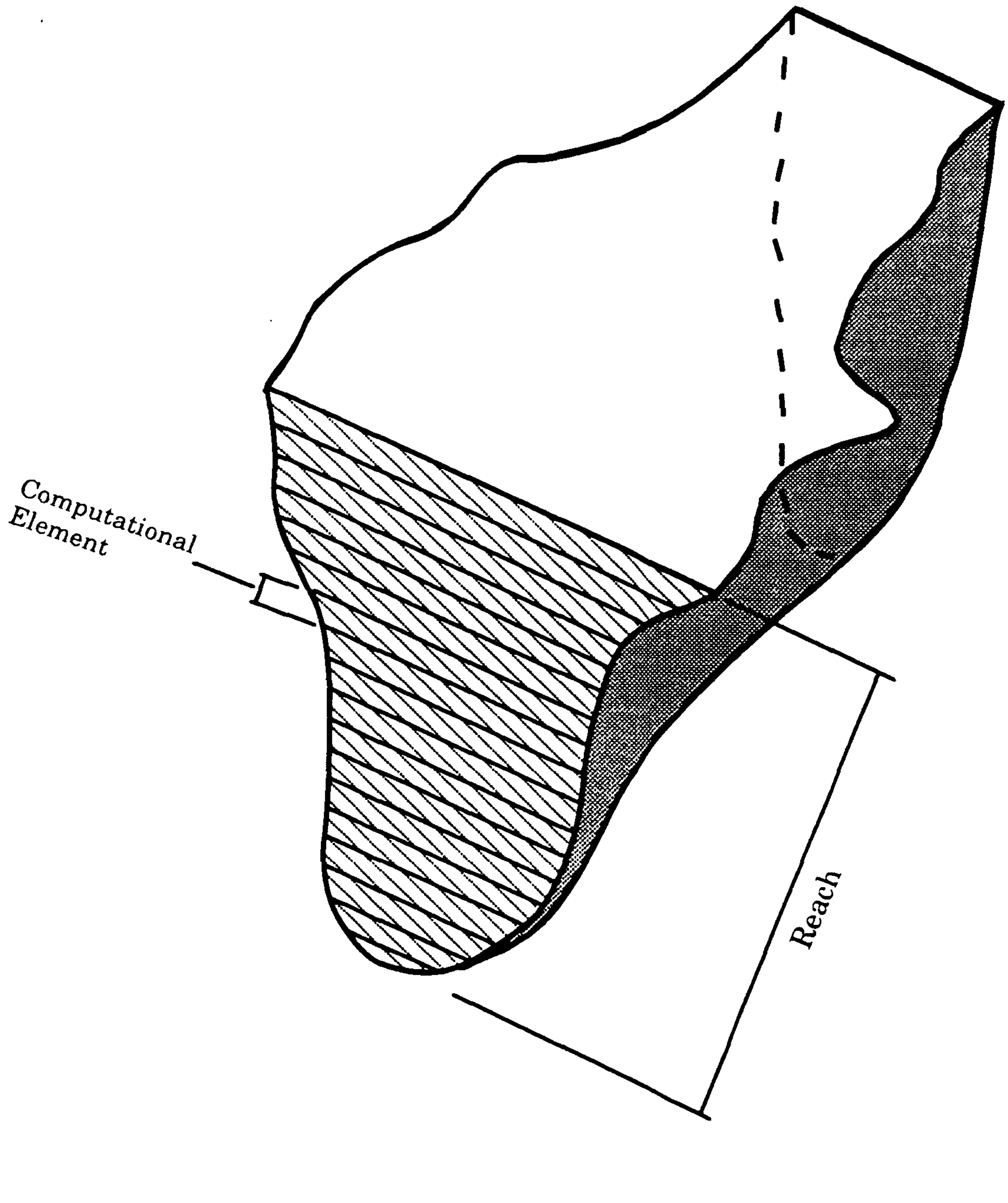

Figure 1.3. Segmentation scheme for stratified reservoir showing typical reach and typical computational element.

For some state variable, C, which is time- and length-averaged over a computational element, the general conservation equation in the ijth free-flowing river or river-run reservoir segment can be written as:

$$\frac{d(CV)_i}{dt} = \Delta(QC)_x + \sum_{n=1}^{N_s} (Q_p C_p)_n + \Phi_i - \Gamma_i \tag{1.1a}$$

Similarly, for the ijth stratified reservoir segment, the general conservation equation is

$$\frac{d(CV)_{ij}}{dt} = \Delta(QC)_x + \Delta(QC)_z + \Delta(KAC)_z + \sum_{n=1}^{N_s} (Q_p C_p)_n + \Phi_{ij} - \Gamma_{ij} \tag{1.1b}$$

where,

V = the volume of the ijth computational element where i refers to the segment number and j to the computational element number within the segment,

C = the length- and time-averaged value of some state variable over the ijth computational element,

$\Delta(QC)_x$ = the advective transfer in the longitudinal (x-) direction,

$\Delta(QC)_z$ = the advective transfer in the vertical (z-) direction,

$\Delta(QC)_n$ = the transfer of flows from the computational element due to inputs or outputs such as point source discharges, non-point source return flows and withdrawals for drinking water or irrigation,

$\Delta(KAC)_z$ = the eddy diffusion in the vertical (z-) direction,

A = the surface area of the ij^{th} element,

Φ_{ij} = the source term for the state variable, C_{ij},

Γ_{ij} = the sink term for the state variable, C_{ij}.

For all state variables, gains and losses due to the physical processes of advection and eddy diffusion are treated in the same manner. The source, Φ_{ij}, and sink, Γ_{ij}, for each of the state variables are determined from existing knowledge of physical, chemical and biological processes. A flow diagram of the interaction among state variables is shown in Figure 1.4. A complete description of the source and sink terms in the mass balance of each state variable is given below.

Carbonaceous Biological Oxygen Demand (CBOD), C_1

The major sink term for (CBOD) included in this model is the following:

- Stabilization of CBOD by microorganisms

The stabilization of CBOD is represented by a first-order, temperature-dependent process. The differential equation for the mass balance, excluding the physical processes of advection and diffusion, is as follows:

$$\frac{d(C_1 V)}{dt} = - K_1 C_1 V \qquad (1.2)$$

where,

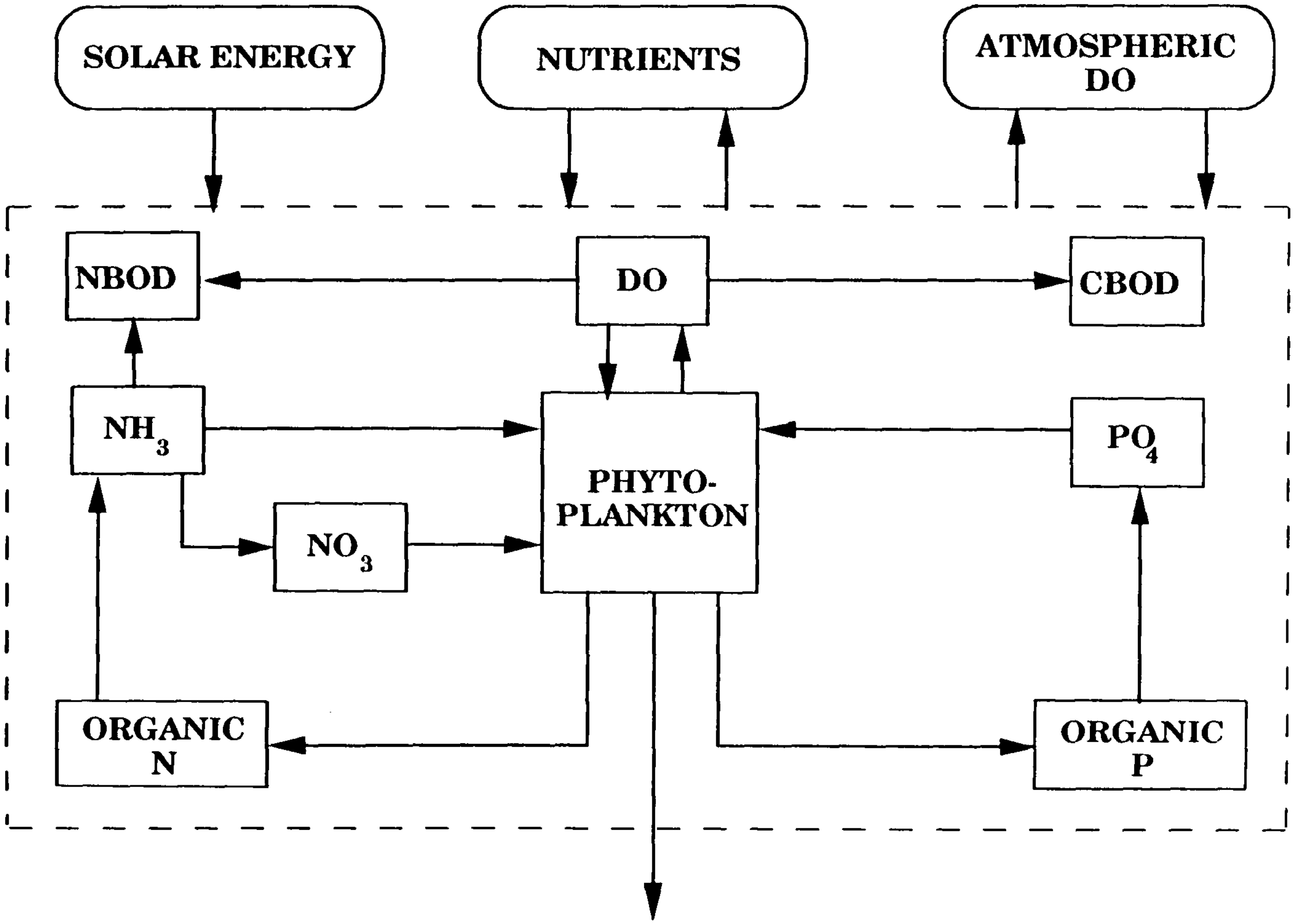

Figure 1.4. Flow diagram for ecologic state variables in the river basin model.

$K_1 \quad = K_1^{20}\,\theta_{1T}$

K_1^{20} = the deoxygenation rate at 20° C, $days^{-1}$

θ_{1T} = the temperature correction factor for deoxygenation.

Dissolved Oxygen (DO), C_2

The major source and sink terms for DO include the following:

- Stabilization of CBOD by microorganisms
- Nitrogenous biological oxygen demand (NBOD)
- Respiration of phytoplankton
- Photosynthesis by phytoplankton

The mass balance is

$$\frac{d(C_2V)}{dt} = (-K_1C_1 - K_2(C_2 - C_{sat}) - \alpha_{25}K_{56}C_5)\,V \qquad (1.3)$$

where,

K_2 = the reaeration rate, $days^{-1}$,

$= K_2^{20}\,\theta_{2T}$

K_2^{20} = the reaeration rate at 20° C

θ_{2T} = $1.024^{(C_9 - 20.0)}$

C_{sat} = saturation level of dissolved oxygen, mg/l

α_{ON} = the stoichiometric relationships between oxygen and nitrogen for the oxidation of ammonia to nitrate,

K_{56} = the nitrification rate for converting ammonia to nitrate, days^{-1}.

Algal Biomass, C_3

The major elements characterizing the dynamics of algal biomass are

- growth driven by energy from sunlight in the presence of the macronutrients, nitrogen and phosphorus
- respiration of organic carbon stores
- settling of plankton due to gravitational influences

Mathematical formulation of the mass balance for these processes is given by

$$\frac{d(C_3V)}{dt} = (G - R - \frac{w_s}{\Delta z}) C_3V \qquad (1.4)$$

where,

G = $G_{max}\, f_T(C_9)\, f_I(I)\, f_N(C_5,C_6)\, f_P(C_6)$

G_{max} = the maximum growth rate for alglal biomass, days^{-1},

$f_T(C_9)$ = the function describing the temperature-dependency of the algal growth rate

$$= e^{(-2.3(\frac{T_{opt} - C_9}{T_{opt} - T_{low}})^2)} \qquad \text{when } C_9 < T_{opt}$$

$$= e^{\left(-2.3\left(\frac{T_{opt} - C_9}{T_{opt} - T_{high}}\right)^2\right)} \qquad \text{when } C_9 > T_{opt}$$

$f_I(I)$ = the function describing the dependency of the growth rate on solar radiation

$$= \frac{2.718\, f_p}{\gamma (z_2 - z_1)} \left(e^{-\frac{I_o}{I_s} e^{-\gamma z_2}} - e^{-\frac{I_0}{I_s} e^{-\gamma z_1}} \right)$$

f_p = the photo period, fraction of days,

γ = the extinction coefficient, meters^{-1},

I_0 = net solar radiation at the water surface, kcal/meter^2/second,

I_s = the optimal radiation for algal growth, kcal/meters^2/second,

z_1 = depth below surface of top of the ijth element, meters,

z_2 = depth below surface of botttom of the ijth element, meters.

f_N = growth limiting factor for nitrogen,

$$= \frac{C_5 + C_6}{(K_N + C_5 + C_6)}$$

K_N = the half-saturation constant for nitrogen, mg/l N,

C_5 = the concentration of ammonia nitrogen, mg/l N,

C_6 = the concentration of nitrate nitrogen, mg/l N,

f_P = growth limiting factor for phosphorus,

$$= \frac{C_8}{(K_P + C_8)}$$

K_P = the half-saturation constant for phosphorus, mg/l P,

C_8 = the concentration of orthophosphate, mg/l P.

Organic Nitrogen, C_4

The major sources and sinks for organic nitrogen are

- waste products due to respiration of algae
- mineralization to ammonia nitrogen due to bacterial action.

The corresponding equation for mass balance is

$$\frac{d(C_4 V)}{dt} = (-K_{44}\, C_4 + \alpha_{NC} R\, C_3)\, V \qquad (1.5)$$

where

K_{44} = the mineralization rate of organic nitrogen, days^{-1},

$= K_{44}^{20}\,\theta_{4T}$

K_{44}^{20} = the mineralization rate at 20° C

$\theta_{4T} = 1.084^{(C_9 - 20.0)}$

α_{NC} = the nitrogen/carbon ratio in algae,

Ammonia Nitrogen, C_5

The major source and sink terms for ammonia nitrogen are

- mineralization of organic nitrogen to ammonia
- nitrification of ammonia to nitrate
- uptake of ammonia by algal growth.

