

4.2(3) Simulate a Free-flowing Reach or Mixed Reservoir (Module RCHRES)

This module simulates the processes which occur in a single reach of open or closed channel or a completely mixed lake. For convenience, such a processing unit is referred to as a RCHRES throughout this documentation. In keeping with the assumption of complete mixing, the RCHRES consists of a single zone situated between two nodes, which are the extremities of the RCHRES.

Flow through a RCHRES is assumed to be unidirectional. The inflow and outflow of materials through a RCHRES are illustrated in Figure 4.2(3)-1. Water and other constituents which arrive from other RCHRES's and local sources enter the RCHRES through a single gate (INFLO). Outflows may leave the RCHRES through one of several gates or exits (OFLO). A RCHRES can have up to five OFLO exits. Precipitation, evaporation, and other fluxes also influence the processes which occur in the RCHRES, but do not pass through the exits.

The ten major subdivisions of the RCHRES module and their functions are shown in Figure 4.2(3)-2. RPTOT, RBAROT, and RPRINT perform the storage and printout of results from the other module sections of RCHRES (HYDR through RQUAL). Within a module section, simulation of physical processes (longitudinal advection, sinking, benthic release) is always performed before simulation of biochemical processes.

The user specifies which module sections are active. If any "quality" sections (CONS through RQUAL) are active, section ADCALC must also be active; it computes certain quantities needed to simulate advection of the quality constituents. Besides fulfilling this requirement, the user must ensure that all the time series required by the active sections are available, either as supplied input time series or as data computed by another module section. For example, if RQUAL is active, the water temperature must be supplied, either as an input time series or by activating section HTRCH which will compute it.

Water Rights Categories

The HYDR section of RCHRES allows the optional simulation of water "categories", which are used to facilitate the modeling of water rights or ownership. If this option is turned on (by including the CATEGORY block in the UCI), each RCHRES in the run keeps track of the user-defined categories of all inflows, storages, and outflows, as well as precipitation and evaporation fluxes. Up to 100 categories can be specified in the CATEGORY block. Details of this option are provided in the discussion of HYDR below (Section 4.2(3).1), and the CATEGORY block documentation (Section 4.12 of Part F). Also, refer to the description of HYDR inputs in Section 4.4(3).2 of Part F.

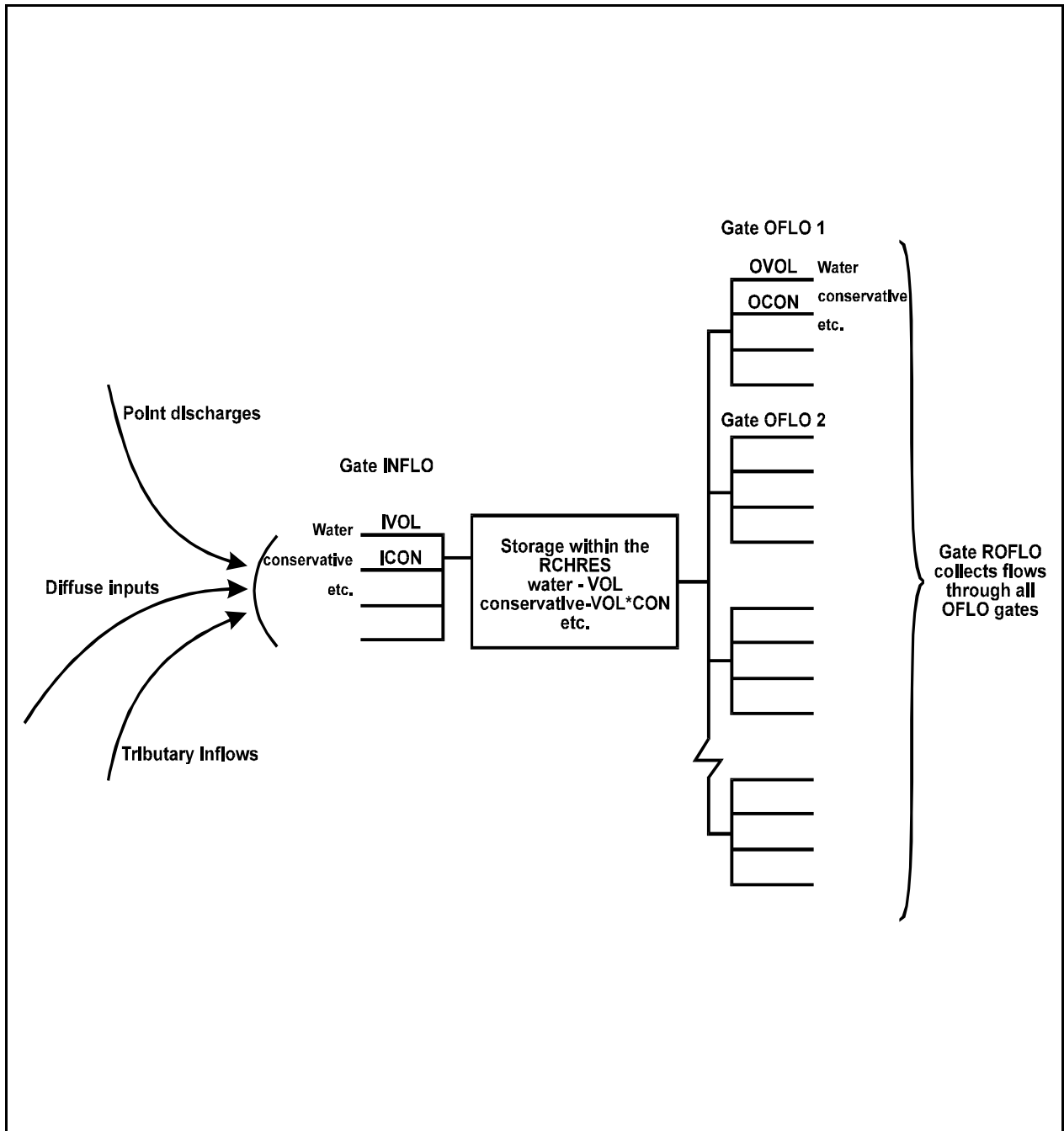


Figure 4.2(3)-1 Flow of materials through a RCHRES

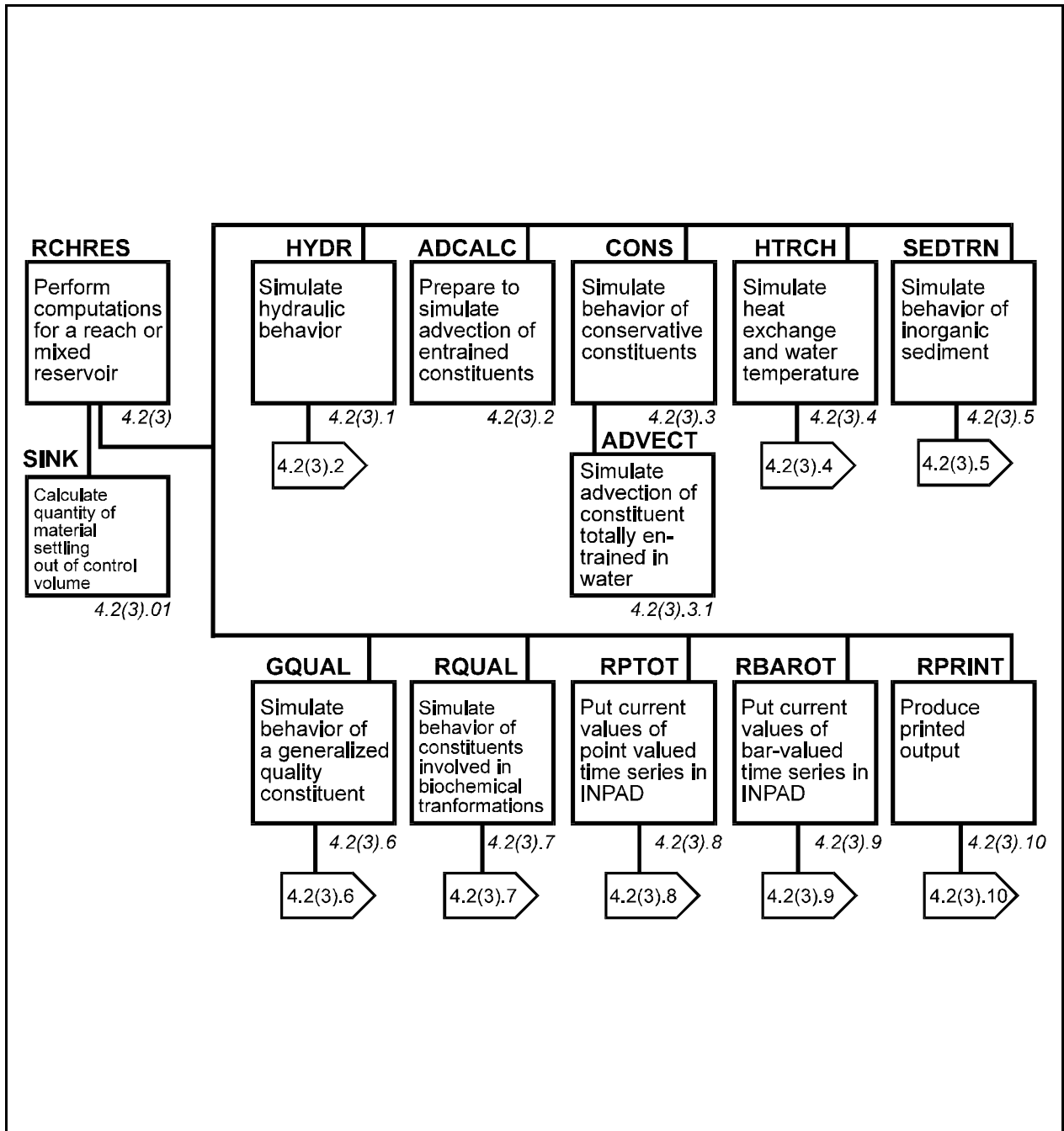


Figure 4.2(3)-2 Structure chart for RCHRES Module

4.2(3).01 Simulate Sinking of Suspended Material (subroutine SINK)

Purpose

SINK calculates the quantity of material settling out of a RCHRES and determines the resultant change in concentration of the material within the RCHRES.

Method

The portion of material settling out of a RCHRES during an interval is calculated by the equation:

$$SNKOUT = CONC * (KSET / AVDEPE) \quad (1)$$

where:

SNKOUT = fraction of material which settles out (reduction of concentration/interval)
 CONC = concentration of material before deposition
 KSET = sinking rate (ft/interval) (dependent upon RCHRES characteristics and type of material)
 AVDEPE = average depth of water (feet)

In any interval in which KSET is greater than AVDEPE, all the material in the RCHRES sinks out of the water.

The mass of material sinking out of the RCHRES is calculated as:

$$SNKMAT = SNKOUT * VOL \quad (2)$$

where:

SNKMAT = mass of material that settles out during the interval
 (mass.ft3/l/interval or mass.m3/l/interval)
 VOL = volume of water in RCHRES (ft3 or m3)

4.2(3).1 Simulate Hydraulic Behavior (Section HYDR of Module RCHRES)

Purpose

The purpose of this code is to simulate the hydraulic processes occurring in a reach or a mixed reservoir (RCHRES). The final goal of the process may be to route floods, study reservoir behavior, or analyze constituents dissolved in the water.

Schematic View of Fluxes and Storage

Figure 4.2(3).1-1 shows the principal state variable (stored volume) and fluxes with which this part of HSPF deals.

All water entering the RCHRES from surface and subsurface sources arrives through "gate" INFLO; this quantity is called IVOL. The user indicates the time series which enter this gate in the EXT SOURCES or NETWORK Block in the User's Control Input (UCI). If no time series are specified, the system assumes the RCHRES has zero inflow.

The volume of water which leaves the RCHRES during a simulation time interval, through gate OFLO(N), is called OVOL(N). The total outflow is ROVOL.

The input of water from precipitation falling directly on the water surface and the loss of water by evaporation from the surface can also be considered. The user activates these options by supplying the time series PREC and/or POTEV in the User's Control Input (External Sources block). These time series are in units of depth/interval. The code multiplies these quantities by the current surface area of the RCHRES to obtain volumes of input or output. If either time series is absent from the UCI it is assumed that the option is inactive and the corresponding flux is zero.

The basic equation is that of continuity:

$$VOL - VOLS = IVOL + PRSUPY - VOLEV - ROVOL \quad (1)$$

where:

VOL = volume at the end of the interval

VOLS = volume at the start of the interval

This can be written as:

$$VOL = VOLT - ROVOL \quad (2)$$

where:

$$VOLT = IVOL + PRSUPY - VOLEV + VOLS$$

The principal task of this subroutine is to estimate ROVOL and, hence, the volume at the end of the interval (VOL).