The mass balance equation is written

$$\frac{d(C_5 V)}{dt} = (-\alpha_{NC}\, f_{NH_3} G C_3 + K_{44}\, C_4 - K_{55}\, C_5) V \qquad (1.6)$$

f_{NH_3} = algal preference factor for ammonia uptake

K_{55} = the nitrification rate for converting ammonia to nitrate, days^{-1}

$= K_{55}^{20}\,\theta_{5T}$

$$\theta_{5T} = 1.084^{(C_9 - 20.0)}$$

Nitrate Nitrogen, C_6

The major sources and sinks for nitrate nitrogen are

- uptake of ammonia by algal growth
- nitrification of ammonia to nitrate.

The mass balance equation is

$$\frac{d(C_6 V)}{dt} = (-\alpha_{NC} (1 - f_{NH_3}) G C_3 + K_{56} C_5) V \quad (1.7)$$

where,

$K_{56} = K_{55}$

Organic Phosphorus, C_7

The major sources and sinks for organic nitrogen are

- Waste products due to respiration of algae
- Mineralization to organic phosphorus due to bacterial action.

The mass balance equation is

$$\frac{d(C_7 V)}{dt} = (\alpha_{PC} R C_3 - K_{77} C_7) V \quad (1.8)$$

where,

$K_{56} = K_{55}$

α_{PC} = the phosphorus/carbon ratio in algae,

K_{77} = the mineralization rate of organic phosphorus, $days^{-1}$.

Orthophosphate, C_8

The major sources and sinks for orthophosphate are

- mineralization of organic phosphorus
- uptake of orthophosphate by algal growth.

The mass balance equation is

$$\frac{d(C_8 V)}{dt} = (-\alpha_{PC}\, G\, C_3 + K_{78}\, C_7)\, V \qquad (1.9)$$

Temperature, C_9

The heat budget method is used to simulate changes in water temperature in the river basin. The elements of the heat budget include

- Net short wave radiation, q_{sn},
- Net atmospheric (long wave) radiation, q_{at},
- Water surface (long wave) radiation, q_w,
- Evaporative heat flux, q_e,
- Convective heat flux, q_c.

The mass balance equation is

$$\rho\, C_p \frac{d(C_9 V)}{dt} = q_{net} A_z \qquad (1.10)$$

where

ρ = the water density, kg/meters^3,

C_p = the specific heat capacity of water, kcal/kg/^{o}C,

q_{net} = $q_{sn} + q_{at} - q_w - q_e + q_c$

= the net heat flux across the air-water interface, kcal/meters^2/second,

A_z = the surface area of the computational element, meters^2.

The methodology used to estimate the individual components of the heat budget is similar to that described by Water Resources Engineers, Inc. (1967).

Coliform Bacteria, C_{10}

The major source and sink terms for coliform bacteria are

- mortality due to hostile environmental conditions

The mass balance equation is written

$$\frac{d(C_{10}V)}{dt} = -K_B C_{10} V \tag{1.11}$$

where,

K_B = the mortality rate for bacteria, seconds^{-1},

$= 2.31 \times 10^{-6} (1 + .01111\, C_{10})$

Conservative Constituents, C_{11} and C_{12}

For the conservative constituents, the only processes affecting changes in concentration are those of dilution, advection and diffusion. These processes are treated in the same way for all constituents.

1.3 Method of Solution

The state-space formulation for the ecologic model described above is based upon the conservation equation for a well-mixed control volume of finite dimensions. The differential equation for each state variaable can be written in the following form:

$$V\frac{dC_n}{dt} + C_n\frac{dV}{dt} = g(C_1.....C_{12}, I_0, Q) \tag{1.12}$$

After rearranging, eq. (1.12) can be written as

$$\frac{dC_n}{dt} = [g(C_1....C_{12}, I_0, Q) - C_n\frac{dV}{dt}]/V \tag{1.13}$$

The conservation equations for all twelve state variables lead to the following system of first-order, nonlinear differential equations:

$$\frac{dC_1}{dt} = [g_1(C_1...C_{12}, I_0, Q) - C_1\frac{dV}{dt}]/V$$

, , , , , ,

, , , , , , (1.14)

, , , , , ,

$$\frac{dC_{12}}{dt} = [g_{12}(C_1...C_{12}, I_0, Q) - C_{12}\frac{dV}{dt}]/V$$

The two-step Runge-Kutta method (Press et al, 1986) is used to solve this system of equations for each computational element, beginning at the first headwater reach and working downstream through the entire system in the sequence specified in the problem description. The accuracy and the stability of the solution will depend upon the time and space increments used to characterize the problem. Because this is basically an explicit formulation in time, stability criteria are associated with N_1, the ratio of the residence time of a computational element and the computational interval, where

$$N_1 = \frac{Q\,\Delta t}{V}$$

Δt = the computational interval,

Q = the net volume associated with the computational element,

V = the volume of the element.

and N_2, the ratio of the diffusion time between elements and the computational interval

$$N_2 = \frac{K \Delta z^2}{\Delta t}$$

Δz = the thickness of the computational element,

K = the vertical coefficient of eddy diffusivity.

Stability criteria associated with N_1 and N_2 apply to the stratified reservoirs. Advection and dilution are the only hydrodynamic processes affecting concentration in the free-flowing and river -run reservoir segments. Therefore, only the criterion associated with N_1 applies to these segments. Since the system of equations is nonlinear, exact criteria cannot be derived. Results from the analysis of the linearized difference equations, as well as common practice, suggests N_1 should be approximately one (1.0) for best results and that instabilities will occur for values larger than one. N_2 should be less than 0.50 (Bella and Dobbins, 1967) to prevent instabilities from occurring in the solution.

1.4 References

Bella, D.A. and W.E. Dobbins. 1967. Finite difference modelling of river and estuary pollution. In: Proceedings of national symposium on estuarine pollution - Stanford University. Stanford University, Stanford, CA., 612-645.

Chen, C.W. and G.T. Orlob. 1975. Ecologic simulation for aquatic environments. In: Systems Analysis and Simulation in Ecology, Vol III. Academic Press, New York, NY. 354 pp.

DiToro, D.M., D.J. O'Connor and R.V. Thomann. 1975. Phytoplankton-zooplankton-nutrient interaction model for Western Lake Erie. In: Systems Analysis and Simulation in Ecology, Vol. III. Academic Press, New York, NY. 354 pp.

Patten, B.C., D.A. Egloff and T.H. Richardson. 1975. Total ecosystem model for a cove in Lake Texacoma. In: B.C. Patten (Editor), Systems Analysis and Simulation in Ecology, Vol. IV Academic Press, New York, NY., 329-371.

Press, W.H., B.P. Flannery, S.A. Teukolsky and W.T. Vetterling. 1986. Numerical recipes, the art of scientific computing. Cambridge University Press. 818 pp.

Scavia, D. 1980. An ecological model of Lake Ontario. Ecologic Modelling, 8, 49-78.

Water Resources Engineers. 1967. Prediction of thermal energy distribution in streams and reservoirs. Prepared for the State of California Department of Fish and Game. 88 pp.

CHAPTER 2

COMPUTER PROGRAM DESCRIPTION

2.1 Introduction

The river basin model described in Chapter 1 has been designed to analyze the impact of

- point source wastes from industries and municipalities
- non-point sources
- water diversions

upon the aquatic ecosystems of freely-flowing rivers, river-run reservoirs and stratified reservoirs. The model design is based upon the river basin concept and the software provides the capability of analyzing branching systems. This volume describes way in which the software implementing the model is structured.

2.2 Data Preparation

For the purposes of preparing input data, the river basin being examined must be first divided into reaches or segments. Within a given reach, the hydraulic characteristics and base reaction rates are constant. The quality and quantity of non-point source, or distributed inputs are also assumed to be constant throughout each reach. In turn, each reach is divided into a number of computational elements. The size of the computational element is specified by the user according to requirements for achieving a stable solution, as well as for resolving changes at a scale consistent with the needs of river basin planners.

Water quality and quantity for all headwaters of the river system, point sources, non-point sources and diversions must be determined. For those reaches which are characterized as stratified reservoirs, the operating schedule of the reservoir must be available. Rate constants for chemical and biological reactions in each reach must be determined. In freely-flowing river segments or river-run reservoirs, the relationship between river flow and river depth and river flow and river velocity must be specified. For stratified reservoirs, it is necessary to know the relationship between volume and stage and surface area and stage. Sediment oxygen demand in each reach must also be estimated.

The heat budget method is used to simulate water temperature. The necessary components of the heat budget can be determined using the methods described by Water Resources Engineers, Inc. (1967). The software is designed so there can be a number of meteorological provinces. This makes it possible to simulate temperatures in those river basins for which the geographical extent is such that meteorological conditions may vary substantially from one region to another.

2.3 Software Organization

Subroutine BEGIN

Data describing the basic structure of the river basin are read in this subroutine. This includes system parameters such as an alphanumeric description of the problem, computation time interval, simulation period parameters and number of meteorological observations per day. Next, parameters describing the topology of the river basin network are read. The sequence in which these data are entered is important because the program logic computes water quality in the same sequence. The first reach should be the headwaters reach of the main stem, followed in sequence by downstream reaches until a confluence is encountered. The reach containing the confluence must have a unique, though not necessarily sequential number, NJUNC(N). The reach following must be a headwater reach of one of the tributaries forming the confluence. If there is more than one tributary in the confluence, the order in which tributary headwaters are considered is not important. From the tributary headwater the sequence is downstream until another confluence is encountered. When all the headwaters which form the confluence have been included, the sequence continues downstream on the main stem.

As an example, consider the network of reaches A, B, C, D, E, F, G, H, I, J, K, L, and M, shown in Figure 2.1. Correct sequences include the following:

(1) A, B, C, D, E, F, G, H, I, J, K, L, M
(2) B, A, D, C, E, F, G, H, K, I, J, L, M
(3) C, D, E, A, B, F, G, H, J, K, I, L, M
(4) D, C, E, B, A, F, G, H, I, K, J, L, M,

as well as a number of others.

Within each reach the user must specify a unique number for the headwater, NHEAD(N), if the reach is a headwater; the number of point sources, NPOINT(N), within the reach; the number of diversions in the reach, NDIV; a unique, but not necessarily sequential number, NRESRV, if the reach is a reservoir reach; and the number of computational elements, NCELM, in the reach.

The program then reads a number of important parameters characterizing the dynamics of the ecosystem. These parameters include

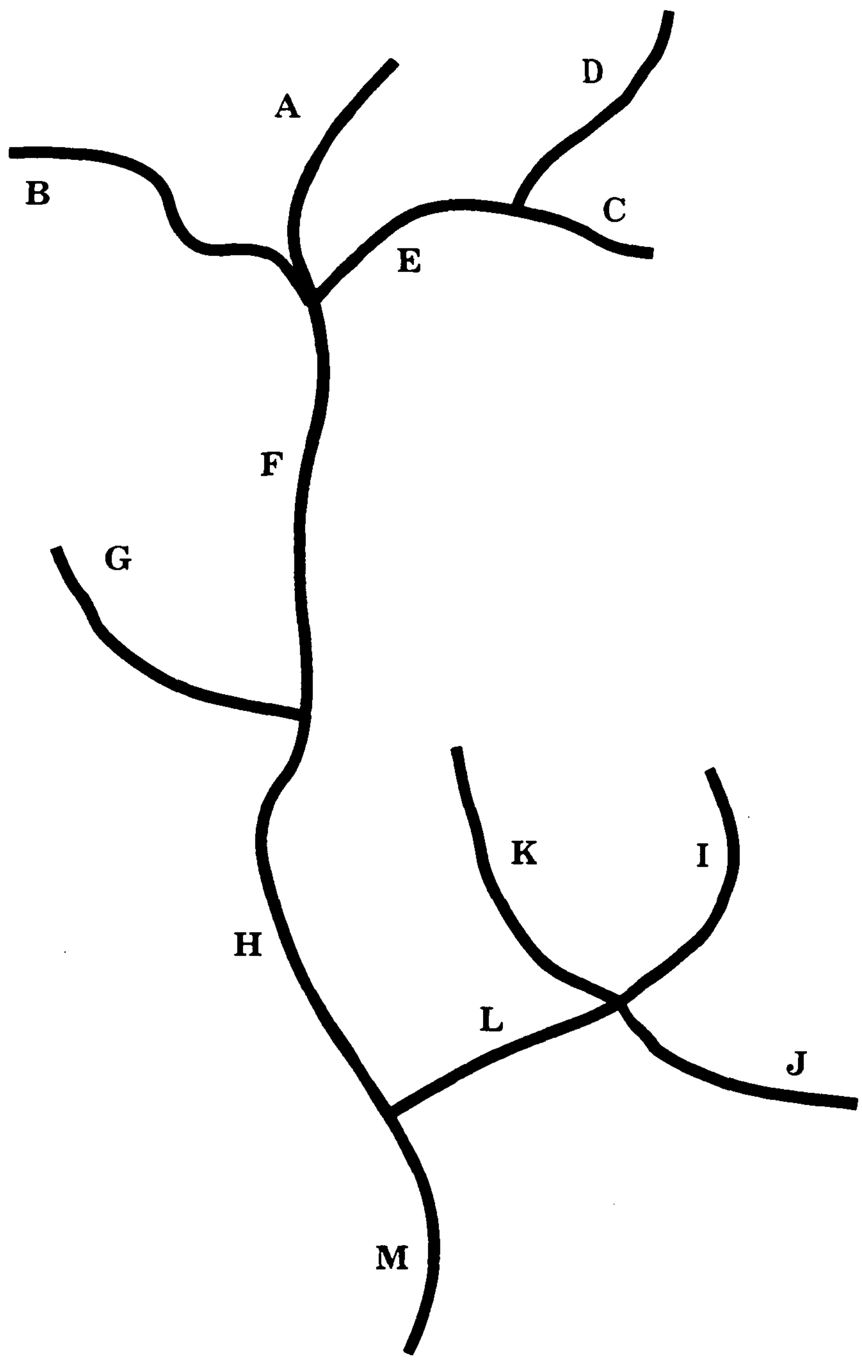

Figure 2.1. Schematic diagram of branching river system.

the oxygen/carbon ratio in photosynthesis, OCRAT; the carbon/chlorophyll a ratio, CCLRAT; the nitrogen/carbon ratio in algae, NCRAT; the phosphorus/carbon ratio in algae, PCRAT; half-saturation constants for nitrogen and phosphorus, KMN and KMP; the fraction of ammonia in nitrogen uptake by algae, NH3PRF; optimal solar radiation for algal growth, QOPT; sinking speed of algae, WSINK; optimal, minimum and maximum water temperatures for algal growth, TOPT, TLO, TUP; and maximum algal growth rate and respiration rate, PG0 and PRES0.