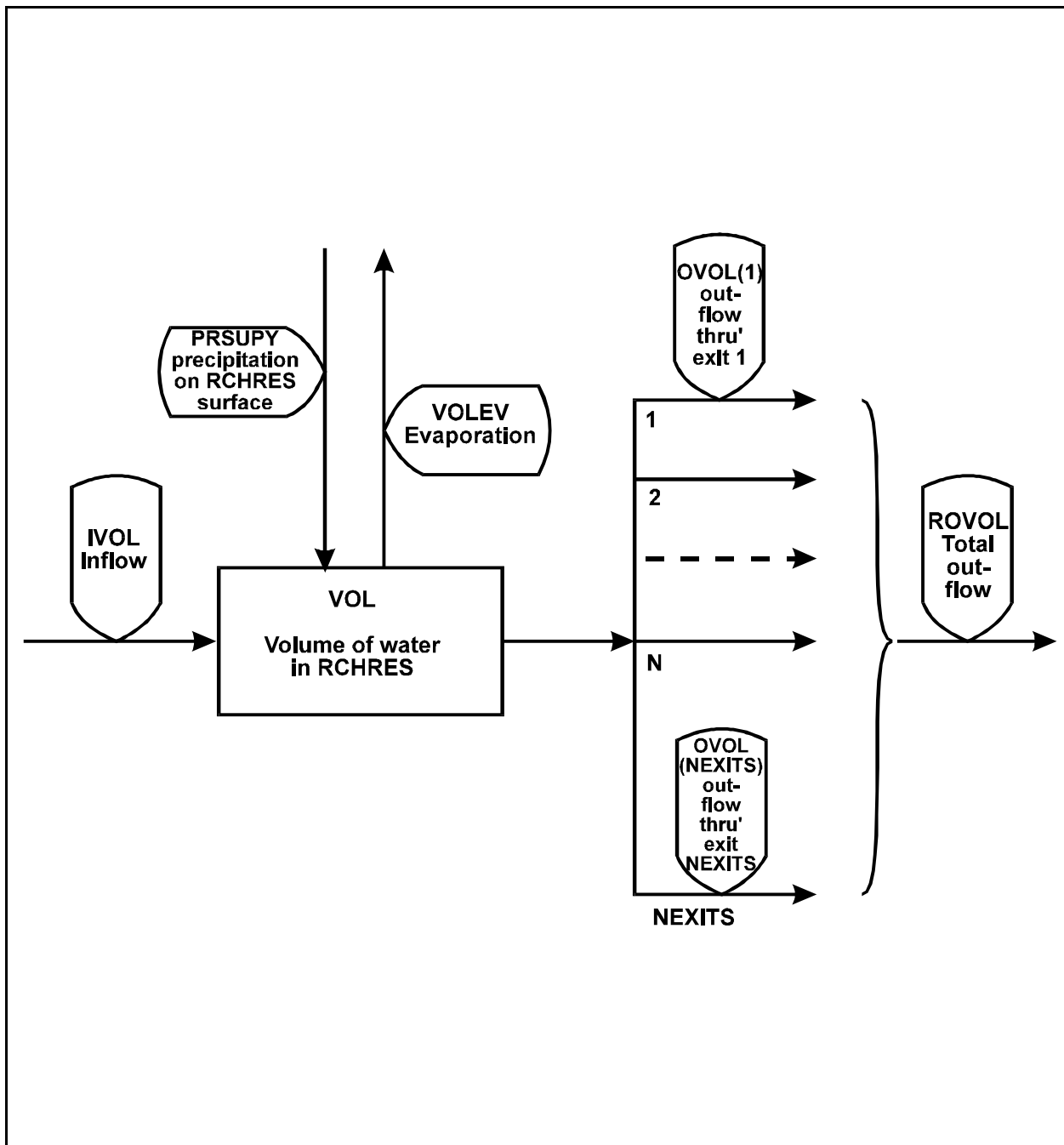


Figure 4.2(3).1-1 Flow diagram for the HYDR Section of the RCHRES Application Module

Calculation of Outflows and VOL

If water is available, it is assumed that the total volume of water leaving a RCHRES in an interval is:

$$ROVOL = (KS*ROS + COKS*ROD)*DELTS \quad (3)$$

where:

KS = weighting factor ($0 \leq KS \leq 0.99$)
 COKS = $1.0 - KS$ (complement of KS)
 ROS = total rate of outflow from the RCHRES at the start of the interval
 ROD = total rate of demanded outflow for the end of the interval
 DELTS = simulation interval in seconds

That is, the mean rate of outflow is assumed to be a weighted mean of the rates at the start and end of the interval. The weighting factor KS is supplied either by the user or by default. Care should be exercised in selecting a value because, as KS increases from 0.0 to 1.0, there is an increasing risk that the computation of outflow rates will become unstable. Theoretically, a value of 0.5 gives the most accurate results, provided oscillations do not occur. The default value of 0.0 has zero risk, but gives less accurate results. Users are advised to be very careful if a nonzero value is used; users should not select a value greater than 0.5.

Combination of Equations 2 and 3 yields:

$$VOL = VOLT - (KS*ROS + COKS*ROD)*DELTS \quad (4)$$

There are two unknown values in this equation: VOL and ROD. Thus, a second relation is required to solve the problem. To provide this function, it is assumed that outflow demands for the individual exits are of the form:

$$\begin{aligned} OD(1) &= f1(VOL,t) \\ OD(2) &= f2(VOL,t) \\ &\vdots \\ OD(NEXITS) &= fNEXITS(VOL,t) \end{aligned} \quad (5)$$

That is, the outflow demand for each exit is a function of volume or time or a combination. This topic is discussed in greater detail in Section 4.2(3).1.1.2. It follows that the total outflow demand is of similar form:

$$ROD = funct(VOL,t) \quad (6)$$

At a given time in the simulation, t is known and the above functions reduce to:

$$OD(N) = fN(VOL) \quad (7)$$

$$ROD = funct(VOL) \quad (8)$$

Equation 8 provides the second relation required to solve the problem.

Equations 4, 7, and 8 are shown in Figure 4.2(3).1-2. The point of intersection of Equations 4 and 8 gives the values RO, VOL, and hence O(1), O(2), etc.

where:

RO = total rate of outflow from the RCHRES at the end of the interval
 O(N) = rate of outflow through exit N at the end of the interval

In HSPF, it is assumed that each outflow demand can be represented by one or both of the following types of components:

Component = function(VOL). This is most useful in simulating RCHRES's where there is no control over the flow or where gate settings are only a function of water level. This component is supplied to the program in the form of an FTABLE.

Component = function(time). This is most useful for handling demands for municipal, industrial, or agricultural use. The function may be cyclic (for example, annual cycle) or general (for example, annual cycle superimposed on an increasing trend). The user must supply this component in the form of an input time series.

If a user indicates that both types of component are present in an outflow demand, then the user must also specify how they are to be combined to get the demand. HSPF allows the following options:

1. $OD(N) = \text{Min} [fN(VOL), gN(t)]$. This is useful in cases such as the following:

Suppose a water user has an optimum demand which may be expressed as a function of time ($g(t)$); however, his pump has a limited capacity to deliver water. This capacity is a function of the water level in the RCHRES from which the pump is drawing the water. Thus, it can be expressed as a function of the volume in the RCHRES ($f(VOL)$). Then, his actual demand for water will be the minimum of the two functions. Note that $g(t)$ is an input time series (OUTDGT). See the Time Series Catalog (Section 4.7).

2. $OD(N) = \text{Max} [fN(VOL), gN(t)]$

3. $OD(N) = fN(VOL) + gN(t)$

If one or more outflow demands have an $f(VOL)$ component (Fig.4.2(3).1-2a), subroutine ROUTE is called to solve the routing equations. In this case, the evaluation of the outflow demands and the solution of the equations can be quite complicated.

If there is no $f(VOL)$ component in any demand, the process is much simpler (Figure 4.2(3).1-2b). Subroutine NOROUT is called in this case.

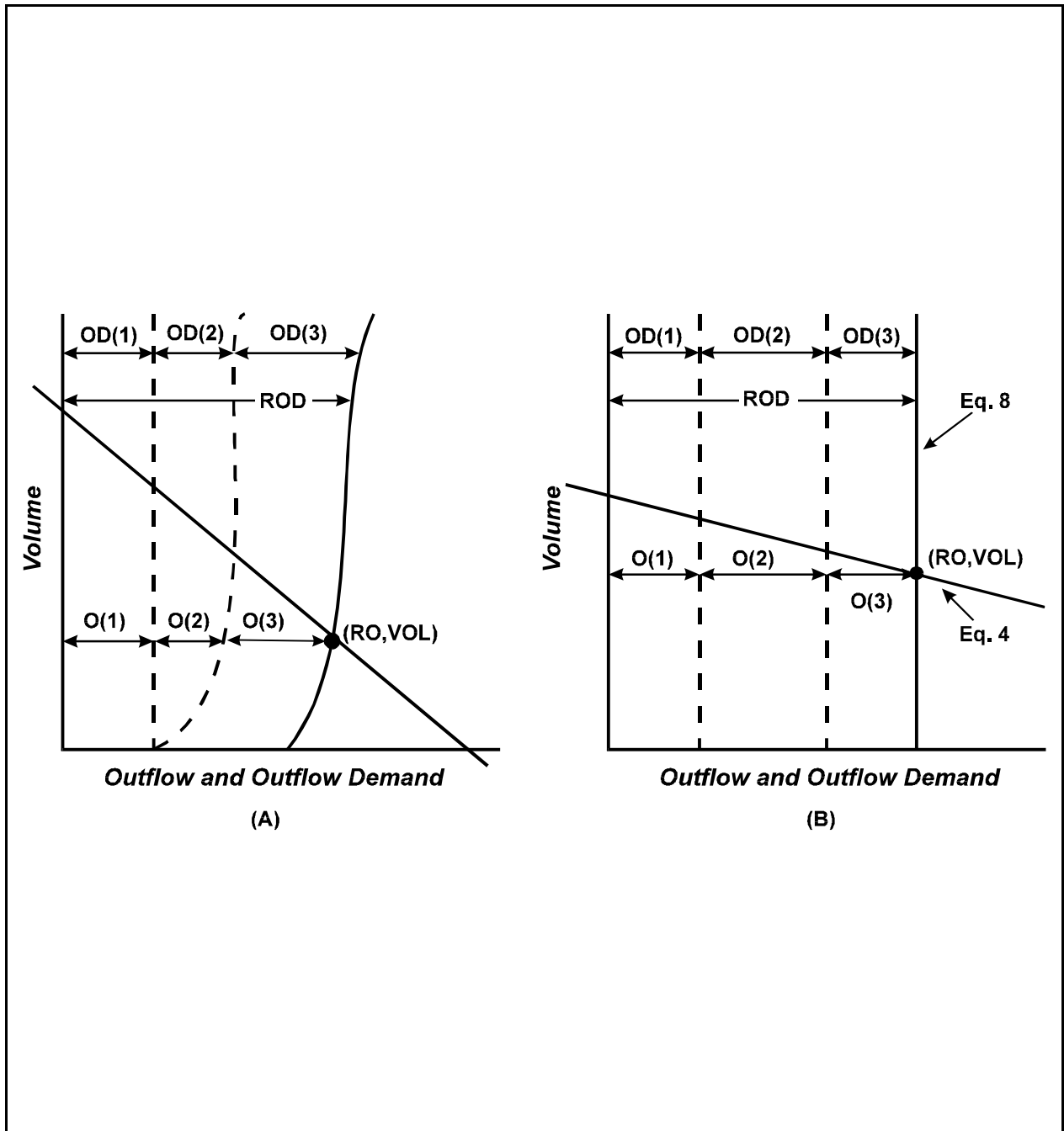


Figure 4.2(3).1-2 Graphical representation of the equations used to compute outflow rates and volume

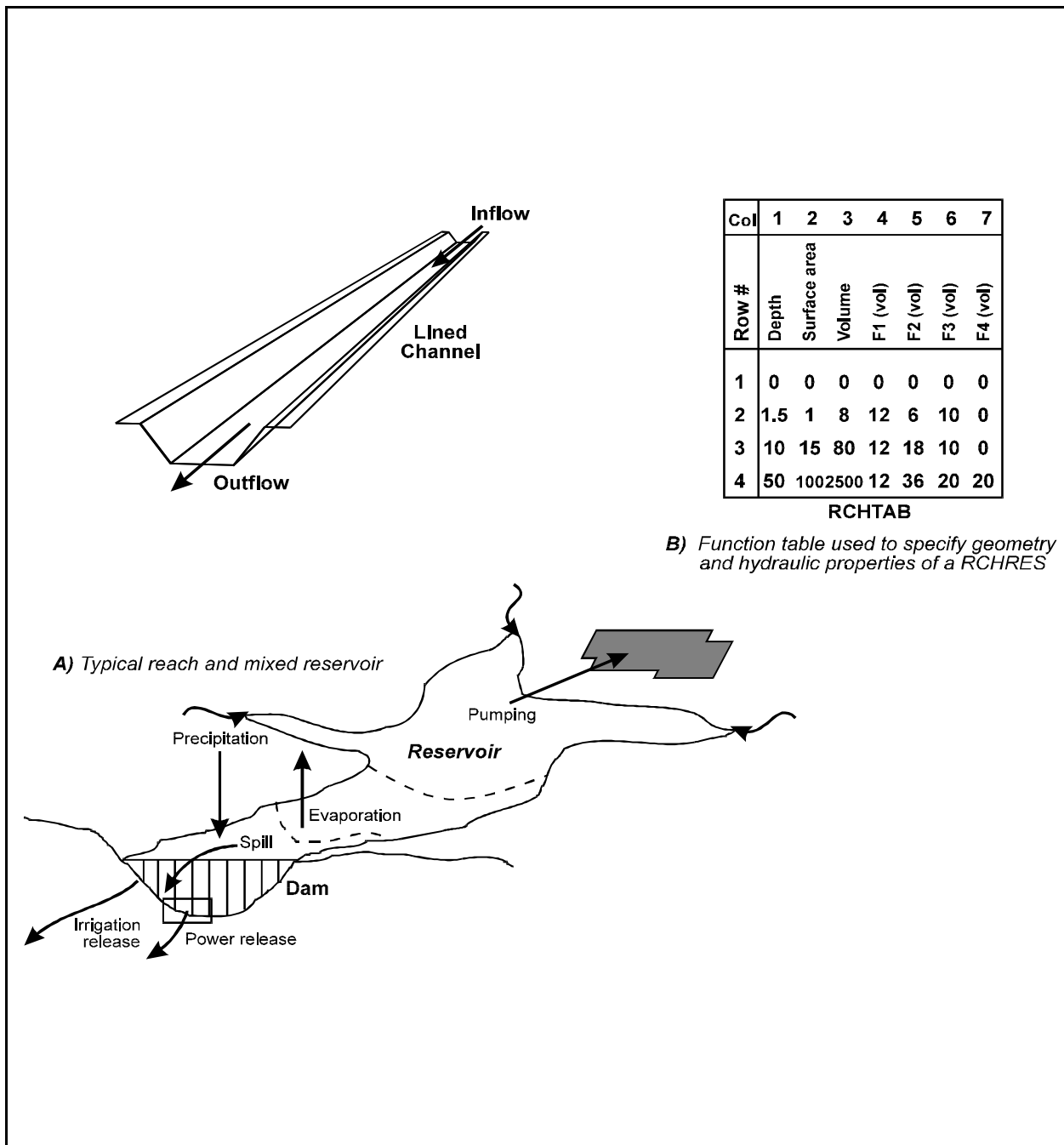


Figure 4.2(3).1-3 Typical RCHRES configurations and the method used to represent geometric and hydraulic properties

Representing the Geometry and Hydraulic Properties of a RCHRES

HSPF makes no assumptions regarding the shape of a RCHRES. It does not require that the cross-section be trapezoidal or even that the shape be prismoidal. This is one reason why both free flowing reaches and reservoirs can be handled by the same application module. Both of the shapes shown in Figure 4.2(3).1-3a are acceptable. However, HSPF does assume that:

1. There is a fixed relation between depth (at the deepest point in the RCHRES), surface area, and volume.
2. For any outflow demand with an $f(VOL)$ component, the functional relation is constant in time (with the exception discussed in Section 4.2(3).2.1.1).

These assumptions rule out cases where the flow reverses direction or where one RCHRES influences another upstream of it in a time-dependent way. No account is taken of momentum. The routing technique falls in the class known as "storage routing" or "kinematic wave" methods.

The user specifies the properties of a RCHRES in a table called RCHTAB (Figure 4.2(3).1-3b). It has columns for the depth, surface area, volume, and volume dependent functions ($fN(VOL)$). Each row contains values appropriate to a specified water surface elevation. The system obtains intermediate values by interpolation. Thus, the number of rows in RCHTAB depends on the size of the cross section and the desired resolution. The table is either included in the User's Control Input (in the function tables (FTABLES) block) or it may be stored in a Watershed Data Management (WDM) file. A subsidiary, stand-alone program can be used to generate this table for RCHRES's with simple properties (for prismoidal channels with uniform flow, use Manning's equation).

Auxiliary Variables

Besides calculating outflow rates and the volume in a RCHRES, HSPF can compute the values of some auxiliary state variables:

1. If $AUX1FG=1$, DEP, STAGE, SAREA, AVDEP, TWID, and HRAD are computed, where: DEP is the depth at the deepest point; STAGE is the water stage at a related point; SAREA is the surface area of water in the RCHRES; AVDEP is the average depth (volume/surface area); TWID is the top width (surface area/length); HRAD is the hydraulic radius.
2. If $AUX2FG=1$, AVSECT and AVVEL are computed, where: AVSECT is the average cross section (volume/length); AVVEL is the average velocity (discharge/AVSECT).
3. If $AUX3FG=1$, USTAR and TAU are computed, where: USTAR is the bed shear velocity; TAU is the bed shear stress.

Note that these are point-valued time series; that is, they apply at the boundaries (start or end) of simulation time intervals.

The user specifies whether $AUX1FG$, $AUX2FG$, and $AUX3FG$ are ON or OFF. If certain

constituents are being simulated, one or more of these flags might be required to be ON. For example, simulation of oxygen (group OXRX) requires that both AUX1FG and AUX2FG be ON. AUX3FG must be ON if sediment is simulated (group SEDTRN).

4.2(3).1.1 Calculate Outflows Using Hydraulic Routing (subroutine ROUTE)

Purpose

ROUTE computes the rates and volumes of outflow from a RCHRES and the new volume in cases where at least one outflow demand has an f(VOL) component.

Method

The problem is to solve simultaneously Equations 4 and 8. The cases which arise are shown graphically in Figure 4.2(3).1-4. Equations 7 and 8 are represented by a series of straight line segments. The breakpoints in the lines correspond to a row of entries in RCHTAB (the FTABLE). A segment of Equation 8 can be represented by the equation:

$$(VOL - V1)/(ROD - ROD1) = (V2 - V1)/(ROD2 - ROD1) \quad (9)$$

where V1,V2 are volumes specified in adjacent rows of RCHTAB, for the lower and upper extremities of the straight-line segment, respectively. ROD1 and ROD2 are the corresponding total outflow demands.

The first step is to find the intercept of Equation 4 on the volume axis:

$$VOLINT = VOLT - KS*ROS*DELTS \quad (10)$$

If VOLINT is less than zero, the equations cannot be solved (case 3). Equation 4 will give a negative value for VOL, even if ROD is zero. Physically, this means that we started the interval with too little water to satisfy the projected outflow demand, even if the outflow rate at the end of the interval is zero. Accordingly, the code does the following:

```
VOL   = 0.0
RO     = 0.0
O(*)   = 0.0
ROVOL  = VOLT
```

If VOLINT is greater than or equal to zero, the outflow rate at the end of the interval will be nonzero (case 1 or 2). To determine the case:

1. The intercept of Equation 4 on the Volume axis is found:

$$OINT = VOLINT/(DELTS*COKS) \quad (11)$$

2. The maximum outflow demand for which the volume is still zero (RODZ) is found.

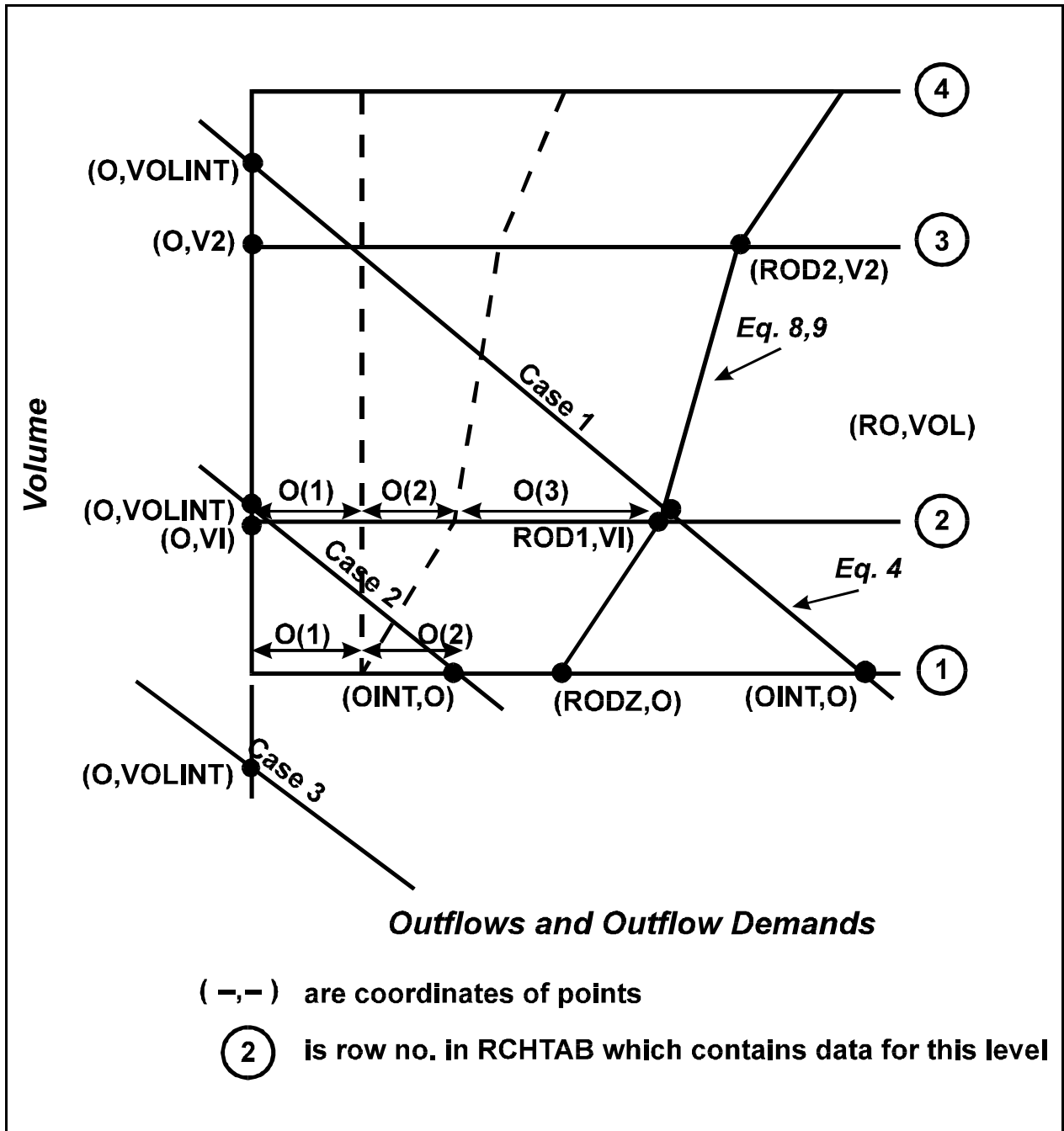


Figure 4.2(3).1-4 Graphical representation of the work performed by subroutine ROUTE

If OINT is greater than RODZ, Equations 4 and 8 can be solved (case 1). The solution involves searching for the segment of Equation 8 which contains the point of intersection of the graphs, and finding the coordinates of the point (RO,VOL). This is done by subroutine SOLVE.

If OINT is less than or equal to RODZ, Equations 4 and 8 cannot be solved (case 2). Physically this means that the RCHRES will instantaneously go dry at the end of the interval with total outflow rate at that time equal to OINT. Accordingly, the code assigns a zero value to the RCHRES volume, and the total outflow is equal to the intercept of Equation 4 on the volume axis in Figure 4.2(3).1-4. As many of the individual demands (O(*)) as possible are satisfied in full by the available water. The remaining water is used to partially satisfy the demand of next highest priority, and any others are not satisfied at all.

4.2(3).1.1.2 Find the Outflow Demands which Correspond to a Specified Row in RCHTAB (subroutine DEMAND)

Purpose

DEMAND finds the individual and total outflow demands which apply at the end of the present interval for a specified level (row) in RCHTAB.

General Method

The approach is to determine the outflow demand for each active exit and accumulate them to find the total demand.

Evaluating the Demand for Exit N

The outflow demand for an individual exit consists of one or both of two components. Their presence or absence is indicated by two flags:

Component	Flag
fN(VOL)	ODFVFG(N)
gN(t)	ODGTFG(N)

Finding the fN(VOL) Component

If ODFVFG(N) is zero, there is no fN(VOL) component.

If ODFVFG(N) is greater than zero, there is a fN(VOL) component. The value of the flag is the column number in RCHTAB containing the value to be used to find the component:

$$\begin{aligned} \text{col} &= \text{ODFVFG}(\text{N}) \\ \text{ODFV} &= \text{fN}(\text{VOL}) = (\text{column value}) * \text{CONVF} \end{aligned} \quad (12)$$

where CONVF is a conversion factor which can vary throughout the year. It is supplied by the user in the RCHRES Block of the User's Control Input. It can be used to incorporate effects into the simulation of, for example, seasonal variation in channel roughness.

If ODFVFG(N) is less than zero, there is an fN(VOL) component, but the function fN is time varying. In this case the determination of the component is less direct. The absolute value of ODFVFG(N), say I, gives the element number of a vector COLIND() which contains a user-supplied time series. The values in this time series indicate which pair of columns in RCHTAB are used to interpolate fN(VOL). For example, if COLIND(I) = 4.6 for a given time step, then the value is interpolated between those in columns 4 and 5:

$$\text{ODFV} = \text{fN}(\text{VOL}) = [0.6 * (\text{column5 value}) + 0.4 * (\text{column4 value})] * \text{CONVF} \quad (13)$$

If the user has selected this option, the time series COLIND(I) must be supplied in the EXT SOURCES Block of the UCI.

This method of outflow demand specification is useful where a set of rule curves (f(VOL)) are specified for releases from a reservoir, and it is necessary to move from one curve to another (gradually or suddenly) as time progresses in the simulation.

Finding the gN(t) Component

If ODGTFG(N) is zero, there is no gN(t) component. If ODGTFG(N) is greater than zero, there is a gN(t) component. The value of this flag is the element number of vector OUTDGT() which contains the required time series:

$$\begin{aligned} \text{FG2} &= \text{ODGTFG}(\text{N}) \\ \text{ODGT} &= \text{gN}(\text{t}) = \text{OUTDGT}(\text{FG2}) \end{aligned} \quad (14)$$

Combining the fN(VOL) and gN(t) Components

If an outflow demand has both of the components described above, the system expects the user to indicate which of the following options to use in combining them:

1. $\text{OD}(\text{N}) = \text{Min} [\text{fN}(\text{VOL}), \text{gN}(\text{t})]$
 2. $\text{OD}(\text{N}) = \text{Max} [\text{fN}(\text{VOL}), \text{gN}(\text{t})]$
 3. $\text{OD}(\text{N}) = \text{fN}(\text{VOL}) + \text{gN}(\text{t})$
- (15)

4.2(3).1.1.3 Solve Routing Equations used in Case 1. (subroutine SOLVE)

Purpose

SOLVE finds the point where Equations 4 and 8 intersect (case 1 in Figure 4.2(3).1-4).

General Approach

The general idea is to select a segment of Equation 8, and determine the point of intersection with Equation 4. If this point lies outside the selected segment, the code will select the adjacent segment (in the direction in which the point of intersection lies) and repeat the process. This continues until the point lies within the segment under consideration. To minimize searching, the segment in which the point of intersection was last located is used to start the process.