The rates for chemical and biological parameters include: the reaeration rate, XKDO; the deoxygenation, rate, XKBODL; the rate of decay of organic nitrogen, XKN44; the rate of decay of ammonia nitrogen, XKN55; the deposition rate of phosphorous, XKP77; the sediment oxygen demand, SOD; and the background light extinction coefficient, EXCO.

Several options are available for specifying the reaeration rate, XKDO. The user may specify the value by inputting the desired positive number in units of $days^{-1}$ (base e). Input of a negative number for XKDO will result in the computation of the reaeration rate according to one of the formulae given in Table 2.1. The values of all rates are adjusted for temperature as described in Volume I.

Table 2.1 Options available for compute the reaeration rate, K_2

XKDO*	Reaeration Rate, K_2 (days^{-1}, base e)	Reference
>0.0	$K_2 = XKDO$	
-1.0	$K_2 = \frac{2.3*5.026\ U^{0.969}}{D^{1.673}}$	Churchill et al (1962)
-2.0	$K_2 = \frac{(D_m\ U)^{0.5}}{D^{1.5}}$	O'Connor and Dobbins (1958)
-3.0	$K_2 = \frac{2.3*9.4\ U^{0.67}}{D^{1.85}}$	Owens et al (1964)

* See Card Group II, Type 6 in Appendix I

The geometric characteristics of the reach are also input in this routine. If the segment is a free-flowing river reach or a river-run reservoir, coefficients relating velocity and depth to flow are required. The coefficients, DEPTH1 and DEPTH2, relate the depth of the reach, D, to the flow, Q, in the following way:

$$D = DEPTH1 * Q^{DEPTH2}$$

The coefficients, VEL1 and VEL2 relate the velocity of the reach U, to the flow, Q as

$$U = VEL1 * Q^{VEL2}$$

If the segment is a stratified reservoir, the lowest level of active storage, Z(NV,1), the thickness of each computational element, ZLAYER, and volume coefficients, AVC(NV) and BVC(NV) are input. The volume coefficients are used to compute reservoir volume, V, at any depth N according to

$$V = AVC(NV) + (Z(NV,N)-Z(NV,1))*BVC(NV)$$

The quantity and quality of non-point sources are specified by the parameters, QRET and CRET(N). Headwater quantity and quality are specified by QHEAD and CHEAD(N). Point source quantity and quality are QPOINT and CPOINT(N), respectively, and the location of the point sources in river miles is RMP. Quantity of diversion water is QDIV and the location of the diversion in river miles is RMDIV.

The last card for the segment is text 'END'. The software keys on this delimiter to indicate to the user whether the amount of information provided is consistent with the amount required. If it is not, the software issues a diagnostic indicating the reach in which the inconsistency occurs.

Subroutine SYSTEM

Subroutine SYSTEM maintains control of the simulation and output portions of the program. Checking to determine whether the reach to be simulated is a river segment or a stratified reservoir segment is performed as are summations of water and water quality for junctions. Calls to RESMOD and RIVMOD are made from this routine depending upon whether the reach has been described as a river-run reservoir or a stratified reservoir.

Subroutine QUALTY

Numerical solutions to the first-order differential equations for ecosystem state variables are obtained in this subroutine using the two-step Runge-Kutta method (Press et al, 1986). The subroutine software implements the mathematical development described in Chapter 1. Subroutine QUALTY is called from either RIVMOD or RESMOD to advance the state variables of a computational element ahead one time step. The results obtained in QUALTY are stored for use as initial conditions for the next time step and for output, if desired.

Subroutine WRITE1

Subroutine WRITE1 provides the output function for the ecosystem model software. Entry at WRITE1 occurs at the beginning of each reach, after all reach parameters, waste loads and diversions have been included. Entry at WRITE2 occurs at the end of each computational element to print the predicted values of the water quality constituents and the status of the water budget. Entry at WRITE3 occurs at the end of the reach to print surface elevation, water depth and velocity, dissolved oxygen saturation and algal dissolved oxygen production and respiration.

Subroutine RESMOD

The physical processes of dilution, advection and turbulent diffusion are developed for each computational element in the stratified reservoir segment. Inflows are assigned to computational elements (layers) within the reservoir segment based upon their density. This determination is made by a call to Subroutine LAYRIN with the temperature of the inflow as an argument. A call is also made to Subroutine MIX to see if the reservoir density profile is stable. This is of importance during the fall as the surface layers begin to cool, initiating overturn in the reservoir.

Subroutine RESMOD accounts for surface phenomena associated with transfer of thermal energy and solar radiation. After performing these calculations, a call is made to Subroutine QUALTY to advance the estimate of the state variables one computational time increment. Upon returning from Subroutine QUALTY, the current time level is compared with time level for which output has been defined. If the two time levels match, The appropriate entry point in Subroutine WRITE1 is called with output to the printer and/or the plotter file.

Subroutine RIVMOD

Subroutine RIVMOD performs functions for the free-flowing river and river-run reservoir segments similar to those performed in Subroutine RESMOD for stratified reservoirs. There is, however, no vertical diffusion, nor is there any account kept of vertical density structure. This is because each segment in the free-flowing river and river-run reservoir segments are assumed to be well-mixed both laterally and vertical.

Subroutine LAYRIN

The density, ρ, of inflowing water to a stratified reservoir is estimated from the relationship

$$\rho = \frac{(C_9+283.)(C_9-3.98)^2}{(503.57(C_9+67.26)}$$

The density of inflow water is compared with density of each computational segment, beginning at the surface and proceeding downward. The segment into which the inflow is placed is the first one encountered for which the segment density exceeds the density of the inflow.

Subroutine MIX

After the state variables have been projected ahead one time step in a stratified reservoir, a call to this subroutine is made from Subroutine

RESMOD to determine if there are instabilities in the density profiles. An instability is defined as condition for which the density decreases with depth. If such an instability is found, the reservoir is mixed uniformly from the surface to the level of the instability. The resulting concentrations are returned to Subroutine RESMOD as the updated state variables for the next time step.

Subroutine ENERGY

Meteorologic data including net solar radiation, QNS, net atmospheric radiation, QNA, dry bulb temperature, DBT, wind speed, WIND, and vapor pressure EA are used to calculate thermal exchange between the computational element at the water surface and the atmosphere. The resulting heat budget is a source term in simulating the water temperature.

2.4 Description of Input Data

Instructions for preparing the input data are given in Appendix I.

2.5 Source Code

The software is written in FORTRAN 77. An effort has been made to simplify the code so as to be easily transported to other FORTRAN compilers. A listing of the source code is given in Appendix II.

2.6 References

Churchill, M.A., H.L. Elmore, and R.A. Buckingham. 1962. The prediction of stream reaeration rates. ASCE Journ of Sanitary Engineering, SA-4, 88, 1-46

O;Connor, D.J. and W.E. Dobbins. 1958. Mechanism of reaeration in natural streams. ASCE Trans., 123, 641-684.

Owens, M., R.W. Edwards and J.W. Gibbs. 1964. Some reaeration studies in streams. Int. Jour. Air and Water Pollution. 8, 469-486.

Press, W.H., B.P. Flannery, S.A. Teukolsky and W.T. Vetterling. 1986. Numerical recipes, the art of scientific computing. Cambridge University Press. 818 pp.

Water Resources Engineers. 1967. Prediction of thermal energy distribution in streams and reservoirs. Prepared for the State of California Department of Fish and Game. 88 pp.

Appendix I

Data input formats for the river basin ecosystem model

Card Group I

Card Type	Columns	Format	Variable Name	Description
1	1-80	20A4	XTITLE	Alphanumeric description of analysis being performed.
2	1-5	F5.0	DT	Simulation time interval, days
	6-10	F5.0	DAY1	First day of simulation
	11-15	F5.0	DAY2	Last day in simulation
	16-20	F5.0	WOBSPD	Meteorological observations per day
	21-25	F5.0	DAYPRT	Time interval for printed output, days
3	1-5	F5.0	REACHX	Number of reaches to be simulated
	6-10	F5.0	LAT	Average latitude of river basin
	11-15	F5.0	ZLOW	Minimum thickness in the surface layer of a stratified reservoir
	16-20	F5.0	ZPLOT	Switch indicating number of reaches for which a plot is desired.
4 (If ZPLOT>0)	1-5	I5	NPLOT(1)	Number of first reach for which plot is desired
	6-10	I5	NPLOT(2)	Number of second reach for which plot is desired
	.	.	.	.
	.	.	.	.
	.	.	.	.
	.	I5	NPLOT(.)	Number of ZPLOTth reach for which plot is desired

Card Group I (continued)

Card Type	Columns	Format	Variable Name	Description
3	1-5	F5.0	OCRAT	Oxygen:carbon ratio in photosynthesis
	6-10	F5.0	CCLRAT	Carbon:chlorophyll a ratio for algae
	11-15	F5.0	NCRAT	Nitrogen:carbon ratio for algae
	16-20		PCRAT	Phosphorus:carbon ratio for algae
	21-25	F5.0	KMN	Half-saturation constant for nitrogen, mg/l N
	26-30	F5.0	KMP	Half-saturation constant for phosphorus, mg/l P
	31-35	F5.0	NH3PRF	Fraction of NH3 in inorganic nitrogen utilized by algae
	36-40	F5.0	QOPT	Optimal radiation level for algae, kcal/m^2/second
	41-45	F5.0	WSINK	Algal sinking rate, meters/day
	46-50	F5.0	TOPT	Optimal temperature for algal growth, ^{o}C
	51-55	F5.0	TLO	Minimum temperature for algal growth, ^{o}C
	56-60	F5.0	THI	Maximum temperature for algal growth, ^{o}C
	61-65	F5.0	PG0	Maximum growth rate for algae, days^{-1}
	66-70	F5.0	PRES0	Maximum respiration rate for algae, days^{-1}

Card Group II (continued)

Card Type	Columns	Format	Variable Name	Description
4	1-20	A20	RNAME(N)	Alphanumeric description of reach
	21-25	F5.0	RMILE1(N)	Beginning (upstream) river mile of reach
	26-30	F5.0	RMILE2(N)	Ending (downstream) river mile of reach
	31-35	F5.0	ELEV(N)	Elevation of surface of reach above Mean Sea Level (MSL), feet
5	1-5	I5	NHEAD	Identification number for headwaters reach. Must be unique, but does not have to be sequential.
	6-10	I5	NPOINT(N)	Number of point sources in reach.
	11-15	I5	NDIV(N)	Number of diversions in reach
	16-20	I5	NJUNC	Identification number if downstream boundary has a confluence with other reaches. Does not have to be sequential, but all reaches with a common confluence must have the same identification number
	21-25	I5	NRESRV(N)	Identification number if reach is a stratified reservoir. Must be unique, but does not have to be sequential.
	26-30	I5	NCELM(N)	Number of computational elements in reach. If NRESRV(N)>0, the maximum number of computational elements in the stratified reservoir

Card Group II (continued)

Card Type	Columns	Format	Variable Name	Description
5	31-35	I5	NWPROV(N)	Identification number for meteorological province in which reach is located.
6	1-10	F10.0	XKDO(N)	Reaeration rate, $days^{-1}$
	11-20	F10.0	XKBODL(N)	Deoxygenation rate, $days^{-1}$
	21-30	F10.0	XKN44(N)	Rate of mineralization of organic nitrogen, $days^{-1}$
	31-40	F10.0	XKN55(N)	Nitrification rate, $days^{-1}$
	41-50	F10.0	XKP77(N)	Rate of mineralization of organic phosphorus, $days^{-1}$
	51-60	F10.0	XKBACT(N)	Rate of dieoff for coliform bacteria, $days^{-1}$
	61-70	F10.0	SOD(N)	Sediment oxygen demand, mg/l(O_2)/day
	71-80	F10.0	EXCO(N)	Background light extinction coefficient, $meters^{-1}$

* *
*   Use Card Type 7a if NRESRV=0   *
* *

Card Type	Columns	Format	Variable Name	Description
7a	1-10	F10.0	DEPTH1(N)	Depth coefficient, D1, in the formula: Depth=D1*$Flow^{D2}$
	11-20	F10.0	DEPTH2(N)	Depth coefficient, D2, in the formula given above. Depth is in feet, Flow is in cubic feet/second

Card Group II (continued)