Solving the Simultaneous Linear Equations

Equations 4 and 9 can be written as:

$$A1*VOL + B1*ROD = C1 \quad (16)$$

$$A2*VOL + B2*ROD = C2 \quad (17)$$

These equations can be solved by evaluating the determinants:

$$\begin{array}{ccc} \begin{array}{cc} *A1 & B1* \\ DET = * & * \\ *A2 & B2* \end{array} & \begin{array}{cc} *C1 & B1* \\ DETV = * & * \\ *C2 & B2* \end{array} & \begin{array}{cc} *A1 & C1* \\ DETO = * & * \\ *A2 & C2* \end{array} \end{array} \quad (18)$$

In the code of this subroutine:

$$FACTA1 = A1 = 1.0/(COKS*DELTS) \quad (19)$$

$$FACTA2 = A2 = ROD1 - ROD2 \quad (20)$$

$$FACTB1 = B1 = 1.0 \quad (21)$$

$$FACTB2 = B2 = V2 - V1 \quad (22)$$

$$FACTC1 = C1 = OINT \quad (23)$$

$$FACTC2 = C2 = (V2*ROD1) - (V1*ROD2) \quad (24)$$

By substituting Equations 19 through 24 in Equation 18, the determinants are evaluated as:

$$DET = FACTA1*FACTB2 - FACTA2 \quad (25)$$

$$DETV = OINT*FACTB2 - FACTC2 \quad (26)$$

$$DETO = FACTA1*FACTC2 - FACTA2*OINT \quad (27)$$

The coordinates of the point of intersection are:

$$VOL = DETV/DET \quad (28)$$

$$RO = DETO/DET \quad (29)$$

4.2(3).1.2 Calculate Outflows Without Using Hydraulic Routing (subroutine NOROUT)

Purpose

NOROUT is used to compute the rates and volumes of outflow from a RCHRES and the new volume in cases where no outflow demand has an $f(VOL)$ component; that is, where all outflow demands are functions of time only.

Method

Equations 4 and 8 are illustrated for this situation in Figure 4.2(3).1-5. The solution procedure is similar to that used in subroutine ROUTE, except that: because no outflow demands depend on volume, no table look-up and interpolation is required to evaluate them, and the simultaneous solution of Equations 4 and 8 is easier.

The intercept of Equation 4 on the volume axis is found, as before, using Equation 10. If VOLINT is less than 0.0, there is no solution (case 3). The code takes similar action to that taken by subroutine ROUTE for this case.

If VOLINT is greater than or equal to 0.0, the solution is either case 1 or case 2, as before. In either case, the first step is to evaluate the outflow demands:

$$\begin{aligned} FG &= ODGTFG(N) \\ OD(N) &= OUTDGT(FG) \end{aligned} \quad (30)$$

$$ROD = OD(1) + \dots OD(NEXITS) \quad (31)$$

The intercept of Equation 4 on the volume axis (OINT) is found using Equation 11. If OINT is greater than ROD, Equations 4 and 8 can be solved (case 1):

$$\begin{aligned} RO &= ROD \\ O(*) &= OD(*) \end{aligned} \quad (32)$$

And from Equations 4 and 10,

$$VOL = VOLINT - COKS*RO*DELTS \quad (33)$$

If OINT is less than or equal to ROD, Equations 4 and 8 cannot be solved (case 2). The physical meaning and the action taken by the code are identical to that described for subroutine ROUTE.

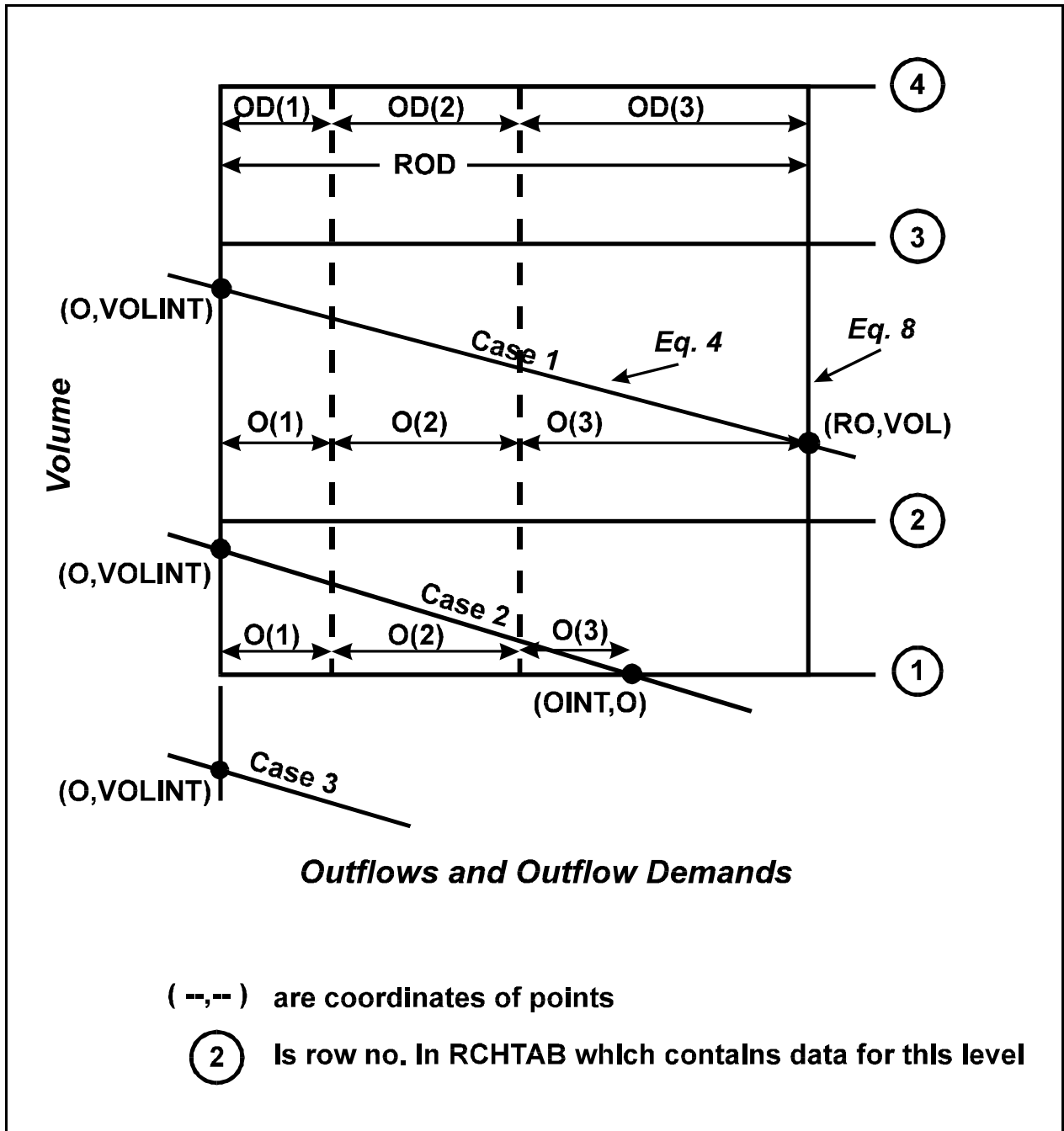


Figure 4.2(3).1-5 Graphical representation of the work performed by subroutine NOROUT

4.2(3).1.3 Compute Values of Auxiliary State Variables (subroutine AUXIL)

Purpose

AUXIL is used to compute the depth, stage, surface area, average depth, top width, and hydraulic radius corresponding to a given volume of water in a RCHRES.

Method of Computing Depth

The basic problem is to interpolate a depth value between those given for discrete values of volume in RCHTAB. This raises the question of how the interpolation should be performed; for example, linear or quadratic. Whatever method is used, it should be consistent with the fact that volume is the integral of surface area with respect to depth.

Most RCHRES's are long and relatively narrow (Figure 4.2(3).1-6). To perform interpolation, it is assumed that surface area varies linearly with depth between neighboring levels (rows) in RCHTAB:

$$SAREA = SA1 + (SA2 - SA1)*RDEP \quad (34)$$

where SAREA is the surface area at depth DEP; SA1, SA2 are the tabulated values of surface area immediately above and below SAREA; RDEP is the relative depth $(DEP-DEP1)/(DEP2-DEP1)$; DEP1, DEP2 are the tabulated values of depth immediately above and below DEP.

By integrating the above equation with respect to depth and equating the result to volume:

$$(A*RDEP**2) + (B*RDEP) + C = 0.0 \quad (35)$$

where:

$$A = SA2 - SA1$$

$$B = 2.0*SA1$$

$$C = -(VOL - VOL1)/(VOL2 - VOL1)*(B + A)$$

Equation 35 provides a means of interpolating depth, given volume. There is a quadratic relation between RDEP and VOL. The equation can be solved for RDEP analytically, but, in HSPF, Newton's method of successive approximations is used because it is generally faster in execution:

1. Calculation starts with an estimate of RDEP: $RDEP1 = 0.5$
2. The function $FRDEP = (A*RDEP1**2) + (B*RDEP1) + C$ is evaluated
3. The derivative $DFRDEP = 2.0*A*RDEP1 + B$ is evaluated
4. A new value $RDEP2 = RDEP1 - FRDEP/DFRDEP$ is calculated
5. Steps 2-4 are repeated with $RDEP1 = RDEP2$ until the change in RDEP is small

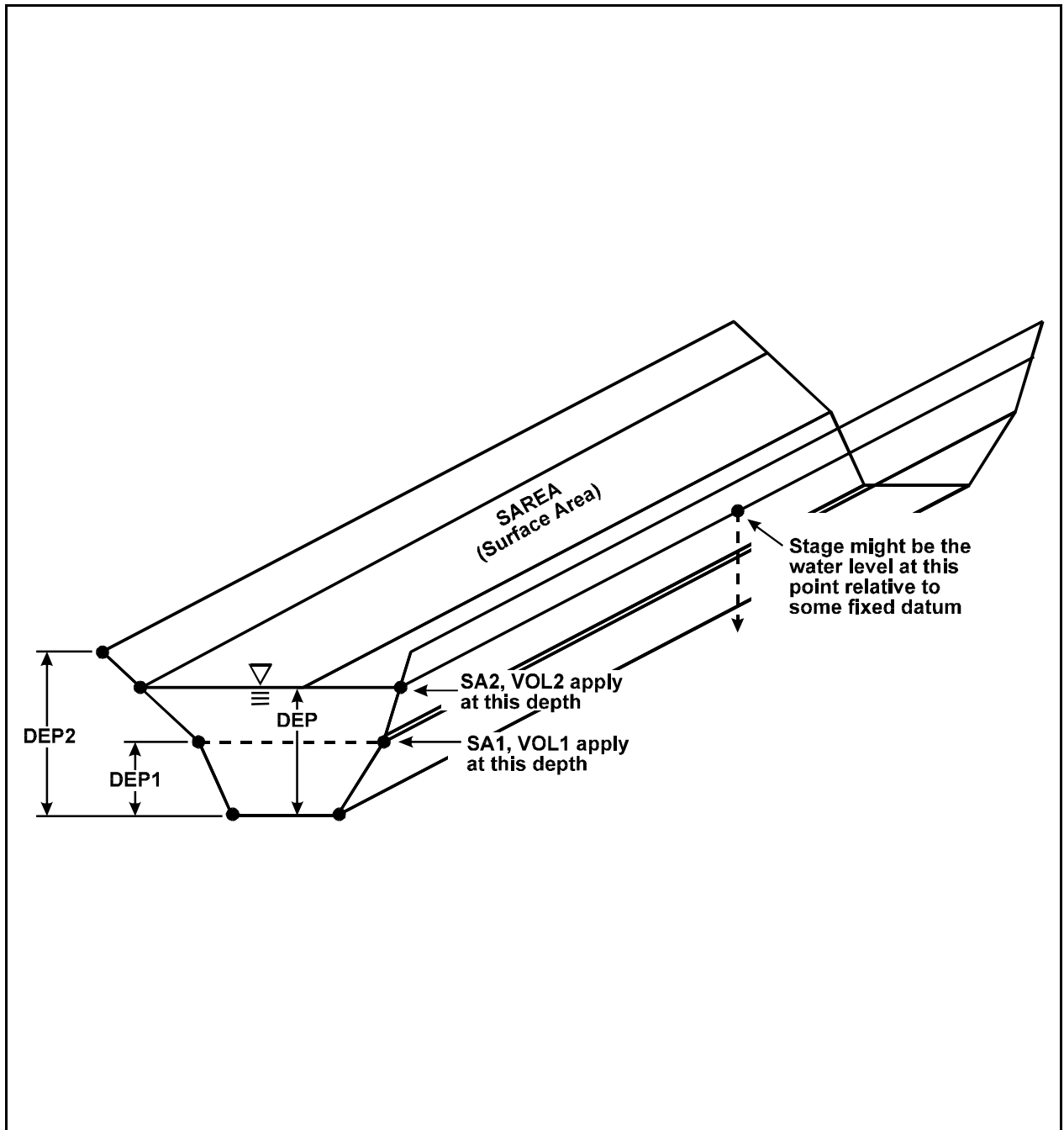


Figure 4.2(3).1-6 Illustration of quantities involved in calculation of depth

The depth is found using:

$$DEP = DEP1 + RDEP2*(DEP2 - DEP1) \quad (36)$$

Computation of Other State Variables

STAGE is the name for any quantity which differs from DEP by a constant:

$$STAGE = DEP + STCOR \quad (37)$$

where:

STCOR = the difference, supplied by the user

Surface area is computed using a formula based on Equation 34:

$$SAREA = SA1 + A*RDEP2 \quad (38)$$

Average depth is computed as:

$$AVDEP = VOL/SAREA \quad (39)$$

The mean top width is found using:

$$TWID = SAREA/LEN \quad (40)$$

where:

LEN = length of the RCHRES, supplied by the user

The hydraulic radius is calculated as a function of average water depth (AVDEP) and mean top width (TWID):

$$HRAD = (AVDEP*TWID)/(2.*AVDEP + TWID) \quad (41)$$

4.2(3).1.4 Calculate Bed Shear Stress and Shear Velocity (subroutine SHEAR)

Purpose

SHEAR is used to compute the bed shear velocity and shear stress, based on the mean particle size of bed sediment and the hydraulic properties of the RCHRES (i.e., average water depth, average velocity, hydraulic radius, and slope).

The method of calculating shear velocity and shear stress depends on whether the RCHRES is a lake or a river. If the RCHRES is a lake (LKFG=1), shear velocity is computed using Equation 8.49 from "Hydraulics of Sediment Transport", by W. H. Graf:

$$USTAR = AVVEL / (17.66 + (ALOG10 (AVDEP / (96.5 * DB50))) * 2.3 / AKAPPA) \quad (42)$$

where:

USTAR = shear velocity (ft/s or m/s)
 AVVEL = average flow velocity (ft/s or m/s)
 AVDEP = average water depth (ft or m)
 DB50 = median diameter of bed material (ft or m)
 AKAPPA = Karman constant (AKAPPA = 0.4)

The shear stress (TAU) on a lake bed is calculated as:

$$TAU = GAM * (USTAR ** 2) / GRAV \quad (43)$$

where:

TAU = bed shear stress (lb/ft² or kg/m²)
 GAM = unit weight, or density, of water (62.4 lb/ft³ or 1000 kg/m³)
 GRAV = acceleration due to gravity (32.2 ft/sec² or 9.81 m/sec²)

If the RCHRES being simulated is a stream or river, both shear velocity and shear stress are determined as functions of the slope and hydraulic radius of the reach:

$$USTAR = SQRT(GRAV * SLOPE * HRAD) \quad (44)$$

where:

SLOPE = slope of the RCHRES (-)
 HRAD = hydraulic radius (ft or m)

and

$$TAU = SLOPE * GAM * HRAD \quad (45)$$

where:

TAU = stream bed shear stress (lb/ft² or kg/m²)

Water Rights Categories

Categories can be used to facilitate the modeling of water rights in a RCHRES. If categories are being simulated ($NCAT > 0$) in the CATEGORY block), each RCHRES in the run keeps track of the categories of all inflows, storages, and outflows, as well as precipitation and evaporation fluxes. Up to 100 categories may be specified in the CATEGORY block.

The storage of each category of water in a RCHRES is called $CVOL(C)$. The inflows of each category are $CIVOL(C)$. The category outflows from exit gate $OFLO(N)$ are called $COVOL(C,N)$, and the total outflow of each category is $CROVOL(C)$. These quantities are illustrated in Figure 4.2(3).1-7.

The initial storage of water in a RCHRES may be assigned to a single category, or fractions of the storage can be assigned to specified categories. The default is to divide the storage equally among all active categories.

All water entering a RCHRES must be assigned a category. The inflow to each category is input as time series $CIVOL$, and $IVOL$ is computed as the sum.

By default, precipitation is divided proportionally among all categories present in a RCHRES according to their current storage fraction $CFRAC(C)$, which is calculated as $CVOL(C)$ divided by VOL . Optionally, it may be assigned to either a single category or to several categories by user-defined fractions.

Assigning evaporation losses to categories is somewhat more complicated. By default, evaporation is taken from all categories proportionally based on $CFRAC$. If a single category is specified, evaporation is taken from that category as long as sufficient water is present. For more complex situations, a priority may be assigned to each of several categories. Multiple categories may be given the same priority, and losses may be divided among them by either user-specified fractions or by $CFRAC$ (the default). When all specified categories are exhausted, any remaining loss is distributed among the other categories by $CFRAC$.

$F(VOL)$ outflows are calculated from the $FTABLE$ normally. Most free-flowing reaches will use the default algorithm, which is to pass all categories downstream unchanged, i.e. according to $CFRAC$. For more complex situations, categories can be assigned in the same way as for evaporation, with separate priorities and categories specified for each exit.

Time series demands ($g(t)$ releases) are handled differently. The time series $OUTDGT$ is replaced by $COTDGT$, which is an array specifying the demand from each category for each exit. If there is not enough water in a category to satisfy the demand, the release is cut back, and the storage of that category is reduced to zero. Water is not "borrowed" from other categories to make up the flow. Any deficit in the demand is accumulated throughout the run in the time series $CDFVOL$. If a category is drawn from more than one exit, a priority may be established for each demand. The priority may be specified as either a real number or a date, such as an ownership date.

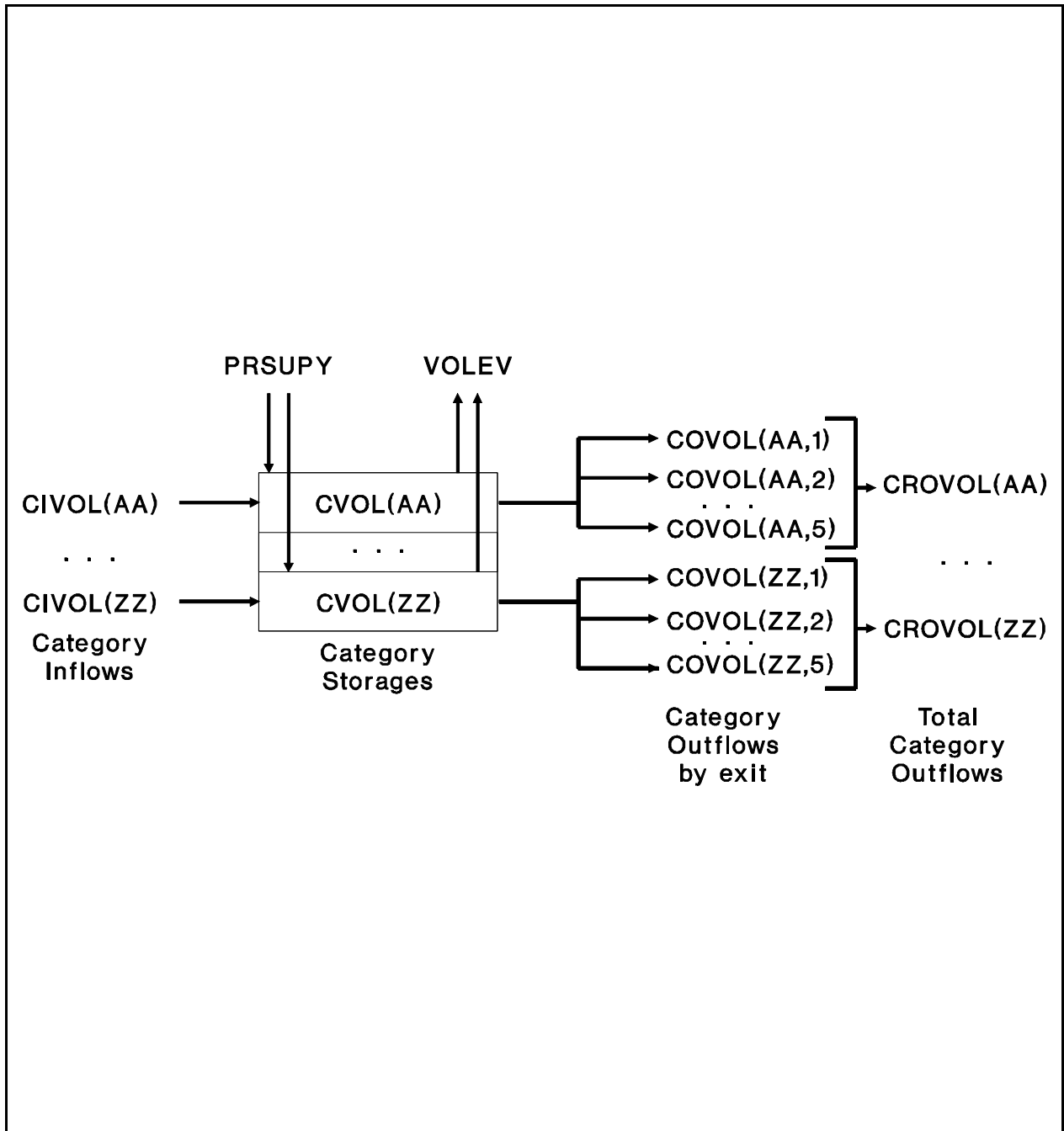


Figure 4.2(3).1-7 Flow diagram for water categories in the HYDR Section of the RCHRES Application Module

If an exit uses FUNCT to combine $f(VOL)$ and $g(t)$ demands, then OUTDGT is calculated as the sum of COTDGT for that exit, and the combining function is applied normally.

COVOL is then the result of the actual releases of $g(t)$ demands COTDGT and the apportionment of $f(VOL)$ flows by category. The outflow rate is called $CO(C,N)$. The total category outflow volume and rate are CROVOL and CRO, respectively.

4.2(3).2 Prepare to Simulate Advection of Fully Entrained Constituents (Section ADCALC of Module RCHRES)

Purpose

ADCALC calculates values for variables which are necessary to simulate longitudinal advection of dissolved or entrained constituents. These variables are dependent upon the volume and outflow values calculated in the hydraulics section (HYDR).

Approach

The outflow of an entrained constituent is a weighted mean of two quantities: one is an estimate based on conditions at the start of the time step, the other reflects conditions at the end of the time step. The weighting factors are called JS and COJS (complement of JS), respectively. The values of the weighting coefficients depend on (1) the relative volume of stored water in the RCHRES compared to the volume leaving in a single time step and (2) the uniformity of the velocity across a cross-section of the RCHRES. In order to represent these factors, two variables are defined: RAT and CRRAT. RAT is the ratio of RCHRES volume at the start of the interval to the outflow volume based on the outflow rate at the start of the interval:

$$RAT = VOLS / (ROS * DELTS) \quad (1)$$

where:

VOLS = volume of water at the start of interval (ft³ or m³)
 ROS = outflow rate at start of interval (ft³/s or m³/s)
 DELTS = number of seconds in interval

The parameter CRRAT is defined as the ratio of maximum velocity to mean velocity in the RCHRES cross-section under typical flow conditions. CRRAT must always have a value of 1.0 or greater. A value of 1.0 corresponds to a totally uniform velocity (plug flow) across the RCHRES.

Determination of JS and COJS

If the value of RAT is greater than that of CRRAT, it is assumed that all outflow over a given time interval was contained in the RCHRES at the start of the interval, and the mean rate of outflow of material is entirely dependent upon the rate of outflow at the start of the interval (JS = 1.0). If the value of RAT is less than CRRAT, it is assumed that part of the water in the outflow entered the RCHRES as inflow during the same interval; in this case, the concentration of inflowing material will affect the outflow concentration in the same interval, and JS will have a value less than 1.0. The relationship of RAT, CRRAT, and JS is illustrated in Figure 4.2(3).2-1. COJS is (1.0 - JS).

Another way to interpret the relationship of these variables is that no inflowing material is present in the outflow in the same interval if the outflow volume is less than (VOLS/CRRAT).

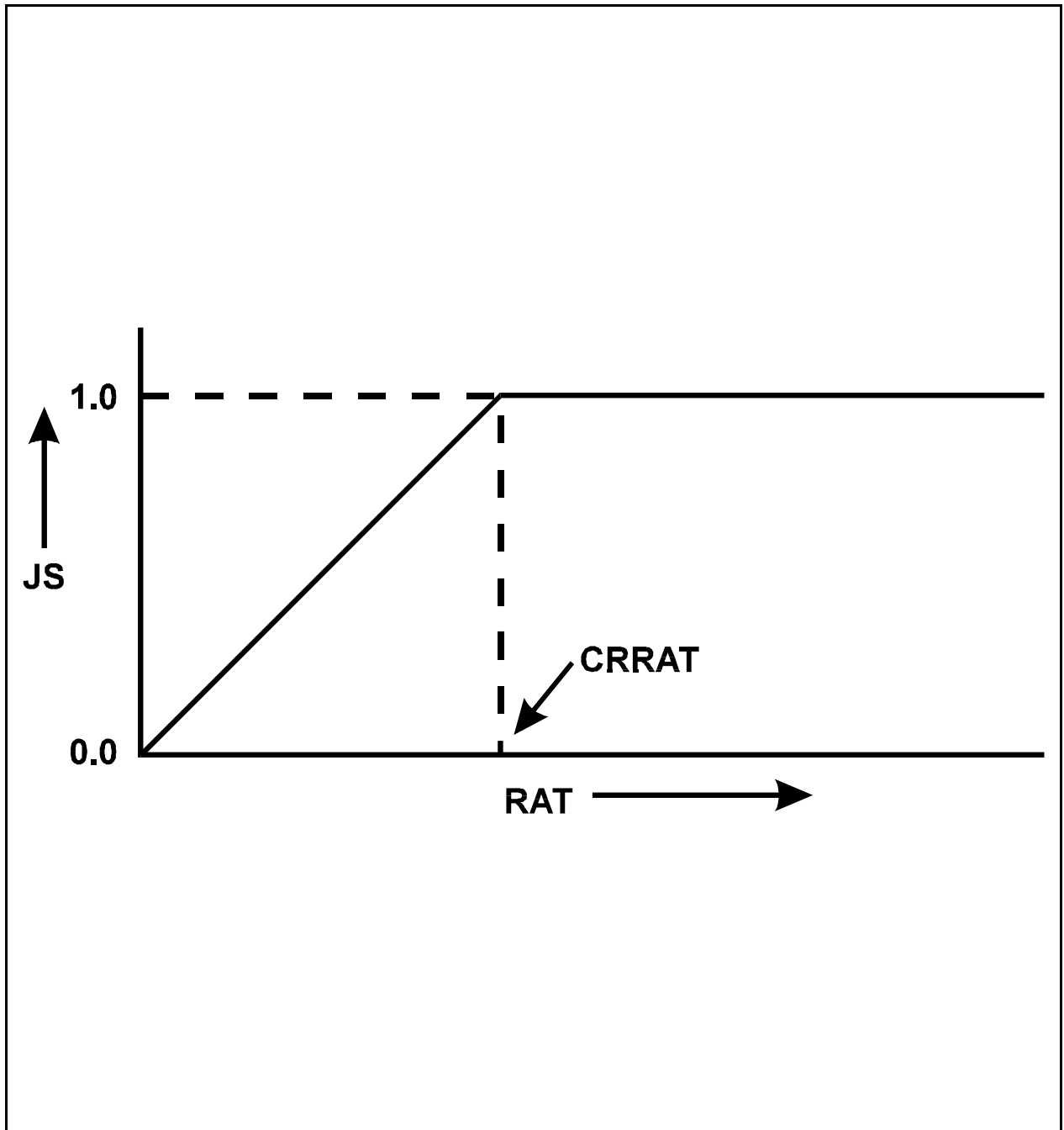


Figure 4.2(3).2-1 Determination of weighting factors for advection calculations

Calculation of Components of Outflow Volume

Components of outflow volume based on conditions at the start of the interval (SROVOL) and the end of the interval (EROVOL) are calculated as:

$$\begin{aligned} \text{SROVOL} &= \text{JS} * \text{ROS} * \text{DELTS} \\ \text{EROVOL} &= \text{COJS} * \text{RO} * \text{DELTS} \end{aligned} \quad (2)$$

where:

SROVOL = outflow volume component based on start of interval
 (ft³/interval or m³/interval)
 EROVOL = outflow volume component based on end of interval
 (ft³/interval or m³/interval)
 ROS = outflow rate at start of interval (ft³/s or m³/s)
 RO = outflow rate at end of interval (ft³/s or m³/s)
 DELTS = number of seconds in interval

Likewise, if there is more than one exit gate for the RCHRES, the corresponding outflow components for each unit, based on conditions at the start and end of each interval, are calculated as:

$$\begin{aligned} \text{SOVOL}(\text{N}) &= \text{JS} * \text{OS}(\text{N}) * \text{DELTS} \\ \text{EOVOL}(\text{N}) &= \text{COJS} * \text{O}(\text{N}) * \text{DELTS} \end{aligned} \quad (3)$$

where:

$\text{SOVOL}(\text{N})$ = outflow volume component based on start of interval for exit
 gate N (ft³/interval or m³/interval)
 $\text{EOVOL}(\text{N})$ = outflow volume component based on end of interval for exit gate N
 (ft³/interval or m³/interval)
 $\text{OS}(\text{N})$ = outflow rate at start of interval for exit gate N (ft³/s or m³/s)
 $\text{O}(\text{N})$ = outflow rate at end of interval for exit gate N (ft³/s or m³/s)
 DELTS = number of seconds in interval

It should be noted that SROVOL, EROVOL, SOVOL(N), and EOVL(N) are not actual outflows from the RCHRES, but instead are components of outflow based on conditions at the start or end of the interval. These variables are used in subroutine ADVECT to estimate the advection of constituents.