Card Type	Columns	Format	Variable Name	Description
7a (continued)	21-30	F10.0	VEL1(N)	Velocity coefficient, V1, in the formula: Velocity=V1*Flow^{V2}
	31-40	F10.0	VEL2(N)	Velocity coefficient, V2, in the formula given above. Velocity is in feet/ second
	41-50	F10.0	DEPTH0	Initial depth of reach, feet
	41-50	F10.0	WIDTH0	Initial width of reach, feet

```
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*       Use Card Type 7b if NRESRV≠0                                                             *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

Card Type	Columns	Format	Variable Name	Description
7b	1-10	F10.0	Z(NV,1)	Elevation, feet above MSL, of lowest, active portion of reservoir
	11-20	F10.0	ZLAYER	Thickness of computational elements in stratified reservoir, feet
	21-30	F10.0	AVC(NV)	Volume coefficient, A1, in the formula: Volume=A1+B1*Depth
	31-40	F10.0	BVC(N)	Volume coefficient, B1, in the above formula. Volume is in cubic feet and Depth is feet above Z(NV,1)
	41-50	F10.0	ZOUT	Elevation of reservoir discharge, feet above MSL
	51-60	F10.0	QQRES	Reservoir discharge, cfs

Card Group II (continued)

Card Type	Columns	Format	Variable Name	Description
8	1-10	F10.0	QRET(N)	Quantity of ground return flow to the reach, cubic feet/second
9	1-5	F5.0	CRET(1,N)	CBOD of return flow, mg/l
	6-10	F5.0	CRET(2,N)	DO of return flow, mg/l
9	11-15	F5.0	CRET(3,N)	Algal biomass of return flow, mg/l C
	16-20	F5.0	CRET(4,N)	Organic nitrogen in return flow, mg/l
	21-25	F5.0	CRET(5,N)	Ammonia-nitrogen in return flow, mg/l
	26-30	F5.0	CRET(6,N)	Nitrate-nitrogen in return flow, mg/l
	31-35	F5.0	CRET(7,N)	Organic phosphorus in return flow, mg/l
	36-40	F5.0	CRET(8,N)	Orthophosphate-phosphorus in return flow, mg/l
	41-45	F5.0	CRET(9,N)	Temperature of return flow, ^{o}C
	46-50	F5.0	CRET(10,N)	Coliform bacteria in return flow, MPN
	51-55	F5.0	CRET(11,N)	Conservative constituent #1 in return flow
	56-60	F5.0	CRET(12,N)	Conservative constituent #2 in return flow

* *
*   *
*   Card Types 10 and 11 should be omitted if the reach is not a   *
*   headwater reach (NHEAD=0)   *
*   *
* *

Card Group II (continued)

Card Type	Columns	Format	Variable Name	Description
10	1-10	F10.0	QHEAD(N)	Headwater flow, cfs
11	1-5	F5.0	CHEAD(1,N)	CBOD of headwater flow, mg/l
	6-10		CHEAD(2,N)	DO of headwater flow, mg/l
11	11-15	F5.0	CHEAD(3,N)	Algal biomass of headwater flow, mg/l C
	16-20	F5.0	CHEAD(4,N)	Organic nitrogen in headwater flow, mg/l
	21-25	F5.0	CHEAD(5,N)	Ammonia-nitrogen in headwater flow, mg/l
	26-30	F5.0	CHEAD(6,N)	Nitrate-nitrogen in headwater flow, mg/l
	31-35	F5.0	CHEAD(7,N)	Organic phosphorus in headwaters flow, mg/l
	36-40	F5.0	CHEAD(8,N)	Orthophosphate-phosphorus in headwaters flow, mg/l
	41-45	F5.0	CHEAD(9,N)	Temperature of headwaters flow, ^{o}C
	46-50	F5.0	CHEAD(10,N)	Coliform bacteria in headwaters flow, # of coliforms/100 ml
	51-55	F5.0	CHEAD(11,N)	Conservative constituent #1 in headwaters flow

Card Group II (continued)

Card Type	Columns	Format	Variable Name	Description
11 (continued)	56-60	F5.0	CHEAD(12,N)	Conservative constituent #2 in headwaters flow

* *

Card Types 12 and 13 should be omitted if there are no point sources in the reach (NPOINT=0)

* *

Card Type	Columns	Format	Variable Name	Description
12	1-10	F10.0	QPOINT(N)	Point source flow, cfs
	11-20	F10.0	RMP(N)	River mile of point source, N
	21-30	F10.0	XNAME(N)	Alphanumeric description of point source

Card Group II (continued)

Card Type	Columns	Format	Variable Name	Description
13	1-5	F5.0	CPOINT(1,N)	CBOD of point source flow, mg/l
	6-10		CPOINT(2,N)	DO of point source flow, mg/l
	11-15	F5.0	CPOINT(3,N)	Algal biomass of point source flow, mg/l C
	16-20	F5.0	CPOINT(4,N)	Organic nitrogen in point source flow, mg/l
	21-25	F5.0	CPOINT(5,N)	Ammonia-nitrogen in point source flow, mg/l
	26-30	F5.0	CPOINT(6,N)	Nitrate-nitrogen in point source flow, mg/l
	31-35	F5.0	CPOINT(7,N)	Organic phosphorus in point source flow, mg/l
	36-40	F5.0	CPOINT(8,N)	Orthophosphate-phosphorus in point source flow, mg/l
	41-45	F5.0	CPOINT(9,N)	Temperature of point source flow, °C
	46-50	F5.0	CPOINT(10,N)	Coliform bacteria in point source flow, # of coliforms/100 ml
	51-55	F5.0	CPOINT(11,N)	Conservative constituent #1 in point source flow
	56-60	F5.0	CPOINT(12,N)	Conservative constituent #2 in point source flow

* *

*   Repeat Card Types 12 and 13 NPOINT times in each reach.   *
*   NPOINT is read as Card Type 4   *

* *

Card Group II (continued)

Card Type	Columns	Format	Variable Name	Description

```
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                                                               *
*     Card Types 14 should be omitted if there are no diversions                                *
*     in the reach (NDIV=0)                                                                     *
*                                                                                               *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

Card Type	Columns	Format	Variable Name	Description
14	1-10	F10.0	QDIV(N)	Quantity of ground return flow to the reach, cubic feet/second
	11-21	F10.0	RMDIV(N)	River mile of diversion

```
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                                                               *
*     Repeat Card Type 14  NDIV times in each reach.                                            *
*     NDIV is defined on Card Type 4                                                            *
*                                                                                               *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

```
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                                                               *
*     Repeat Card Types 4-14 REACHX times.                                                      *
*     REACHX is defined on Card Type 3                                                          *
*                                                                                               *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

Meteorological Data

The heat budget method is used to simulate water temperature. The data needed for the heat budget of each meteorological province must be stored in a binary file. The required data and the order which they should occur are given in Table A.1. A set of data is required for each of the WOBSPD (defined on Card Type 2, above) periods per day, beginning on DAY1 (defined on Card Type 2, above) and continuing for a total number of days as defined by the input variable, DAY2 (defined on Card Type 2, above).

Table A.1 Meteorological variables for heat budget estimates and order in which they must occur on the binary storage file

QNS	Net solar radiation	kcal/meter^2/second
QNA	Net atmospheric radiation	kcal/meter^2/second
DBT	Dry bulb temperature	^oC
WIND	Wind speed	meters/second
PF	$6.41 x 10^{-4}$ * (Air pressure)	$(^oC)^{-1}$
EA	Water vapor pressure	mb
PHOTO	Photo period	Fraction of days

Appendix II

Listing of FORTRAN 77 Source Code

```
      PROGRAM RBM10
C
C     Dynamic river basin model for simulating water quality in
C     branching river systems with freely-flowing river segments,
C     river-run reservoirs and stratified reservoirs. Documentation
C     is given in EPA 910/9-91-019.
C
C     John Yearsley
C     EPA Region 10   ES-098
C     1200 Sixth Ave
C     Seattle, WA    98101
C     (206) 553-1532
C
      CHARACTER*30 NAMEI
      INCLUDE :RBM10.COM
C
C     Open file containing reach data
C
      WRITE(*,2600)
      CALL FNAME(NAMEI)
       OPEN(UNIT=4,FILE=NAMEI,STATUS='OLD')
C
C     Open file for output
C
      WRITE(*,2700)
      CALL FNAME(NAMEI)

       OPEN(UNIT=7,FILE=NAMEI,STATUS='NEW')
C
C     Call systems programs to get started
C
      CALL BEGIN
      CALL SYSTEM
C
C     Close file after simulation is complete
C
      CLOSE(UNIT=4)
      CLOSE(UNIT=7)
 1500 FORMAT(30A1)
 1600 FORMAT(8F10.0)
 2600 FORMAT(' Name of file containing river reach data: ')
 2700 FORMAT(' Name of output data file: ')
      STOP
      END
```

```
      PROGRAM RBM10
C
C     Dynamic river basin model for simulating water quality in
C     branching river systems with freely-flowing river segments,
C     river-run reservoirs and stratified reservoirs. Documentation
C    is given in EPA 910/9-91-019.
C    Modified for Macintosh Classic II on October 1, 1992
C     For additional information contact:
C
C    John Yearsley
C    EPA Region 10    ES-098
C    1200 Sixth Ave
C    Seattle, WA     98101
C    (206) 553-1532
C
      CHARACTER*30 NAMEI
      INCLUDE :RBM10.COM
C
C     Open file containing reach data
C
      WRITE(*,2600)
      CALL FNAME(NAMEI)
       OPEN(UNIT=4,FILE=NAMEI,STATUS='OLD')
C
C    Open file for output
C
      WRITE(*,2700)
      CALL FNAME(NAMEI)

       OPEN(UNIT=7,FILE=NAMEI,STATUS='NEW')
C
C     Call systems programs to get started
C
      CALL BEGIN
      CALL SYSTEM
C
C     Close file after simulation is complete
C .
      CLOSE(UNIT=4)
      CLOSE(UNIT=7)
 1500 FORMAT(30A1)
 1600 FORMAT(8F10.0)
 2600 FORMAT(' Name of file containing river reach data: ')
 2700 FORMAT(' Name of output data file: ')
      STOP
      END
```

```
      SUBROUTINE BEGIN

       CHARACTER END*3,NAMEI*30,DLIM*3
       REAL*4 LAT,DDATA(7)
C
      INCLUDE :RBM10.COM
      CHARACTER*1 EXT(10)
      CHARACTER*11 PFILE
      CHARACTER*12 PPFILE
      CHARACTER*20 BLANK
        DATA  DLIM/'END'/,PFILE/'RIVPLOT.DAT'/
          DATA  EXT/'0','1','2','3','4','5','6','7','8','9'/
      DATA BLANK/'                    '/
C
C     Initialize arrays of dimension 10
C
      DO 9 N=1,10
       PNAME(N)=BLANK
       HDNAME(N)=BLANK
       RSNAME(N)=BLANK
       WPNAME(N)=BLANK
    9 CONTINUE
C
C     Initialize arrays and constants
C
      DO 19 N=1,10
      NINJ(N)=0
      NPLOT(N)=0
      QHEAD(N)=0.
      QPOINT(N)=0.
      QDIV(N)=0.0
      RMP(N)=-100.
      RMDIV(N)=-100.
   19 CONTINUE
C
C     Initialize rate constants and reach name
C
      DO 29 N=1,15
       HEAD(N)=.FALSE.
      NPOINT(N)=0
       NDPNT(N)=.FALSE.
       RNAME(N)=BLANK
      NDIV(N)=0
      QRET(N)=0.
      NRESRV(N)=0
      XKBACT(N)=1.0E-10
      XKDO(N)=1.0E-10
      XKBODL(N)=1.0E-10
      XKN44(N)=1.0E-10
      XKN55(N)=1.0E-10
      XKN66(N)=1.0E-10
      XKP77(N)=1.0E-10
   29 CONTINUE
```

```
      DO 39 N=1,12
      DO 39 NN=1,100
      DO 39 NNN=1,2
       CONC(N,NN,NNN)=0.0
   39 CONTINUE
      NPONT=0
      NDIVRS=0
      NRES=0
      IHEAD=0
      IRES=0
      IWPROV=0
C
C   Card Group I
C
C    Card Type 1. Alphanumeric information for title
C
      READ(4,1020) XTITLE
C
C    Card Type 2. Simulation time interval, starting day, number of days
C            to be simulated,number of meteorological observations
C          per day.
C
      READ(4,1040) DT,DAY1,DAY2,WOBSPD,DAYPRT
C
C    Read number of reaches, average latitude,
C    maximum number of elements
C    in any stratified reservoir and minimum thickness for the the surface
C    element of a stratified reservoir.
C
      READ(4,1040) REACHX,LAT,ZLOW,ZPLOT
C
C    Change floating point constants to integers
C
      IPLOT=ZPLOT
      NWPD=WOBSPD
      NCONST=12
      NDAYS=DAYSX
      NDPRNT=DAYPRT
      LDAY1=DAY1
      LDAY2=DAY2
      PD=1./DT
      DT=86400.*DT


      DT2=DT/2.
      NPD=PD
C
C    Determine period of weather observations in terms of number of
C    simulations per day
C
      NWMOD=NPD/NWPD
      NREACH=REACHX
```

```
C
C    Convert DT from fraction of days to seconds
C
C
C    Check to see if plot output has been requested.  If so, read
C    reach numbers for which there will be plotter output and
C    open RIVPLOT.DAT for output
C
      IF(IPLOT.EQ.0) GO TO 55
      READ(4,1044) (NPLOT(I),I=1,IPLOT)
      DO 49 IP=1,IPLOT
      NFILE=19+IP
      PPFILE=PFILE//EXT(IP)
      OPEN(UNIT=NFILE,FILE=PPFILE,STATUS='NEW')
   49 CONTINUE
   55 CONTINUE
C
C    Card Group IIa. Oxygen:carbon ratio, carbon:chlorophyll a ratio,
C             nitrogen:caron ratio, phosphophorus ratio,
C             Michaelis-Menton term for N and P, algal preference
C             for ammonia, optimal light, plankton settling rate,
C             optimal, upper and lower temperatures for algal growth,
C             maximum algal growth rate, maximum algal respiration rate
C
      READ(4,1040) OCRAT,CCLRAT,NCRAT,PCRAT,KMN,KMP,NH3PRF
     .      ,QOPT,WSINK,TOPT,TLO,TUP,PG0,PRES0
C
C    Convert meters/day to feet/second
C
      VSINK=3.2808*WSINK/86400.
C
C    Card Group IIb. Reach characteristics
C
      DO 499 N=1,NREACH
C
C    Card Type 3. Reach description, begin and end river mile, elevation
C
      READ(4,1050) RNAME(N),RMILE1(N),RMILE2(N),ELEV(N)
C
C    Card Type 4. Headwater ID #, # of point sources, # of diversions,
C             junction ID #, reservoir ID #, # of computational elements,
C             weather province ID #.
C
      READ(4,1044) NHEAD,NPOINT(N),NDIV(N),NJUNC,NRESRV(N),NCELM(N)
     .      ,NWPROV(N)
      IF(NWPROV(N).GT.IWPROV) IWPROV=NWPROV(N)
C
C    Card Type 5. Rate constants - XKDO,XKBODL,XKN44,XKN55,XKP77,SOD,EXCO
C
      READ(4,1048) XKDO(N),XKBODL(N),XKN44(N),XKN55(N),XKP77(N),
     .      XKBACT(N),SOD(N),EXCO(N)
```

```
C
C
C    Card Type 7a. River reaches: Depth and velocity coefficients,
C             initialize segment volume.
C
      IF(NRESRV(N).EQ.0) THEN
       READ(4,1048) DEPTH1(N),DEPTH2(N),VEL1(N),VEL2(N),DEPTH0,WIDTH0
       VOL(N)=DEPTH0*WIDTH0*(RMILE1(N)-RMILE2(N))*5280.
C
C    ***CARD TYPE 7b. Reservoir reaches. Layer thickness, bottom depth
C              and coefficients for estimating reservoir geometry
C
      ELSE
       XKDO(N)=-10.0
       NV=NRESRV(N)
        RSNAME(NV)=RNAME(N)
       IRES=IRES+1
        READ(4,1048) Z(NV,1),ZLAYER,AVC(NV),BVC(NV),ZOUT,QQRES
       ZSURF(NV,1)=ELEV(N)-Z(NV,1)
        IOUT=((ZOUT-Z(NV,1))/ZLAYER)+1
       QRES(IOUT,NV)=QQRES
       AAC(NV)=BVC(NV)
       BAC(NV)=BVC(NV)
C
C    Establish initial reservoir volume
C
        VRES(NV,1)=AVC(NV)+ZSURF(NV,1)*BVC(NV)
       ZHIGH(NV)=ZLOW+ZLAYER
       NFIX=NCELM(N)
       DO 79 NF=1,NFIX+1
       F=NF
        Z(NV,NF)=(F-1.)*ZLAYER
        ASURF(NV,NF)=AAC(NV)
   79 CONTINUE
       VOL0=AVC(NV)
        VSEG(NV,1)=VOL0+ZLAYER*BVC(NV)
       JSURF(NV)=1
       DO 89 NF=2,NFIX
        IF(Z(NV,NF).LT.ZSURF(NV,1)) JSURF(NV)=NF
        VSEG(NV,NF)=ZLAYER*BVC(NV)
   89 CONTINUE
       END IF
C
C    Card Types 8 and 9. Groundwater return quantity and quality.
C
       READ(4,1065) QRET(N),(CRET(I,N),I=1,12)
```

```
C
C    Check to see if this is a headwater reach
C
     IF(NHEAD.EQ.0) GO TO 100
      HEAD(N)=.TRUE.
     IHEAD=IHEAD+1
      NMHEAD(IHEAD)=NHEAD
C
C    Card Types 10 and 11. Headwater quantity and quality.
      READ(4,1063) QHEAD(IHEAD),HDNAME(IHEAD),(CHEAD(I,IHEAD),I=1,12)
C
  100 CONTINUE
C
C    Check to see if there are point sources in the reach.
C
     IF(NPOINT(N).EQ.0) GO TO 150
     NCYCLE=NPOINT(N)
     DO 139 NN=1,NCYCLE
     NPONT=NPONT+1
     NRCH(NPONT)=N
C
C    Card Types 12 and 13. Point source quantity and quality.
C
       READ(4,1060) QPOINT(NPONT),RMP(NPONT),PNAME(NPONT),
    +         (CPOINT(I,NPONT),I=1,12)
  139 CONTINUE
  150 CONTINUE
     NCYCLE=NDIV(N)
C
C    Check for diversions
C
     IF (NDIV(N).EQ.0) GO TO 180
     DO 159 NN=1,NCYCLE
     NDIVRS=NDIVRS+1
C
C    Card Type 14. Diversion quantity and river mile of diversion.
     READ(4,1048) QDIV(NDIVRS),RMDIV(NDIVRS)
C
  159 CONTINUE
  180 CONTINUE
C
C    Check for stream junction.  If NJUNC.NE.0 set junction traps
C
     IF (NJUNC.EQ.0) GO TO 250
      NDPNT(N)=.TRUE.
     NJNCTN(N)=NJUNC
     NINJ(NJUNC)=NINJ(NJUNC)+1
  250 CONTINUE
C
C    Card Type 15. Delimiter card.
C
     READ(4,1080) END
```

```
C
C    Checking for card sequence error.  If there is, terminate program
C    with diagnostic identifying reach # with error
C
     IF(END.EQ.DLIM) GO TO 499
     WRITE(*,3000) N
 499 CONTINUE
 800 CONTINUE
     DO 899 I=1,IWPROV
     NWTAPE=50+I
     WRITE(*,2500) I
      CALL FNAME(NAMEI)
       OPEN(UNIT=NWTAPE,FILE=NAMEI)
       READ(NWTAPE,1400) WPNAME(I)
     DO 899 II=1,LDAY1-1
       READ(NWTAPE,1500) LL,(DDATA(J),J=1,7)
 899 CONTINUE
C
C    Call to output routine to write system information
C
     CALL WRITE0
 1020 FORMAT(A80)
 1040 FORMAT(16F5.0)
 1042 FORMAT(8I10)
 1044 FORMAT(16I5)
 1048 FORMAT(8F10.0)
 1050 FORMAT((A20,12F5.0))
 1060 FORMAT(2F10.0,A20/16F5.0)
 1063 FORMAT(F10.0,A20/16F5.0)
 1065 FORMAT(F10.0/16F5.0)
 1080 FORMAT(A3)
 1145 FORMAT(8F10.2)
 1152 FORMAT(6I3)
 1400 FORMAT(A20)
 1500 FORMAT(I5,7F10.0)
 2500 FORMAT(' Energy budget file for meteorologic province - ',I5)
 3000 FORMAT(1H0,' Card sequence error for data in Reach # - ',I5)
C
C         ****************************************************
C               Return to RMAIN
C         ****************************************************
C
     RETURN
 900 END
```

```
      SUBROUTINE SYSTEM

       DIMENSION CONCJ(12,10),NINJA(10),QNJ(10),WDATA(5,7),EDATA(7)
      EQUIVALENCE (EDATA(1),QNS)
C
      INCLUDE :RBM10.COM
C
     n1=1                          5/13/92
     n2=2                          5/13/92
      DO 999 ND=LDAY1,LDAY2
       WRITE(*,*) ' DAY =',ND
      DO 999 NDD=1,NPD
C
C     Read weather data from files if time period is correct
C
       IMOD=MOD(NDD,NWMOD)
      IF(IMOD.EQ.1) THEN
      DO 9 I=1,IWPROV
      NWR=50+I
       READ(NWR,1500) LDUMM,(WDATA(I,II),II=1,7)
 1700 FORMAT(I5,7E11.3)
    9 CONTINUE
      END IF
C
C     Begin reach computations
C
      IND=ND
      IPD=NDD
      DAY=ND
   20 IH1=1
      QSUM=0.0
      IHEAD=1
      NPONT=1
      NDIVRS=1
      DO 39 I=1,12
      C1(I)=CHEAD(I,IHEAD)
   39 CONTINUE
      DO 49 II=1,10
      NINJA(II)=0
      QNJ(II)=0.0
      DO 49 I=1,12