4.2(3).3 Simulate Conservative Constituents (Section CONS of Module RCHRES)

Purpose

CONS simulates constituents which, for all practical purposes, do not decay with time or leave the RCHRES by any mechanism other than advection. Examples include: total dissolved solids, chlorides, and pesticides and herbicides which decay very slowly. Figure 4.2(3).3-1 illustrates the fluxes of conservative material that are modeled in CONS.

Method

Subroutine CONS performs three functions. First, a value for inflow of material (INCON) is obtained and converted to internal units. The inflow is the sum of inputs from upstream reaches, tributary land areas, and atmospheric deposition:

$$\text{INCON} = \text{ICON} + \text{SAREA} \cdot \text{ADFX} + \text{SAREA} \cdot \text{PREC} \cdot \text{ADCN} \quad (1)$$

where:

INCON = total input to reach (mass/interval)
 ICON = input from upstream reaches and tributary land (mass/interval)
 SAREA = surface area of reach (area)
 ADFX = dry or total atmospheric deposition flux (mass/area per interval)
 PREC = precipitation (depth)
 ADCN = concentration for wet atmospheric deposition in mass/volume

The atmospheric deposition inputs can be specified in two possible ways depending on the form of the available data. If the deposition is in the form of a flux (mass per area per time), then it is considered "dry deposition". If the deposition is in the form of a concentration in rainfall, then it is considered "wet deposition", and the program automatically combines it with the input rainfall time series to compute the resulting flux. Either type of deposition data can be input as a time series, or as a set of monthly values. The atmospheric deposition time series are documented in the EXTNL table of the Time Series Catalog for RCHRES, and are specified in the EXT SOURCES block of the UCI. Monthly values are input in the MONTH-DATA block.

After computing inflows, CONS calls subroutine ADVECT to perform longitudinal advection of this material and the material already contained in the RCHRES. Finally, CONS calculates the mass of material remaining in the RCHRES after advection; this value, RCON, is necessary for the mass balance checks on conservatives and is calculated as:

$$\text{RCON} = \text{CON} \cdot \text{VOL} \quad (2)$$

where:

RCON = mass of material in RCHRES after advection
 CON = concentration of conservative after advection
 VOL = volume of water in RCHRES at end of interval (ft³ or m³)

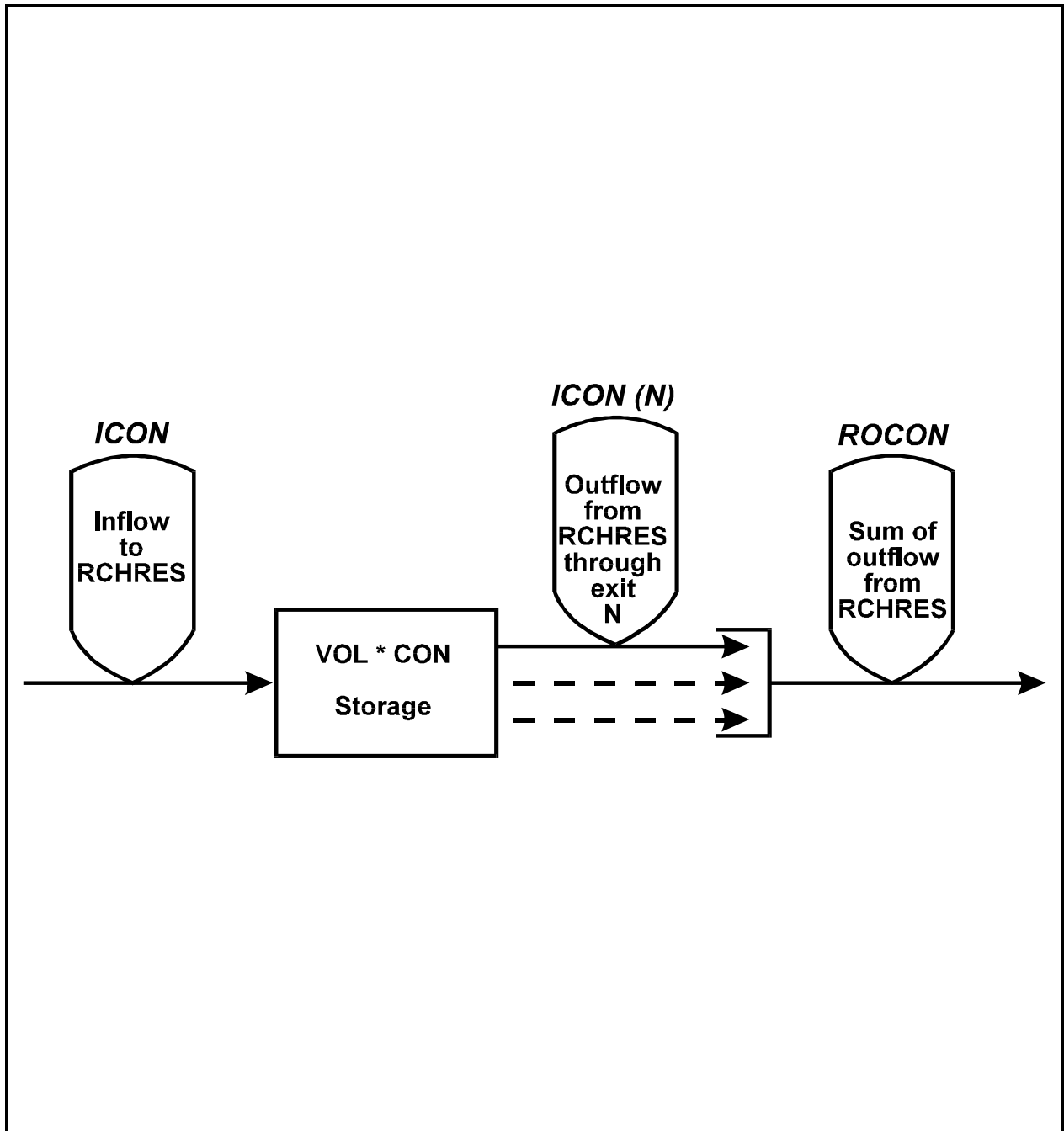


Figure 4.2(3).3-1 Flow diagram for conservative constituents in the CONS section of the RCHRES Application Module

Additional Requirements

HSPF allows a maximum of ten conservative constituents. The user selects the units for each constituent; thus, different conservative constituents may have different units. However, in order to provide this flexibility, additional input is required. For each constituent the following information must be provided in the User's Control Input:

1. CONID: the name of the constituent (up to 20 characters long)
2. QTYID: this string (up to 8 characters) contains the units used to describe the quantity of constituent entering or leaving the RCHRES, or the total quantity of material stored in it. Examples of possible units for QTYID are 'kg' for kilograms or 'lbs' for pounds
3. CONCID: the concentration units for each conservative (up to 8 characters long); examples are 'mg/l' or 'lbs/ft3'
4. CONV: conversion factor from QTYID/VOL to desired concentration units: $CONC = CONV * (QTY/VOL)$ (in English system, VOL is expressed in ft3) (in metric system, VOL is expressed in m3)
For example, if:
 CONCID is mg/l
 QTYID is kg
 VOL is in m3
then $CONV = 1000.0$

4.2(3).3.1 Simulate Advection of Constituent Totally Entrained in Water (subroutine ADVECT)

Purpose

ADVECT computes the concentration of material in a RCHRES and the quantities of material that leave the RCHRES due to longitudinal advection through active exits. ADVECT is a generalized subroutine, and is called by each module section which simulates constituents which undergo normal longitudinal advection.

Assumptions

Two assumptions are made in the solution technique for normal advection:

1. Each constituent advected by calling subroutine ADVECT is uniformly dispersed throughout the waters of the RCHRES.
2. Each constituent is completely entrained by the flow; that is, the material moves at the same horizontal velocity as the water.

Method

The equation of continuity may be written as:

$$\text{IMAT} - \text{ROMAT} = (\text{CONC} * \text{VOL}) - (\text{CONCS} * \text{VOLS}) \quad (2)$$

where:

IMAT = inflow of material over the interval
 ROMAT = total outflow of material over the interval
 CONCS = concentration at the start of the interval
 CONC = concentration at the end of the interval
 VOLS = volume of water stored in the RCHRES at the start of the interval
 VOL = volume of water stored in the RCHRES at the end of the interval

The other basic equation states that the total outflow of material over the time interval is a weighted mean of two estimates; one based on conditions at the start of the interval, the other on ending conditions:

$$\text{ROMAT} = ((\text{JS} * \text{ROS} * \text{CONCS}) + (\text{COJS} * \text{RO} * \text{CONC})) * \text{DELTS} \quad (3)$$

where:

JS = weighting factor
 COJS = 1.0 - JS
 ROS = rates of outflow at the start of the interval (m3/s or ft3/s)
 RO = rates of outflow at the end of the interval (m3/s or ft3/s)
 DELTS = length of interval (seconds)

Using Equations (2) in Section 4.2(3).2 (Subroutine ADCALC), Equation (3) can be written:

$$\text{ROMAT} = (\text{SROVOL} * \text{CONCS}) + (\text{EROVOL} * \text{CONC}) \quad (4)$$

where SROVOL and EROVOL are as defined earlier.

By combining Equations (2) and (4) we can solve for CONC:

$$\text{CONC} = (\text{IMAT} + \text{CONCS} * (\text{VOLS} - \text{SROVOL})) / (\text{VOL} + \text{EROVOL}) \quad (5)$$

The total amount of material leaving the RCHRES during the interval is calculated from equation (4).

If there is more than one active exit from the RCHRES, the amount of material leaving through each exit is calculated as:

$$\text{OMAT} = \text{SOVOL} * \text{CONCS} + \text{EOVOL} * \text{CONC} \quad (6)$$

where:

OMAT = amount of material leaving RCHRES through individual exit
 SOVOL = outflow volume component for individual exit based on start
 of interval
 EOVL = outflow volume component for individual exit based on end
 of interval

(SOVOL and EOVL are defined in Section 4.2(3).2)

If the RCHRES goes dry during the interval, the concentration at the end of the interval is undefined. The total amount of material leaving the RCHRES is:

$$\text{ROMAT} = \text{IMAT} + (\text{CONCS} * \text{VOLS}) \quad (7)$$

If there is more than one active exit from the RCHRES, the amount of material leaving through each exit from a RCHRES which has gone dry during the interval is calculated as:

$$\text{OMAT} = (\text{SOVOL} / \text{SROVOL}) * \text{ROMAT} \quad (8)$$

The units in the preceding equations are:

VOLS,VOL	m3 or ft3 (call these volunits)
SROVOL,etc	volunits/interval
CONCS,CONC	user defined (call these concunits)
IMAT,ROMAT,etc	concunits * volunits/interval

4.2(3).4 Simulate Heat Exchange and Water Temperature (Section HTRCH of Module RCHRES)

Purpose

The purpose of this code is to simulate the processes which determine the water temperature in a reach or mixed reservoir. Water temperature is one of the most fundamental indices used to determine the nature of an aquatic environment. Most processes of functional importance to an environment are affected by temperature. For example, the saturation level of dissolved oxygen varies inversely with temperature. The decay of reduced organic matter, and hence oxygen demand caused by the decay, increases with increasing temperature. Some form of temperature dependence is present in nearly all processes. The prevalence of individual phytoplankton and zooplankton species is often temperature dependent.

Required Time Series

Five time series of meteorological data are required to simulate the temperature balance within a RCHRES. These are:

1. solar radiation in langleys/interval
2. cloud cover expressed as tenths
3. air temperature in degrees F (English) or degrees C (Metric)
4. dewpoint temperature in degrees F (English) or degrees C (Metric)
5. wind speed in miles/interval (English) or km/interval (Metric)

Note that solar radiation data are usually available as daily totals. The user must generally convert these data to hourly or two hourly values before using them in HSPF. If the standard HSPF disaggregation rule were used, a daily value would be divided into equal increments for each interval of the day; this would not account for the rising and setting of the sun. A similar kind of preprocessing needs to be done if daily max/min air temperatures are used.

Schematic View of Fluxes and Storages

Figure 4.2(3).4-1 illustrates the fluxes involved in this module section. There are no significant internal sources or sinks of temperature within a RCHRES. Changes in heat content are due only to transport processes across the RCHRES boundaries. Module section HTRCH considers three major processes: heat transfer by advection, heat transfer across the air-water interface, and optionally, heat transfer across the water-sediment (bed) interface. The processes of diffusion and dispersion are not considered in HSPF.