      CONCJ(I,II)=0.0
   49 CONTINUE
      DAY=ND
      QSUM=QHEAD(IHEAD)
C
C     Begin cycling through the reaches.
C
      NRR=0
```

```
      DO 899 N=1,NREACH
C
C     Read meteorological data from the appropriate file
C
       IWR=NWPROV(N)
C       QNS=WDATA(IWR,1)
C       QNA=WDATA(IWR,2)
C       DBT=WDATA(IWR,3)
C       WIND=WDATA(IWR,4)
C       PF=WDATA(IWR,5)
C       EA=WDATA(IWR,6)
C       PHOTO=WDATA(IWR,7)
      DO 59 I=1,7
        EDATA(I)=WDATA(IWR,I)
   59 CONTINUE
      NR=N
      RM1=RMILE1(N)
      RM2=RMILE2(N)
C
C     Check for reservoir.  If NRESRV(N).NE.0 set reservoir traps
C
       IF (NRESRV(N).NE.0) THEN
      CALL RESMOD
      ELSE
       CALL RIVMOD(RM1,RM2)
      END IF
  260 CONTINUE
C
C     Check for a junction
C
       IF (.NOT.NDPNT(N)) GO TO 300
      DO 279 NJ=1,10
       IF (NJNCTN(N).NE.NJ) GO TO 279
      QNJ(NJ)=QSUM+QNJ(NJ)
       NINJA(NJ)=NINJA(NJ)+1
      DO 269 IJ=1,12
      CONCJ(IJ,NJ)=CONCJ(IJ,NJ)+C1(IJ)*QSUM
       IF (NINJA(NJ).EQ.NINJ(NJ)) THEN
      C1(IJ)=CONCJ(IJ,NJ)/QNJ(NJ)
      END IF
  269 CONTINUE
      QSUM=0.0
       IF (NINJA(NJ).EQ.NINJ(NJ)) QSUM=QNJ(NJ)
  279 CONTINUE
  300 CONTINUE
```

```
C
C    Check for new headwaters
C
      IF (HEAD(N+1)) THEN
      IHEAD=IHEAD+1
      QSUM=QHEAD(IHEAD)
     DO 399 I=1,12
      C1(I)=CHEAD(I,IHEAD)
 399 CONTINUE
     END IF
 450 CONTINUE
 899 CONTINUE
     ntmp=n1                              5/13/92
    n1=n2                               5/13/92
    n2=ntmp                              5/13/92
 999 CONTINUE
 1500 FORMAT(I5,7F10.0)
 2600 FORMAT(16I5)
C
C         *****************************************************
C              Return to RMAIN
C         *****************************************************
C
 950 RETURN
     END
```

```
      SUBROUTINE QUALTY(TIME,CT,NLL,NSURF)

      REAL*4 IA,IS,KB,KT,K1,K2,K44,K55,K66,K77,KPI
      DIMENSION CT(12),C(12),DCDT(12)
      INCLUDE :RBM10.COM
      DATA ONRAT/3.42857/
C
C     Light limitation function
C
      FLIGHT(F,Z1,Z2,IA,IS,GAMMA)=
     . (2.718*F/(GAMMA*(Z2-Z1)))*
     . (EXP((-IA*EXP(-GAMMA*Z2))/IS)
     . -EXP((-IA*EXP(-GAMMA*Z1))/IS))
C
C     Nutrient limitation function
C
      FNUTR(Y,HALF)=Y/(Y+HALF)
C
C     Initialize concentrations
C
      DO 49 N=1,NCONST
      C(N)=CT(N)
      DCDT(N)=0.0
   49 CONTINUE
      DOFAC=C(1)/(0.5+C(1))
C
      DO 899 NRNG=1,2
C
C     Increment volume in second step of Runge-Kutta method
C
      FCTR=0.5*(NRNG-1)
      V=VELM+FCTR*DVOL
      DVDT=DVOL/DT
      QFCTR=QNOUT+DVDT
      D=DEPTH/3.2808
C
C     Compute typical temperature factors for various biological
C     processes
C
      T=C(9)
      TM20=T-20.0
      TF45=1.045**TM20
      TF84=1.084**TM20
C
C     Calculate rate constants which are in feedback loop
C     from nutrients to algae to nutrients
C
      DZQ=Z2-Z1
      DIN=C(5)+C(6)
      DIP=C(8)
      IA=VLIGHT
      IS=QOPT
```

```
      IF(T.GT.TOPT) GO TO 130
        TLIM=EXP(-2.3*((TOPT-T)/(TOPT-TLO))**2)
      GO TO 140
  130 CONTINUE
        TLIM=EXP(-2.3*((TOPT-T)/(TOPT-TUP))**2)
  140 CONTINUE
      NLIM=FNUTR(DIN,KMN)
      PLIM=FNUTR(DIP,KMP)
      QLIM=FLIGHT(PHOTO,Z1,Z2,IA,IS,GAMMA)
      XLIM=QLIM
      KLIM=1
      IF(XLIM.LT.NLIM.AND.XLIM.LT.PLIM) GO TO 144
      KLIM=2
      XLIM=NLIM
  144 IF(XLIM.LT.PLIM) GO TO 148
      KLIM=3
  148 CONTINUE
      PG=TLIM*QLIM*NLIM*PLIM*PG0/86400.
C
C
      PRES=PRES0*TF45/86400.
      KPI=PG-PRES
C
C     Calculate algal concentration - mg/l of carbon
C
      DCDT(3)=KPI*C(3)+(PLOAD(3)-C(3)*QFCTR)/V
C
C     Calculate organic nitrogen
C
  150 CONTINUE
C
C     Temperature factor for Organic-N mineralization
C
      TF4=TF84
      IF(TF4.LT.1.0E-5) TF4=1.0E-5
      K44=TF4*XKN44(NR)/86400.
      DCDT(4)=NCRAT*PRES*C(3)-K44*C(4)+(PLOAD(4)-C(4)*QFCTR)/V
C
C     Calculate ammonia-nitrogen
C
  200 CONTINUE
C
C     Temperature factor for NH4-N nitrification
C
      TF5=TF45
      IF(TF5.LT.1.0E-5) TF5=1.0E-5
      K55=TF5*XKN55(NR)/86400.
      DCDT(5)=-NCRAT*NH3PRF*PG*C(3)+K44*C(4)-K55*C(5)
     .       +(PLOAD(5)-C(5)*QFCTR)/V
```

```
C
C    Calculate nitrate-nitrogen
C
 250 CONTINUE


C
C     Temperature factor for NO3-N denitrification
C
     TF6=TF45
      IF(TF6.LT.1.0E-5) TF6=1.0E-5
      K66=TF6*XKN66(NR)/86400.
        DCDT(6)=-NCRAT*(1.-NH3PRF)*PG*C(3)+K55*C(5)
     .      -K66*C(6)+(PLOAD(6)-C(6)*QFCTR)/V
C
C    Calculate organic phosphorus
C
 300 CONTINUE
C
C     Temperature factor for Organic-P mineralization
C
     TF7=TF84
      IF(TF7.LT.1.0E-5) TF7=1.0E-5
      K77=TF7*XKP77(NR)/86400.
        DCDT(7)=PCRAT*PRES*C(3)-K77*C(7)+(PLOAD(7)-C(7)*QFCTR)/V
C
C    Calculate inorganic phosphorus
C
 350 CONTINUE
C
        DCDT(8)=-PCRAT*PG*C(3)+K77*C(7)+(PLOAD(8)-C(8)*QFCTR)/V
C
C    Calculate carbonaceous BOD
C
 400 CONTINUE
C
C   BOD
C
C     Temperature factor for BOD deoxygenation
C
     TF1=TF45
      IF(TF1.LT.1.0E-5) TF1=1.0E-5
      K1=TF1*XKBODL(NR)/86400.
        DCDT(1)=-K1*C(1)+(PLOAD(1)-C(1)*QFCTR)/V
C
C     Calculate dissolved oxygen
C
 500 CONTINUE
C
C     Temperature factor for DO rearation
C
     TF2=1.024**TM20
      IF(TF2.LT.1.0E-5) TF2=1.0E-5
```

```
C
C   Saturation level
C
     CSAT=(14.62-0.3898*T+0.006969*T**2-5.897E-5*T**3)
      CSAT=CSAT*((1.-(6.97E-6*ELEV(NR)))**5.167)
     SDMND=TF45*SOD(NR)/(DEPTH*86400.)
C
     IF (XKDO(NR).GT.0.0) GO TO 519
     ZPOINT=ABS(XKDO(NR))
     IPOINT=ZPOINT
     REARC=0.0
     IF(IPOINT.EQ.0) GO TO 520
 505 CONTINUE
     GO TO (511,513,515,518),IPOINT
C
C    Wind-driven effects on reaeartion in lakes and reservoirs
C
 511 CONTINUE
      REARC=(0.64+0.128*WIND*WIND)*3.2808/DZQ
     GO TO 520
C
C    Churchill-Elmore-Buckingham equation for reaeration
C
 513 REARC=11.6*(U**0.969)/(DEPTH**1.673)
     GO TO 520
C
C    O'Connor-Dobbins equation for reaeration
C
 515 REARC=12.9*U**0.5/DEPTH**1.5
     GO TO 520
C
C    Owens-Edwards-Gibbs equation for reaeration
C
 518 REARC=21.6*((U**0.67)/(DEPTH**1.85))
     GO TO 520
C
C   User-defined reaeration rate
C
 519 CONTINUE
     REARC=XKDO(NR)
C
 520 K2=TF2*REARC/86400.
C
C   OCRAT and ONRAT are stoichiometric ratios for oxygen produced by
C   carbon fixation and nitrate uptake.  Defined in DATA statement in
C   RBM10.COM
C
       O2PROD=PG*C(3)*(OCRAT+ONRAT*NCRAT*(1.-NH3PRF))
     O2LOSS=OCRAT*PRES*C(3)
```

```
C
      DCDT(2)=-K2*(C(2)-CSAT)-K1*C(1)-4.57*K55*C(5)
     .  +O2PROD-O2LOSS-SDMND+(PLOAD(2)-C(2)*QFCTR)/V

C
C    Temperature calculation
C    R= Rho * Cp * Conversion Factor= 1000. * 1.0 / 3.2808
C    (Converts energy budget from MKS units to English units)
C    Initialized in DATA statement above
C
      DCDT(9)=(PLOAD(9)-C(9)*QFCTR)/V
 600  CONTINUE
C
C
C     Calculate coliform concentrations
C
C
C    Temperature-dependent rate constant
C
      KB=XKBACT(NR)*2.3E-6*(1.+0.111*T)
      DCDT(10)=-KB*C(10)
     .  +(PLOAD(10)-C(10)*QFCTR)/V
      IF(NRNG.EQ.1) THEN
      DO 849 N=1,NCONST
       C(N)=C(N)+DT2*DCDT(N)
 849  CONTINUE
      END IF
 899  CONTINUE
      DO 949 N=1,NCONST
        CT(N)=CT(N)+DT*DCDT(N)
        IF(CT(N).LT.0.0) CT(N)=0.0
 949  CONTINUE
 999  CONTINUE
C
C         *****************************************************
C         Return to Subroutine RESMOD/RIVMOD
C         *****************************************************
C
      RETURN
      END
C
```

```
      SUBROUTINE WRITE0(XARG)
C
      CHARACTER*1 CMMA,LIM(3)
      INCLUDE :RBM10.COM
        DATA CMMA/',',LIM/'L','N','P'/
C
C     Print general information regarding river system
C
      WRITE(7,2010) XTITLE
C
C     General systems parameters
C
      WRITE(7,2015) NREACH,DT,LDAY1,LDAY2,NWPD,NDPRNT
C
C     Headwaters
C
      WRITE(7,2020) (NMHEAD(I),HDNAME(I),I=1,IHEAD)
C
C     Point sources
C
      WRITE(7,2025) (I,PNAME(I),NRCH(I),I=1,NPONT)
C
C     Reservoirs
C
      WRITE(7,2030) (I,RSNAME(I),I=1,IRES)
C
C     Meteorologic provinces
C
      WRITE(7,2035) (I,WPNAME(I),I=1,IWPROV)
C
C     Parameters for phytoplankton dynamics
C
      WRITE(7,2040) OCRAT,CCLRAT,NCRAT,PCRAT
     .      ,KMN,KMP,NH3PRF
     .      ,QOPT,WSINK
     .      ,TOPT,TLO,TUP
     .      ,PG0,PRES0
      RETURN
C
C     First entry point from river/reservoir modules
C
      ENTRY WRITE1(XARG)
      JPLOT=0
      DO 19 I=1,IPLOT
      IF(NR.NE.NPLOT(I)) GO TO 19
      IPFILE=19+I
      JPLOT=I
   19 CONTINUE
      RM1=RMILE1(NR)
      RM2=RMILE2(NR)
      WRITE(7,2045) XTITLE
      WRITE(7,2050) NR,RNAME(NR),RM1,RM2,ND
```

```
      IF(.NOT.HEAD(NR)) GO TO 30
      WRITE(7,2060) QHEAD(IHEAD),(CHEAD(I,IHEAD),I=1,10)
   30 CONTINUE
      WRITE(7,2080) QRET(NR),(CRET(I,NR),I=1,10)
      NCYCLE=NPOINT(NR)
      NPNT1=0
      NDV1=0
      NR1=NR-1
      IF(NR1.EQ.0) GO TO 50
      DO 49 I=1,NR1
       NPNT1=NPNT1+NPOINT(I)
      NDV1=NDV1+NDIV(I)
   49 CONTINUE
   50 CONTINUE
C
C     Write titles for point sources
C
      IF(NCYCLE.EQ.0) GO TO 100
      WRITE(7,2052)
      DO 99 I=1,NCYCLE
      NPNT1=NPNT1+1
        XBOD=CPOINT(1,NPNT1)*5.4*QPOINT(NPNT1)
        XNH3=CPOINT(5,NPNT1)*5.4*QPOINT(NPNT1)
        XN23=CPOINT(6,NPNT1)*5.4*QPOINT(NPNT1)
        XPO4=CPOINT(8,NPNT1)*5.4*QPOINT(NPNT1)
        WRITE(7,1053) PNAME(NPNT1),RMP(NPNT1),QPOINT(NPNT1)
     .        ,CPOINT(2,NPNT1),XBOD,XNH3,XN23,XPO4
     .        ,CPOINT(9,NPNT1),CPOINT(10,NPNT1)
   99 CONTINUE
  100 CONTINUE
C
C     Write titles for diversions
C
      NCYCLE=NDIV(NR)
      IF(NCYCLE.EQ.0) GO TO 200
      WRITE(7,2054)
      DO 199 I=1,NCYCLE
      NDV1=NDV1+1
      QDV1=QDIV(NDV1)
       WRITE(7,1055) RMDIV(NDV1),QDIV(NDV1)
  199 CONTINUE
  200 CONTINUE
```

```
      IF(NRESRV(NR).EQ.0) THEN
       WRITE(7,2056) DEPTH1(NR),DEPTH2(NR),REARC,XKBODL(NR),QNS
      . ,VEL1(NR),VEL2(NR),XKN44(NR),PHOTO,XKN55(NR),XKN66(NR)
     . ,XKP77(NR)
     GO TO 250
     ELSE
      NV=NRESRV(NR)
      WRITE(7,2057) REARC,XKBODL(NR),QNS
      . ,XKN44(NR),PHOTO,XKN55(NR),XKN66(NR),XKP77(NR)
       WRITE(7,2058) NV,QOUT,ZSURF(NV,1),VRES(NV,2),ZSURF(NV,2)
     END IF
  250 CONTINUE
     WRITE(7,2045) XTITLE
      WRITE(7,2050) NR,RNAME(NR),RM1,RM2,ND
C
C   Call first entry point in output routine.  Pass argument with
C    information about hydrologic regime.
C
     IF(XARG.GE.0.0) THEN
     WRITE(7,2100)
     ELSE
     WRITE(7,2110)
     END IF
C
C    First return point
C
C
C         ******************************************************
C         Return to Subroutine RESMOD/RIVMOD
C         ******************************************************
C
     RETURN
C
C    Entry point to write simulated values of water quality and water budget
C
      ENTRY WRITE2(XARG)
     DO 269 N=1,12
     COUT(N)=CONC(N,NRR,n1)                      5/13/92
  269 CONTINUE
C
      XSAT=100.*COUT(2)/CSAT
      XALGAE=1000.*COUT(3)/CCLRAT
     PKA=0.0902+(2730./(COUT(9)+273.2))