Heat transfer by advection is simulated by treating water temperature as a thermal concentration. This enables the use of subroutine ADVECT, a standard subroutine which calculates advective transport of constituents totally entrained in the moving water.

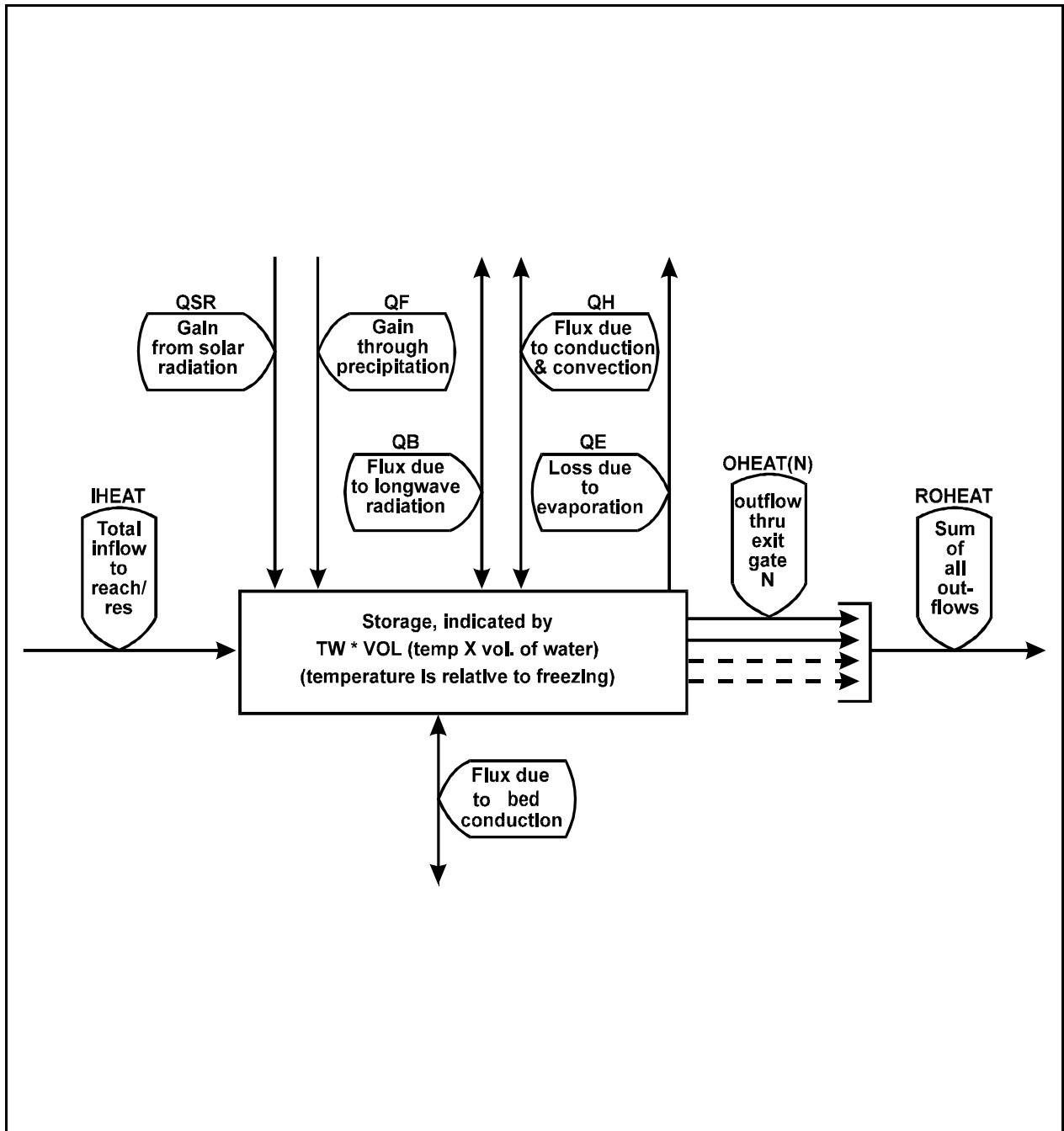


Figure 4.2(3).4-1 Flow diagram for HTRCH section of the RCHRES Application Module

Heat is transported across the air-water interface by a number of mechanisms, and each must be evaluated individually. The net transport across the air-water interface is the sum of the individual effects. Mechanisms which can increase the heat content of the water are absorption of solar radiation, absorption of longwave radiation, and conduction-convection. Mechanisms which decrease the heat content are emission of longwave radiation, conduction-convection, and evaporation.

Shortwave Solar Radiation

The shortwave radiation absorbed by a RCHRES is approximated by the following equation:

$$QSR = 0.97 * CFSAX * SOLRAD * 10.0 \quad (1)$$

where:

QSR = shortwave radiation (kcal/m2/interval)
 0.97 = fraction of incident radiation which is assumed absorbed
 (3 percent is assumed reflected)
 CFSAX = ratio of radiation incident to water surface to radiation
 incident to gage where data were collected. This factor also
 accounts for shading of the water body, e.g., by trees
 SOLRAD = solar radiation (langleys/interval)
 10.0 = conversion factor from langleys to kcal/m2

Longwave Radiation

All terrestrial surfaces, as well as the atmosphere, emit longwave radiation. The rate at which each source emits longwave radiation is dependent upon its temperature. The longwave radiation exchange between the atmosphere and the RCHRES is estimated using the formula:

$$QB = SIGMA * ((TWKELV^{**4}) - KATRAD * (10^{**-6}) * CLDFAC * (TAKELV^{**6})) * DELT60 \quad (2)$$

where:

QB = net transport of longwave radiation (kcal/m2/interval)
 SIGMA = Stephan-Boltzman constant multiplied by 0.97 to account
 for emissivity of water
 TWKELV = water temperature (degrees Kelvin)
 KATRAD = atmospheric longwave radiation coefficient with a typical
 value of 9.0
 CLDFAC = $1.0 + (.0017 * C^{**2})$
 TAKELV = air temperature corrected for elevation difference (deg K)
 C = cloud cover, expressed as tenths (range = 0 - 10)
 DELT60 = DELT(minutes) divided by 60

Both atmospheric radiation to the water body and back radiation from the water body to the atmosphere are considered in this equation. QB is positive for transport of energy from the water body to the atmosphere.

Conduction-Convection

Conductive-convective transport of heat is caused by temperature differences between the air and water. Heat is transported from the warmer medium to the cooler medium; heat can therefore enter or leave a water body, depending upon its temperature relative to air temperature. HSPF assumes that the heat transport is proportional to the temperature difference between the two media. The equation used is:

$$QH = CFPRES*(KCOND*10^{-4})*WIND*(TW - AIRTMP) \quad (3)$$

where:

QH = conductive-convective heat transport (kcal/m2/interval)
 CFPRES = pressure correction factor (dependent on elevation)
 KCOND = conductive-convective heat transport coefficient
 (typically in the range 1 - 20)
 WIND = wind speed (m/interval)
 TW = water temperature (deg C)
 AIRTMP = air temperature (deg C)

QH is positive for heat transfer from the water to the air.

Evaporative Heat Loss

Evaporative heat transport occurs when water evaporates from the water surface. The amount of heat lost depends on the latent heat of vaporization for water and on the quantity of water evaporated. For purposes of water temperature simulation, HSPF uses the following equation to calculate the amount of water evaporated:

$$EVAP = (KEVAP*10^{-9})*WIND*(VPRESW - VPRESA) \quad (4)$$

where:

EVAP = quantity of water evaporated (m/interval)
 KEVAP = evaporation coefficient with typical values of 1 - 5
 WIND = wind movement 2 m above the water surface (m/interval)
 VPRESW = saturation vapor pressure at the water surface (mbar)
 VPRESA = vapor pressure of air above water surface (mbar)

The heat removed by evaporation is then calculated:

$$QE = HFACT*EVAP \quad (5)$$

where:

QE = heat loss due to evaporation (kcal/m2/interval)
 HFACT = heat loss conversion factor (latent heat of vaporization
 multiplied by density of water)

Heat Content of Precipitation

In module section HYDR, an option exists to include the input of water from precipitation falling directly on the water surface. If this option is activated, it is necessary to assign a temperature to the water added to the RCHRES in this manner. HSPF assumes that precipitation has the same temperature as the water surface on which it falls.

Bed conduction

Heat movement between water and bed sediment contributes significantly to the diurnal variation of water temperature, especially in shallow streams and rivers. Simulation of bed conduction is optional, and the user may select from three alternative methods to represent this process.

Method 1:

If BEDFLG = 1, streambed conduction is computed as a simple function of the difference in temperature between the water-streambed interface (temperature = water temperature) and the streambed at an equilibrium ground temperature at some depth below the bed. The equation is:

$$QBED = KMUD * (TGRND - TW)$$

where:

QBED = heat flux from ground to water (kcal/m2/interval)
 TGRND = equilibrium ground temperature (C)
 TW = water temperature (C)
 KMUD = water-ground heat conduction coefficient (kcal/m2/C/interval)

KMUD can be estimated as the thermal conductivity of the streambed material divided by the depth (below the water-sediment interface) where equilibrium temperature is assumed to occur.

Method 2:

If BEDFLG = 2, bed conduction is based on the method of Caupp et al. (1994) that was used in modeling the Truckee River. The method is an extension of Method 1 to include a finite sediment or mud layer (consisting of water-saturated sediment) overlying the ground, which is at an equilibrium temperature. Heat fluxes between the ground and sediment and between the sediment and water are computed, as well as sediment and water temperatures. The algorithm, which includes a differencing scheme for updating the sediment temperature is described below:

The heat transfer between the ground and sediment is computed as follows:

$$QGRMUD = KGRND * (TGRND - TMUD)$$

where:

QGRMUD = heat transfer from ground to sediment layer (kcal/m²/interval)
 KGRND = ground-sediment heat conduction coefficient
 (kcal/m²/C/interval); (default value = 1.419)
 TGRND = equilibrium ground temperature (C)
 TMUD = sediment temperature (C)

This heat transfer is used to update the sediment temperature as follows:

$$TMUD = TMUD + QGRMUD / CPR / MUDDEP$$

where:

CPR = heat capacity of sediment (1000 kcal/m³/C)
 (CPR is assumed to be the heat capacity of water)
 MUDDEP = depth of sediment layer (m)

Finally, the new sediment temperature is used to compute the heat transfer between the sediment and water column:

$$QBED = KMUD * (TMUD - TW)$$

where:

QBED = heat flux from sediment to water (kcal/m²/hr)
 KMUD = water-sediment heat conduction coefficient (kcal/m²/C/hr)
 TW = water temperature (C)

Method 3:

If BEDFLG = 3, the bed conduction computation is based on the method proposed by Jobson (1977, 1979) in which the advection-dispersion equation for heat is solved analytically. Jobson's solution reduces the bed conduction to a convergent series consisting of the product of the following quantities:

1. Temperature change (deg C) of the water over a specific period (TSTOP intervals) prior to the current time interval. ()T)
2. Heat flux per degree C between the bed and water (over the TSTOP time period). The units are kcal/m²/C/interval. ()H)

Assuming time intervals of one hour, the equation is:

$$QBED = \sum_{(I=1, TSTOP)} [DELH(I) * DELTT(I)]$$

where:

'_(I=1, TSTOP) = summation over the past TSTOP hours
 DELH(I) = heat flux from bed to water at current interval resulting from
 a 1.0 degree C temperature increase at hour I (kcal/m²/C/hr)
 DELTT(I) = temperature change over hour I

Therefore, at each time step, the total bed conduction flux is simply the summation, over TSTOP, of the product of these two arrays. As implemented in HSPF, the temperature change at the current time step is computed twice. The first computation includes all heat flux components except bed conduction; then the resulting temperature change is used to compute the bed conduction flux, which is used to compute the final water temperature change.

Values of DELH and TSTOP can be developed from Jobson's equations; a utility program is available to compute these inputs as a function of the thickness and thermal properties of the bed. Note: The input values of DELH depend upon time-step, i.e., the units are kcal/m²/C/interval. Also, DELH values are negative.

Net heat exchange

The net heat exchange at the water surface is represented as:

$$QT = QSR - QB - QH - QE + QP + QBED \quad (6)$$

where:

QT = net heat exchange in kcal/m²/interval
 QSR = net heat transport from incident shortwave radiation
 QB = net heat transport from longwave radiation
 QH = heat transport from conduction-convection
 QE = heat transport from evaporation
 QP = heat content of precipitation
 QBED = net heat exchange with bed

Calculation of Water Temperature

Of the five heat transport mechanisms across the air-water interface, three are significant and dependent upon water temperature. In order to obtain a stable solution for water temperature, these three terms (QB, QH, QE) are evaluated for the temperature at both the start and end of the interval, and the average of the two values is taken (trapezoidal approximation). For this purpose, the unknown ending temperature is approximated by performing a Taylor series expansion about the starting temperature, and ignoring nonlinear terms. This formulation leads to the following equation for the change in water temperature over the interval:

$$DELTTW = CVQT * QT / (1.0 + SPD * CVQT) \quad (7)$$

where:

DELTTW = change in water temperature (deg C)
 CVQT = conversion factor to convert total heat exchange expressed in kcal/m²/interval to deg C/interval (volume dependent)
 QT = net heat exchange in kcal/m²/interval (with terms evaluated at starting temperature)
 SPD = sum of partial derivatives of QB, QH, and QE with respect to water temperature

The heat exchange calculations do not give realistic results when the water body becomes excessively shallow. Consequently, heat transport processes are not considered if the average depth of water in the RCHRES falls below 2 inches. When this happens, the water temperature is set equal to the air temperature.

4.2(3).4.1 Correct Air Temperature for Elevation Difference (subroutine RATEMP)

Purpose

The purpose of this code is to correct air temperature for any elevation difference between the RCHRES and the temperature gage.