      PERN=1./(1.+10.**(PKA-COUT(11)))
     UNNH3=1000.*COUT(5)*PERN
     XPORG=1000.*COUT(7)
     XPO4=1000.*COUT(8)
     XPTOT=XPO4+XPORG
     ISAT=XSAT
```

```
      IF(XARG.GE.0.0) THEN
     XAVE=XARG
       WRITE(7,2400) XAVE,COUT(2),ISAT,COUT(1),XALGAE,LIM(KLIM),COUT(5)
      . ,COUT(6),XPO4,COUT(9),COUT(10),Q1,QTPNT,QRETRN,QTDIV,DVDT,Q2
     ELSE
     XAVE=-XARG
     QV1= QVRT1
     QV2=-QVRT2
       WRITE(7,2410) XAVE,COUT(2),ISAT,COUT(1),XALGAE,LIM(KLIM)
      . ,COUT(5),COUT(6),XPO4,COUT(9),COUT(10),QRINN,QV1,QV2,DVDT,QROUTN
  350 CONTINUE
     END IF
     IF(JPLOT.EQ.0) GO TO 380
       IF(IPD.EQ.1.AND.NR.EQ.NPLOT(JPLOT)) then
      BOD5=COUT(2)*(1-EXP(-5*XKBODL(NR)))
C
C     WRITE PLOTTER OUTPUT TO RIVPLOT.DAT.  RECORD CONTAINS BOD(5-DAY),
C     DO, Chlorophyll a,AMMONIA NITROGEN,NITRITE + NITRATE NITROGEN,
C     DISSOLVED ORTHOPHORUS, AND TEMPERATURE.
C
      WRITE(IPFILE,1010) ND,CMMA,COUT(2),CMMA,BOD5,CMMA,XALGAE
      . ,CMMA,COUT(5),CMMA,COUT(6),CMMA,COUT(7),CMMA,COUT(9)
     end if
  380 CONTINUE
 1010 FORMAT(I5,3(A1,F6.1),3(A1,F6.3),A1,F6.1)
 1025 FORMAT(16I5)
 1050 FORMAT(7X,I3,A20,7X,F7.0,8X,F7.0,8X,F7.0)
 1052 FORMAT(40I2)
 1053 FORMAT(T12,A20,T34,F6.1,1X,F7.1,4X,F4.1,1X,F6.0,1X,F6.0,
    . 2X,F6.0,1X,F6.0,1X,F6.0,1X,F6.0,3X,F4.1)
 1054 FORMAT(16X,F6.1,8X,F6.1,6X,F6.1,6X,F6.1)
 1055 FORMAT(T12,F6.1,T25,F6.1)
 1056 FORMAT(14X,F6.3,8X,F6.3,8X,F6.3,8X,F6.3,8X,F6.3,4X)
 1070 FORMAT(34X,F6.3,7X,F6.3,A20/
    . (14X,F6.3,6X,F6.3,6X,F6.3,6X,F6.3,6X,F6.3,12X))
 1080 FORMAT(14X,F6.1,7X,F6.1,8X,I6,7X,F6.1)
 2010 FORMAT(1H1//T12
     .,' --------------',33X,'RIVER BASIN MODEL'
    .          ,32X,'-------------'//
    .            T12,' -------------- ',A80,' -------------')
 2015 FORMAT(//T12,' NUMBER OF REACHES      - ',I5/
    .        T12,' TIME INCREMENT         - ',F5.0,' seconds'/
    .       T12,' STARTING DAY          - ',I5/
    .       T12,' ENDING DAY            - ',I5/
    .         T12,' WEATHER DATA INCREMENT - ',I5,' per day'/
    .        T12,' PRINTOUT INTERVAL      - ',I5,' days')
 2020 FORMAT(//T12,'       HEADWATERS'/
    .       T12,'  #    NAME'/
    .          T12,' ________________________________'/
    .      T12,I5,A20)
```

```
2025 FORMAT(//T12,'     POINT SOURCES'/
 .      T12,'  #     NAME      REACH NO.'/
 .          T12,' _____________________________'/
 .      T12,I5,A20,I5)
2030 FORMAT(//T12,'     RESERVOIRS'/
 .      T12,'  #     NAME    '/
 .          T12,' _____________________________'/
 .      T12,I5,A20)
2035 FORMAT(//T12,'     METEOROLOGIC PROVINCES'/
 .      T12,'  #     NAME     '/
 .          T12,' _____________________________'/
 .      T12,I5,A20)
2040 FORMAT(//T12,' Parameters for Algal Dynamics '/
 .        T12,' ---------------------------- '/
 .    T12,' O:C Ratio               - ',F5.2/
 .     T12,' Carbon:Chlorophyll Ratio  - ',F5.1/
 .    T12,' N:C Ratio               - ',F5.3/
 .    T12,' P:C Ratio               - ',F5.3/
 .      T12,' Nitrogen Half-Saturation   - ',F5.3,' mg/l'/
 .      T12,' Phosphorus Half-Saturation - ',F5.3,' mg/l'/
 .     T12,' Algal Preference for NH4  - ',F5.1/
 .      T12,' Optimal Light Intensity    - ',F5.3,' kcal/m**2/sec'/
 .     T12,' Sinking Rate              - ',F5.3,' meters/day'/
 .     T12,' Optimal Temperature       - ',F5.1,' Deg. C'/
 .     T12,' Minimum Temperature       - ',F5.1,' Deg. C'/
 .     T12,' Maximum Temperature       - ',F5.1,' Deg. C'/
 .     T12,' Maximum Growth Rate       - ',F5.1,' 1/days'/
 .      T12,' Maximum Respiration Rate   - ',F5.2,' 1/days')
2045 FORMAT(1H1////1X,A80)
2050 FORMAT(1X,'REACH NUMBER ',I2/1X,A20,/1X,
  . 'R.M. ',F5.1,' TO R.M. ',F5.1/1X,
  . 'DAY -',I5)
2052 FORMAT(////T12,'POINT SOURCES'/
 .        T12,'-------------'/
  . T12,'NAME',T35,'RIVER  FLOW   DO   BODL  NH3  NO2+NO3',
  . ' PHOS TEMP  BACT'/
  . T36,'MILE  (CFS) (MG/L) (LB/D) (LB/D) (LB/D)  (LB/D) (CENT)'
  . ,' (/100ML)'/)
2054 FORMAT(////T12,'DIVERSIONS'/
 .        T12,'----------'/
   . T12,'RIVER',T25,'FLOW'/T12,'MILE',T25,'(CFS)'/)
2056 FORMAT(////T12,'HYDAULIC COEFFICIENTS',18X,'RATE CONSTANTS(BAS',
  .'E E), DAYS**-1',10X,'HEAT BUDGET PARAMETERS'/
    .11X,'---------------------',18X,'------------------------------'
   .,10X,'--------------------'/
  . T12,'DEPTH    = ',F7.4,'*FLOW**',F6.4,T51,'K2(D0) = ',F6.3,
  . T68,'K1(BOD) = ',F6.4,T92,'Q(NET SOLAR) = ',F6.4,' KCAL'/
  . T12,'VELOCITY = ',F7.4,'*FLOW**',F6.4,T51,'  KN44 = ',F6.3
 .               ,T92,'PHOTO PERIOD = ',F5.2,' DAYS/DAY'/
 .                       T51,'  KN55 = ',F6.3/
 .                       T51,'  KN66 = ',F6.4/
 .                       T51,'  KP77 = ',F6.4)
2057 FORMAT(////T51,'RATE CONSTANTS(BAS',
```

```
     .'E E), DAYS**-1',10X,'HEAT BUDGET PARAMETERS'/
       .11X,'--------------------',18X,'------------------------------'
     .,10X,'--------------------'/
                     T51,'K2(D0) = ',F6.3,
     . T68,'K1(BOD) = ',F6.4,T92,'Q(NET SOLAR) = ',F6.4,' KCAL'/
                     T51,' KN44 = ',F6.3
                ,T92,'PHOTO PERIOD = ',F5.2,' DAYS/DAY'/
                     T51,' KN55 = ',F6.3/
                     T51,' KN66 = ',F6.4/
     .               T51,' KP77 = ',F6.4)
 2058 FORMAT(////T12,'RESERVOIR NUMBER ',I2/
     . T12,'------------------------'//T12,'OUTFLOW',9X,' = ',F10.0,
     .  ' FT**3/SEC.',T54,'INITIAL DEPTH = ',F5.0,' FEET'/
     .  T12,'RESERVOIR VOLUME = ',1PE10.2,' FT**3',T54,
     .  'FINAL DEPTH   = ',0PF5.0,' FEET')
 2060 FORMAT(////T12,'HEADWATERS',10X,'FLOW    BODL    DO    ALGAE',
     .     ' ORG-N  NH3-N  NO3-N  ORG-P  PO4-P  TEMP   BACT '/
     .       T12,'----------',
     .      T32,'(CFS)  (MG/L) (MG/L)  (MG/L) (MG/L) (MG/L) (MG/L)',
     .      ' (MG/L) (MG/L)(CENT) (/100ML)'//
     .    28X,F7.0,3X,8(F5.1,2X),1X,F4.1,2X,F8.0)
 2080 FORMAT(////T12,'GROUNDWATER',9X,'FLOW    DO    BODL   ALGAE',
     .     ' ORG-N  NH3-N  NO3-N  ORG-P  PO4-P  TEMP   BACT '/
     .      T12,'RETURN',14X,'(CFS)  (MG/L) (MG/L)  (MG/L) (MG/L)',
     .      ' (MG/L) (MG/L) (MG/L) (MG/L)(CENT) (/100ML)'/
     .      T12,'-----------'/
     .    28X,F7.0,3X,8(F5.1,2X),1X,F4.1,2X,F8.0//)
C
 2100 FORMAT(////1X,'RIVER    DO     BODL  ALGAE  NH3-N NO2+NO3 ',
     . ' PHOS',
     .'   TEMP   BACT    INFLOW  + POINT  + SEEPAGE - DIVERSIONS',
     . ' -  DVDT  = OUTFLOW'/1X,'MILE  (MG/L)(%SAT)(MG/L) (uG/L)  ',
     . '(MG/L)',
     . ' (MG/L) (uG/L)  (CENT) (/100ML)    (CFS)   (CFS)    (CFS)',
     .'     (CFS)    (CFS)   (CFS)'//)
 2110 FORMAT(////1X,'ELEV     DO     BODL  ALGAE  NH3-N NO2+NO3 ',
     . ' PHOS',
     .'   TEMP   BACT    INFLOW  + VERT(N-1) + VERT(N)',
     . ' -  DVDT  = OUTFLOW'/1X,'(FT) (MG/L)(%SAT)(MG/L) (uG/L)  ',
     . '(MG/L)',
     . ' (MG/L) (uG/L)  (CENT) (/100ML)    (CFS)   (CFS)    (CFS)',
     .'     (CFS)    (CFS)'//)
 2400 FORMAT(1X,F5.1,1X,F4.1,2X,I3,2H% ,F6.1,1X,F6.1,A1
     . ,2X,F5.2,2X,F5.2,2X,F6.1,4X,F4.1,1X,F8.0,3X
     . ,F7.1,3X,F7.1,3X,F7.1,4X,F7.1,4X,F7.1,3X,F7.1)
 2410 FORMAT(1X,F5.1,1X,F4.1,2X,I3,2H% ,F6.1,1X,F6.1,A1
     . ,2X,F5.2,2X,F5.2,2X,F6.1,4X,F4.1,1X,F8.0,3X
     . ,F7.1,3X,F7.1,3X,F7.1,4X,F7.1,4X,F7.1,3X,F7.1)
 2450 FORMAT(8F10.2)
```

```
C
C        *****************************************************
C        Return to Subroutine RESMOD/RIVMOD
C        *****************************************************
C
   RETURN
C
C   Entry point to write end-of-reach values
C
   ENTRY WRITE3
   O2L=O2LOSS*86400.
   O2P=O2PROD*86400.
C
   WRITE(7,2500)
    WRITE(7,2700) ELEV(NR),DEPTH,U,CSAT,O2P,02L,SOD(NR)
 2500 FORMAT(1H1,20X,'END-OF-REACH VALUES FOR VARIOUS PARAMETERS'//)
C
 2700 FORMAT(21X,'SURFACE ELEVATION         - ',F8.1,' FEET'/
   .     21X,'WATER DEPTH              - ',F8.1,' FEET'/
   .     21X,'WATER VELOCITY           - ',F8.4,' FEET/SEC'/
   .     21X,'DISSOLVED OXYGEN SATURATION - ',F8.1,' MG/L'/
   .     21X,'OXYGEN PRODUCTION        - ',F8.4,' MG/L/DAY'/
   .     21X,'RESPIRATION RATE         - ',F8.4,' MG/L/DAY'/
   .     21X,'SEDIMENT OXYGEN DEMAND   - ',F8.2,' GM/M**2/DAY'/)
C
C        *****************************************************
C        Return to Subroutine RESMOD/RIVMOD
C        *****************************************************
C
   RETURN
   END
```

```
      SUBROUTINE RESMOD
       REAL*4 C(12),CRES(12,10),DCDT(12),INFRED(10),QRIN(10),QROUT(10)
     .     ,QVERT(0:10),RSLOAD(12,10)
      INCLUDE :RBM10.COM
      DATA DIFF/1.0E-4/
      GFUNC(A,B,EL)=A+B*EL
      HFUNC(A,B,EL)=A*EXP(B*EL)
C
C     Initialize important counters, constants and variables
C
      NFIX=NCELM(NR)
      NDVRN=NDIV(NR)
      NPNN=NPOINT(NR)
      NPN=NPONT
      NV=NRESRV(NR)
      NSURF=JSURF(NV)
      NSRFM1=NSURF-1
      IF(NSRFM1.LE.0) NSRFM1=1
      QIN=QSUM
      QOUT=0.0
      DO 19 N=1,NFIX
       AXY(N)=BVC(NV)
      IR=NRR+N
      DO 19 NN=1,NCONST
      CRES(NN,N)=CONC(NN,IR,n1)                         5/13/92
   19 CONTINUE
      DO 29 N=1,NFIX
      QRIN(N)=0.0
      QROUT(N)=0.0
      DO 29 NN=1,12
       RSLOAD(NN,N)=0.0
   29 CONTINUE
C
C     Determine level of inflow for upstream flow and update loading for
C     appropriate element
C
      TMPIN=CONC(9,NRR,n1)                           5/13/92
        CALL LAYRIN(CRES,TMPIN,NSURF,NLYR)
        QRIN(NLYR)=QRIN(NLYR)+QSUM
      DO 39 NNN=1,NCONST
         RSLOAD(NNN,NLYR)=RSLOAD(NNN,NLYR)+QSUM*C1(NNN)
   39 CONTINUE
C
C     Determine level of inflow for point sources and update loading
C     for appropriate element
C
      IF(NPNN.EQ.0) GO TO 95
      DO 89 NN=1,NPNN
       QIN=QIN+QPOINT(NPN)
       TMPIN=CPOINT(9,NPN)
        CALL LAYRIN(CRES,TMPIN,NSURF,NLYR)
```

```
      QRIN(NLYR)=QRIN(NLYR)+QPOINT(NPN)
      DO 49 NNN=1,NCONST
        RSLOAD(NNN,NLYR)=RSLOAD(NNN,NLYR)+QPOINT(NPN)*CPOINT(NNN,NPN)
   49 CONTINUE
      NPN=NPN+1
   89 CONTINUE
   95 CONTINUE
      IF(NDVRN.EQ.0) GO TO 105
      DO 99 NN=1,NDVRN
       QOUT=QOUT+QDIV(NDIVRS)
        QROUT(NSURF)=QROUT(NSURF)+QDIV(NDVR)
      NDIVRS=NDIVRS
   99 CONTINUE
  105 CONTINUE
C
C     Determine inflow layer for return flow and update loading for
C     appropriate element
C
      QIN=QIN+QRET(NR)
      TMPIN=CRET(9,NR)
       CALL LAYRIN(CRES,TMPIN,NSURF,NLYR)
        QRIN(NLYR)=QRIN(NLYR)+QRET(NR)
      DO 149 NNN=1,NCONST
        RSLOAD(NNN,NLYR)=RSLOAD(NNN,NLYR)+QRET(NR)*CRET(NNN,NR)
  149 CONTINUE
      QOUT=QOUT+QRES(NSURF,NV)
      QDWN=QRES(NSURF,NV)
       QROUT(NSURF)=QROUT(NSURF)+QRES(NSURF,NV)
      DO 189 NN=1,NSRFM1
      QOUT=QOUT+QRES(NN,NV)
       QDWN=QDWN+QRES(NN,NV)
        QROUT(NN)=QROUT(NN)+QRES(NN,NV)
  189 CONTINUE
C
C     Mass balance, estimate new volum and surface elevation
C
      DVOL=(QIN-QOUT)*DT
      VRES(NV,2)=VRES(NV,1)+DVOL
       ZSURF(NV,2)=(VRES(NV,2)-AVC(NV))/BVC(NV)
C
C     Calculate vertical velocities from continuity
C
      QVERT(1)=QRIN(1)-QROUT(1)
      IF(NSRFM1.LE.1) GO TO 300
      DO 249 NN=2,NSRFM1
        QVERT(NN)=QRIN(NN)-QROUT(NN)+QVERT(NN-1)
  249 CONTINUE
  300 CONTINUE
      QVERT(NSURF)=0.0
```

```
C
C    Calculate advective load using upstream weighting
C
      DO 349 NN=1,NSRFM1
      NR1=NN+1
      NR2=NN
      FQ=1.0
       IF(QVERT(NN).LE.0.0) THEN
      NR1=NN
      NR2=NN+1
      FQ=-1.0
      END IF
      DO 347 NNN=1,NCONST
        RSLOAD(NNN,NR1)=RSLOAD(NNN,NR1)+FQ*QVERT(NN)*CRES(NNN,NR2)
  347 CONTINUE
  349 CONTINUE
C
C    Calculate diffusion load
C
      DO 399 N=1,NSRFM1
      Nz1=N
     Nz2=N+1                          5/13/92
      dz=z(nv,nz2)-z(nv,nz1)                  5/13/92
      DO 399 NN=1,NCONST                       5/13/92
      DFFUSN
     . =DIFF*AXY(N+1)*(CRES(NN,Nz2)-CRES(NN,Nz1))/dz             5/13/92
       RSLOAD(NN,N)=RSLOAD(NN,N)+DFFUSN
       RSLOAD(NN,N+1)=RSLOAD(NN,N+1)-DFFUSN
  399 CONTINUE
C
C    Call Subroutine QUALTY to calculate concentrations in each element
C
       INFRED(NSURF+1)=0.5*QNS
       DZZ=ZSURF(NV,1)-Z(NV,NSURF)
       AREA2=ASURF(NV,NSURF+1)
      XKDO(NR)=-1.0
      DO 419 N=NSURF,1,-1
       AREA1=ASURF(NV,N)
C
C    Account for sinking rates of plankton
C
        RSLOAD(3,N)=RSLOAD(3,N)+VSINK*(AREA2*CRES(3,N+1)-AREA1*CRES(3,N))
C
C    Light shading due to plankton
C
       CHLR=1000.*CRES(3,N)/CCLRAT
       GAMMA=(EXCO(NR)+0.0088*CHLR+0.054*CHLR**0.67)/3.2808
        INFRED(N)=HFUNC(INFRED(N+1),GAMMA,-DZZ)
        HEAT=INFRED(N+1)*AREA2-INFRED(N)*AREA1
```

```
C
C    Update thermal load.  RFAC=Rho*Cp*Conversion=1000.*1./3.2808
C                =304.8
C
      RSLOAD(9,N)=RSLOAD(9,N)+HEAT/304.8
      IF(N.GT.1) DZZ=(Z(NV,N)-Z(NV,N-1))
C
C    Initialize constituent loading factors
C
     DO 409 NN=1,NCONST
      PLOAD(NN)=RSLOAD(NN,N)
 409 CONTINUE
      IF(N.EQ.NSURF.OR.NSURF.EQ.1) THEN
     TSURF=CRES(9,N)
      CALL ENERGY(TSURF,QSURF)
       VELM=GFUNC(AVC(NV),BVC(NV),ZSURF(NV,1)-Z(NV,NSURF))
     VSURF=VELM
      IF(NSURF.EQ.1) VSURF=VSURF+VOL0
C
C    Account for heat flux at surface
C
      PLOAD(9)=PLOAD(9)+QSURF*AREA2/304.8
     ELSE
      VELM=VSEG(NV,N)
     DVOL=0.0
     QSURF=0.0
     END IF
      Z1=ZSURF(NV,1)-Z(NV,N+1)
      Z2=ZSURF(NV,1)-Z(NV,N)
        QNOUT=QROUT(N)+AMAX1(QVERT(N),0.0)-AMIN1(QVERT(N-1),0.0)
      VLIGHT=INFRED(N+1)
       CALL QUALTY(TIME,CRES(1,N),N,NSURF)
      NLIMT(N)=KLIM
     XKDO(NR)=0.0
     AREA2=AREA1
 419 CONTINUE
C
C    Call Subroutine MIX if there is a temperature instability
C
      IF (NSURF.GT.1) THEN
      CALL MIX(CRES,VSURF,NSURF,NV)
     END IF
     DO 429 N=NSURF,1,-1
     DO 429 NN=1,NCONST
     nrrn=nrr+n
      CONC(NN,NRRN,n2)=CRES(NN,N)
 429 CONTINUE
     NRR=NRR+NSURF
     DO 439 N=NSURF,1,-1
      KLIM=NLIMT(N)
      QRINN=QRIN(N)
      QROUTN=QROUT(N)
     QVRT1=0.0
```

```
     IF(N.NE.1) QVRT1=QVERT(N-1)
     QVRT2=QVERT(N)
     XARG=-(Z(NV,N+1)+Z(NV,N))*0.5
     NPMOD=MOD(ND,NDPRNT)
    IF(NPMOD.NE.0) GO TO 435
    IF(IPD.EQ.1) THEN
     IF(N.EQ.NSURF) CALL WRITE1(XARG)
    CALL WRITE2(XARG)
   END IF
 435 CONTINUE
    NRR=NRR-1
 439 CONTINUE
C
C     Update downstream loading by computing loading released from
C     reservoir
C
    DO 459 NN=1,NCONST
    CSUM=0.0
    DO 449 N=1,NSURF
    CSUM=CSUM+QRES(N,NV)*conc(NN,N+nrr,n1)                 5/13/92
 449 CONTINUE
    C1(NN)=CSUM/QDWN
 459 CONTINUE
C
C     Combine surface element with next lower one if thickness is less than
C     minimum
C
     ZDIFF=ZSURF(NV,2)-Z(NV,NSURF)
     IF(ZDIFF.LE.ZLOW) THEN
    NR1=NSURF
    NR2=NSURF+1
    NRR1=NRR+NSURF-1
    NRR2=NRR+NSURF
      DVOL1=GFUNC(AVC(NV),BVC(NV),Z(NV,NR2))
    .     -GFUNC(AVC(NV),BVC(NV),Z(NV,NR1))
     DVOL2=GFUNC(AVC(NV),BVC(NV),ZSURF(NV,1))
    .     -GFUNC(AVC(NV),BVC(NV),Z(NV,NR2))
    DO 469 NN=1,NCONST
    CONC(NN,NRR1,n2)
   .=(DVOL1*CONC(NN,NRR1,n2)+DVOL2*CONC(NN,NRR2,n2))           5/13/92
   ./(DVOL1+DVOL2)
C
C     Zero out concentration in the element which was eliminated so
C     there will be no artificial fluxes from the top down
C
    CONC(NN,NRR2,n2)=0.0
 469 CONTINUE
    NSURF=NSURF-1
    END IF
```

```
C
C   If layer thickness exceeds tolerance, create a new element with
C   concentration equal to value in the old surface layer
C
     IF(ZDIFF.GE.ZHIGH(NV)) THEN
    NR1=NSURF
    NR2=NSURF+1
    DO 479 NN=1,NCONST
    CONC(NN,NR2,n2)=CONC(NN,NR1,n2)                    5/13/92
 479 CONTINUE
    NSURF=NSURF+1
    END IF
C
C   Increment sub-reach index (NRR) by NFIX since that is the
C   number of places reserved for vertical layers in each reservoir.
C   NFIX is initialized in the input data
C
    NRR=NRR+NFIX
C
C   Update reservoir surface elevation and volume
C
    ZSURF(NV,1)=ZSURF(NV,2)
    VRES(NV,1)=VRES(NV,2)
C
C        ******************************************************
C         Return to Subroutine SYSTEM
C        ******************************************************
C
    RETURN
    END
```

```
      SUBROUTINE RIVMOD(RM1,RM2)

      REAL*4 C(12),DCDT(12)
      INCLUDE :RBM10.COM
        EQUIVALENCE (NCONST,NC),(AXY(1),AREA1),(AXY(2),AREA2)
      DATA None/1/                              5/13/92
C
C   Specify some constants and determine the number of
C   computational elements in the reach.
C
      NCYCLE=NCELM(NR)
      CYCLE=NCYCLE
      NSURF=1
      DXM=(RM1-RM2)/CYCLE
      DX=5280.*DXM
       QRETRN=QRET(NR)/CYCLE
      XKDO(NR)=-2.0
C
C   Calculate properties in each of the computational elements
C
      DO 249 NN=1,NCYCLE
C
C   Update loading rates with return flow
C
      DO 99 NNN=1,12
        PLOAD(NNN)=QRETRN*CRET(NNN,NR)
   99 CONTINUE
C
C    Index segment number (NRR)
C
      NRR=NRR+1
C
C    Initialize reach flows
C
      QTDIV=0.0
      QTPNT=0.0
C
C    Location of upstream and downstream boundaries
C
       X1=RM1-DX*(NN-1.)/5280.
      X2=RM1-DX*NN/5280.
      XAVE=(X1+X2)/2.
C
C    Check for diversions
C
       IF (NDIV(NR).EQ.0) GO TO 150
  135 XMDIV=RMDIV(NDIVRS)
        IF (XMDIV.GT.X1.OR.XMDIV.LT.X2) GO TO 150
        QTDIV=QDIV(NDIVRS)+QTDIV
       NDIVRS=NDIVRS+1
      GO TO 135
  150 CONTINUE
```

```
C
C   Check for point sources
C
    IF (NPOINT(NR).EQ.0) GO TO 165
155 XMP=RMP(NPONT)
C
C   if a point source is within reach boundaries, combine
C   the waste flow with the river flow.
C
    IF (XMP.GT.X1.OR.XMP.LT.X2) GO TO 165
    DO 159 NNN=1,12
       PLOAD(NNN)=PLOAD(NNN)+CPOINT(NNN,NPONT)*QPOINT(NPONT)
159 CONTINUE
     QTPNT=QTPNT+QPOINT(NPONT)
    NPONT=NPONT+1
    GO TO 155
165 CONTINUE
C
C   Determine the water balance
C
    Q1=QSUM
     Q2=QSUM+QRETRN+QTPNT-QTDIV
     QIN=QSUM+QRETRN+QTPNT
    QNOUT=QIN
C
C   Update loading rates with upstream input
C
    DO 169 NNN=1,12
      PLOAD(NNN)=PLOAD(NNN)+Q1*C1(NNN)
169 CONTINUE
C
C   Perform mass balance and estimate volume change
C
    DVOL=(Q1-Q2)*DT
    VELM=VOL(NR)/CYCLE
    QAVE=0.5*(Q1+Q2)
     U=VEL1(NR)*QAVE**VEL2(NR)
      DEPTH=DEPTH1(NR)*QAVE**DEPTH2(NR)
    DO 179 NNN=1,2
     AXY(NNN)=VELM/DEPTH
179 CONTINUE
    Z1=0.0
    Z2=DEPTH
C
C   Initialize concentrations prior to calling the
C   Runge-Kutta differential equation solver
C
    DO 189 NNNN=1,12
      C(NNNN)=CONC(NNNN,NRR,n1)
189 CONTINUE
```

```
C
C    Account for sinking rates of plankton
C
     PLOAD(3)=PLOAD(3)-VSINK*AREA1*C(3)
C
C    Surface exchange of thermal energy
C
    TSURF=C(9)
     CALL ENERGY(TSURF,QSURF)
      PLOAD(9)=PLOAD(9)+AREA2*(0.5*QNS+QSURF)/304.8
     VLIGHT=0.5*QNS
C
C    Calculate light extinction coefficient
C
     CHLR=1000.*C(3)/CCLRAT
     GAMMA=EXCO(NR)+0.0088*CHLR+0.054*CHLR**0.67
C
C    Call SUBROUTINE QUALTY, the Runge-Kutta
C     differential equation solver
C
      CALL QUALTY(TIME,C,None,None)
      NPMOD=MOD(ND,NDPRNT)
     IF(NPMOD.NE.0) GO TO 195
     IF(IPD.EQ.1) THEN
      IF(NN.EQ.1) CALL WRITE1(XAVE)
     CALL WRITE2(XAVE)
    END IF
 195 CONTINUE
    DO 199 NNNN=1,12
    CONC(NNNN,NRR,n2)=C(NNNN)                        5/13/92
    C1(NNNN)=CONC(NNNN,NRR,n1)                        5/13/92
 199 CONTINUE
    QSUM=Q2
 249 CONTINUE
      IF(IPD.EQ.1.AND.NPMOD.EQ.0) CALL WRITE3
C
C         ****************************************************
C          Return to Subroutine SYSTEM
C         ****************************************************
C
    RETURN
    END
```

```
FUNCTION RHO(T)

 RHO=1000.-(((T-3.98)**2)*(T+283.))/(503.57*(T+67.26))
RETURN
END
```

```
      SUBROUTINE LAYRIN(CRES,TMPIN,NSURF,NLYR)

      REAL*4 CRES(12,10)
      INCLUDE :RBM10.COM
       IF(NSURF.EQ.1) THEN
      NLYR=1
      RETURN
      END IF
      N=NSURF
   10 CONTINUE
       RHO1=RHO(TMPIN)
       RHO2=RHO(CRES(9,N))
       IF(RHO1.GT.RHO2) THEN
      N=N-1
      IF(N.EQ.1) GO TO 50
      GO TO 10
   50 CONTINUE
      END IF
      NLYR=N
C
C         *****************************************************
C          Return to Subroutine RESMOD
C         *****************************************************
C
      RETURN
      END
```

```
      SUBROUTINE MIX(CRES,VSURF,NSURF,NV)

      DIMENSION CRES(12,10),CSUM(12)
      INCLUDE :RBM10.COM
      NMIX=NSURF
      NSRFM1=NSURF-1
      VSUM=VSURF
      TMIX=CRES(9,NSURF)
      RHO1=RHO(TMIX)
      DO 49 NN=1,NCONST
       CSUM(NN)=CRES(NN,NSURF)*VSURF
   49 CONTINUE
      DO 99 N=NSRFM1,1,-1
       RHO2=RHO(CRES(9,N))
       IF(RHO1.GT.RHO2) THEN
       VSUM=VSUM+VSEG(NV,N)
      DO 79 NN=1,NCONST
        CSUM(NN)=CSUM(NN)+CRES(NN,N)*VSEG(NV,N)
   79 CONTINUE
      TMIX=CSUM(9)/VSUM
       RHO1=RHO(TMIX)
      NMIX=N
      END IF
   99 CONTINUE
      DO 199 N=NSURF,NMIX,-1
      DO 199 NN=1,NCONST
       CRES(NN,N)=CSUM(NN)/VSUM
  199 CONTINUE
C
C        ******************************************************
C         Return to Subroutine RESMOD
C        ******************************************************
C
      RETURN
      END
```

```
      SUBROUTINE ENERGY(TSURF,QSURF)

      REAL*4 LVP
      INCLUDE :RBM10.COM
      DATA PI/3.14159/,EVRATE/1.5E-9/
      E0=2.1718E8*EXP(-4157.0/(TSURF+239.09))
      RB=PF*(DBT-TSURF)/(E0-EA)
      LVP=597.0-0.57*TSURF
      QEVAP=1000.*LVP*EVRATE*WIND*(E0-EA)
      QCONV=RB*QEVAP
      BOWEN=2.-SIN(2.*PI*DAY/365.+PI/6.)
      QWS=6.693E-2+1.471E-3*TSURF
      QSURF=0.5*QNS+QNA-QWS-QEVAP+QCONV
C
C        ****************************************************
C        Return to Subroutine RESMOD/RIVMOD
C        ****************************************************
C
      RETURN
      END
```

```
      SUBROUTINE FNAME(INFILE)

      CHARACTER*30 INFILE
      READ(*,1000) INFILE
 1000 FORMAT(A30)
C
C        ****************************************************
C             Return to RMAIN
C        ****************************************************
C
  900 RETURN
      END
```