Approach

The lapse rate for air temperature is dependent upon whether or not precipitation occurs during the time interval. If precipitation does occur, a wet lapse rate of $1.94\text{E-}3$ degrees C/ft is assumed. Otherwise, a dry lapse rate which is a function of the time of day is used. A table of 24 hourly dry lapse rates is built into HSPF. The corrected air temperature is:

$$\text{AIRTMP} = \text{GATMP} - \text{LAPS} * \text{ELDAT} \quad (8)$$

where:

AIRTMP = corrected air temperature (deg C)
 GATMP = air temperature at gage
 LAPS = lapse rate (degrees C/ft)
 ELDAT = elevation difference between mean RCHRES elevation and gage elevation (feet) (ELDAT is positive if the mean RCHRES elevation is greater than the gage elevation)

4.2(3).5 Simulate Behavior of Inorganic Sediment (Section SEDTRN of Module RCHRES)

Purpose

The purpose of this code is to simulate the transport, deposition, and scour of inorganic sediment in free-flowing reaches and mixed reservoirs. The modeling of sediment in channels may be needed for analysis of such problems as:

1. Structural instability of bridge piers or water intakes caused by scouring.
2. Reduction of reservoir capacity and clogging of irrigation canals and navigable waterways due to deposition.
3. Reduction of light available to aquatic organisms caused by suspended sediment.
4. Transport of adsorbed pollutants such as fertilizers, herbicides, and pesticides.

Schematic View of Fluxes and Storages

Figure 4.2(3).5-1 shows the principal state variables and fluxes with which module section SEDTRN deals.

Both the migration characteristics and the adsorptive capacities of sediment vary significantly with particle size. Consequently, HSPF divides the inorganic sediment load into three components (sand, silt, and clay), each with its own properties. Parametric information required for cohesive sediments (silt and clay) include:

1. particle diameter - D
2. particle settling velocity in still water - W
3. particle density - RHO
4. critical shear stress for deposition - TAUCD
5. critical shear stress for scour - TAUCS
6. erodibility coefficient - M

Parameter values required for noncohesive, or sand, particles depend on the method used to compute sandload (alternate methods are described in the functional description of subroutines SANDLD, TOFFAL, and COLBY). If the Toffaleti method is used, values must be defined for median bed sediment diameter (DB50) and particle settling velocity (W). The Colby method requires a value for DB50, and the power function method requires both a coefficient (KSAND) for the power function and an exponent (EXPSND).

As Figure 4.2(3).5-1 indicates, the same material fluxes are modeled for all three fractions of sediment. Only the methodology used to determine fluxes between suspended storage and bed storage differ.

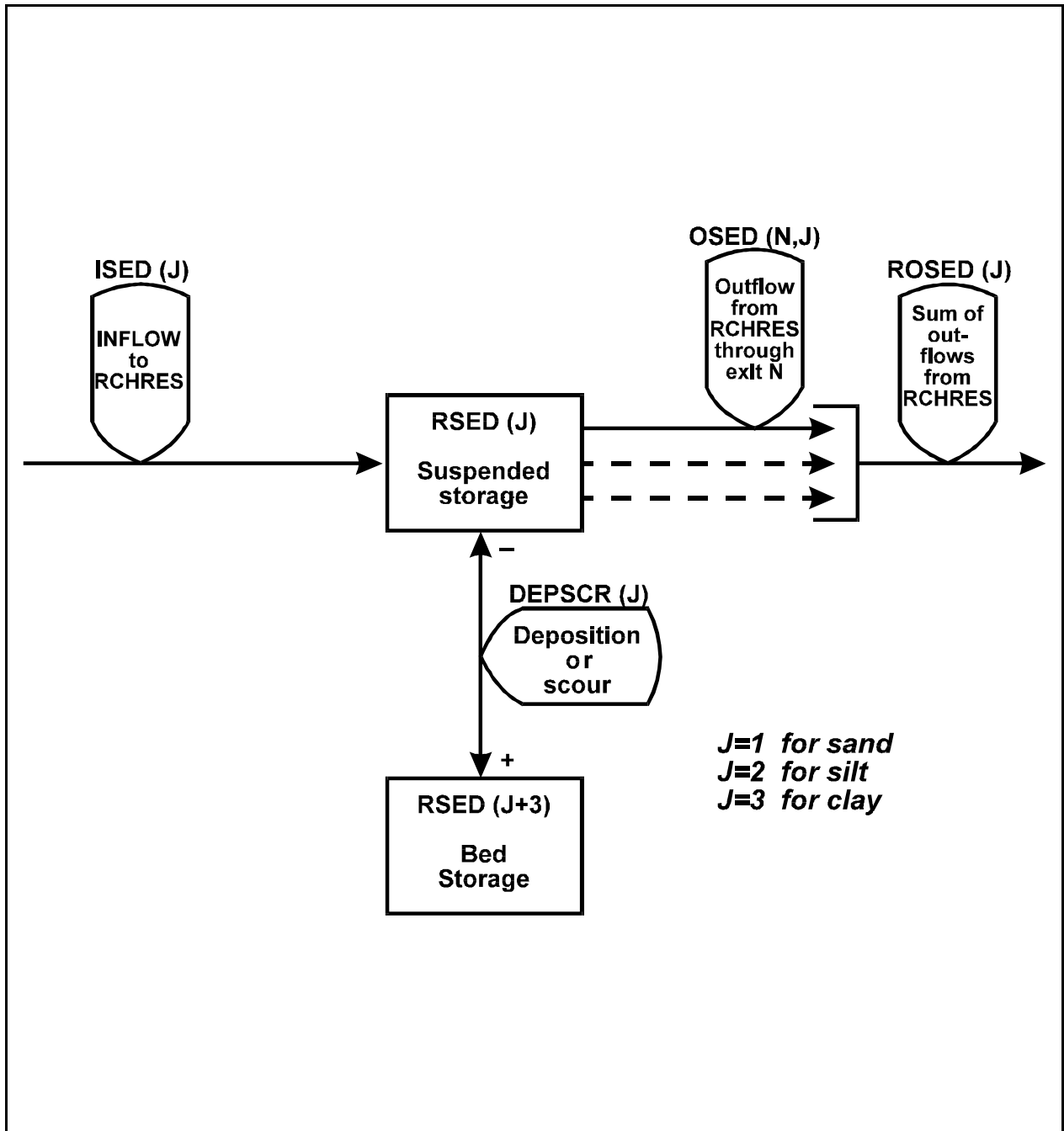


Figure 4.2(3).5-1 Flow diagram of inorganic sediment fractions in the SEDTRN section of the RCHRES Application Module

HSPF assumes that scour or deposition of inorganic sediment does not affect the hydraulic properties of the channel. Furthermore, it is assumed that sand, silt, and clay deposit in different areas of the RCHRES bed; consequently, the deposition or scour of each material is not linked to the other fractions (i.e., "armoring" is not modeled). Longitudinal movement of bed sediments is not modeled.

The details of the transport, deposition, and scour techniques are outlined in the functional descriptions of the lower level routines of the SEDTRN module section. Following these calculations, the depth of sediment in the RCHRES bed is determined in order to warn the user whenever the deposited sediment exceeds a pre-specified level. First, the volume occupied by each fraction of bed sediment is calculated:

$$\text{VOLSED}(J) = \text{RSED}(J+3)/\text{RHO}(J)*1.0\text{E}06 \quad (1)$$

where:

VOLSED(J) = volume occupied by bed sediment of fraction J (m³ or ft³)
 RSED(J+3) = bed storage of sediment fraction J (mg.m³/l or mg.ft³/l)
 RHO(J) = particle density of fraction J (gm/cm³)

The volumes of the three fractions of bed sediment are summed, and the total bed volume is adjusted to account for the fraction of the volume which is void of sediment (i.e., the porosity):

$$\text{VOLSEDA} = \text{VOLSED}/(1.0 - \text{POR}) \quad (2)$$

where:

VOLSEDA = volume of bed adjusted to account for volume occupied
 by materials other than sediment
 VOLSED = volume of sediment contained in the bed (sand + silt + clay)
 POR = porosity of bed sediment (ratio of pore volume to total volume)

Finally, the depth of bed sediment is calculated for use as an indicator of excessive deposition:

$$\text{BEDDEP} = \text{VOLSEDA}/(\text{LEN}*\text{BEDWID}) \quad (3)$$

where:

BEDDEP = depth of bed (m or ft)
 VOLSEDA = volume of bed (m³ or ft³)
 LEN = length of RCHRES (m or ft)
 BEDWID = effective width of bed for calculation of bed thickness
 (an input parameter expressed in m or ft)

If the calculated value for BEDDEP exceeds a user specified value, a warning message is printed to alert the user to potential modeling problems.

The PERLND module of HSPF simulates removal of total inorganic sediment due to washoff from the land surface and erosion from gullies. Therefore, the user must divide this total sediment into the three components (sand, silt, and clay) so that this material can be routed through the channel system in the RCHRES module.

4.2(3).5.1 Simulate Cohesive Sediments (subroutine COHESV)

Purpose

COHESV simulates the deposition, scour, and transport processes of cohesive sediments (silt and clay).

Method

The modeling effort consists of two steps. First, subroutine ADVECT is called to perform advective transport (see section 4.2(3).3.1). Then subroutine BDEXCH is called, and deposition or scour is calculated based on the bed shear stress and the Krone and Partheniades equations. (see section 4.2(3).5.1.1).

4.2(3).5.1.1 Simulate Exchange with Bed
(subroutine BDEXCH)

Purpose

BDEXCH simulates the deposition and scour of cohesive sediment fractions (silt and clay).

Approach

Exchange of cohesive sediments with the bed is dependent upon the shear stress exerted upon the bed surface. The shear stress within the RCHRES is calculated in subroutine SHEAR of the HYDR section. Whenever shear stress (TAU) in the RCHRES is less than the user-supplied critical shear stress for deposition (TAUCD), deposition occurs; whenever shear stress is greater than the user-supplied critical shear stress for scour (TAUCS), scouring of cohesive bed sediments occurs. The rate of deposition for a particular fraction of cohesive sediment is based on a simplification of Krone's (1962) equation to the following form:

$$D = W*CONC*(1.0 - TAU/TAUCD) \quad (4)$$

where:

D = rate at which sediment fraction settles out of suspension
(mass/len2.iv1)
W = settling velocity for cohesive sediment fraction (len/iv1)
CONC = concentration of suspended sediment fraction (mass/len3)
TAU = shear stress (lb/ft2 or kg/m2)
TAUCD = critical shear stress for deposition (lb/ft2 or kg/m2)

The rate of change of suspended sediment fraction concentration in the RCHRES due to deposition can be expressed as:

$$d(CONC)/dt = -(D/AVDEPM) \quad (5)$$

where:

AVDEPM = average depth of water in RCHRES (m)

By substituting the expression for deposition rate (D) from Equation 4, the following equation is obtained:

$$d(\text{CONC})/dt = -(W \cdot \text{CONC} / \text{AVDEPM}) \cdot (1 - \text{TAU} / \text{TAUCD}) \quad (6)$$

By integrating and rearranging this equation, a solution may be obtained for the concentration of suspended sediment lost to deposition during a simulation interval (DEPCONC):

$$\text{DEPCONC} = \text{CONC} \cdot (1.0 - \text{EXP}((-W / \text{AVDEPM}) \cdot (1.0 - \text{TAU} / \text{TAUCD}))) \quad (7)$$

where:

CONC = concentration of suspended sediment at start of interval (mg/l)

W = settling velocity for sediment fraction (m/ivl)

AVDEPM = average depth of water in RCHRES in meters (calculated in HYDR)

TAU = shear stress (lb/ft² or kg/m²)

TAUCD = critical shear stress for deposition (lb/ft² or kg/m²)

The user must supply values for settling velocity (W) and critical shear stress for deposition (TAUCD) for each fraction of cohesive sediment (silt and clay).

Following the calculation of DEPCONC, the storage of sediment in suspension and in the bed is updated:

$$\text{SUSP} = \text{SUSP} - (\text{DEPCONC} \cdot \text{VOL}) \quad (8)$$

$$\text{BED} = \text{BED} + (\text{DEPCONC} \cdot \text{VOL}) \quad (9)$$

where:

SUSP = suspended storage of sediment fraction (mg.ft³/l or mg.m³/l)

BED = storage of sediment fraction in bed (mg.ft³/l or mg.m³/l)

VOL = volume of water in RCHRES (ft³ or m³)

The rate of resuspension, or scour, of cohesive sediments from the bed is derived from a modified form of Partheniades' (1962) equation:

$$S = M \cdot (\text{TAU} / \text{TAUCS} - 1.0) \quad (10)$$

where:

S = rate at which sediment is scoured from the bed (mass/len².ivl)

M = erodibility coefficient for the sediment fraction (kg/m².ivl)

TAUCS = critical shear stress for scour (lbs/ft² or kg/m²)

The rate of change of suspended sediment fraction concentration in the RCHRES due to scour can be expressed as:

$$d(\text{CONC})/dt = S / \text{AVDEPM} \quad (11)$$

By substituting the expression for scour rate (S) from Equation 10 the following equation is obtained:

$$d(\text{CONC})/dt = (M/\text{AVDEPM}) * (\text{TAU}/\text{TAUCS} - 1.0) \quad (12)$$

By integrating and rearranging this equation, a solution may be obtained for the concentration of suspended sediment added to suspension by scour during a simulation interval (SCRCONC):

$$\text{SCRCONC} = M/\text{AVDEPM} * 1000 * (\text{TAU}/\text{TAUCS} - 1.0) \quad (13)$$

where:

M = erodibility coefficient (kg/m².ivl)
 AVDEPM = average depth of water (m)
 1000 = conversion from kg/m³ to mg/l

The user is required to supply values for the erodibility coefficient (M) and critical shear stress for scour (TAUCS) for each fraction of cohesive sediment (silt and clay) which is modeled.

Following the calculation of SCRCONC, the storage of sediment in suspension and in the bed is updated:

$$\text{BED} = \text{BED} - (\text{SCRCONC} * \text{VOL}) \quad (14)$$

$$\text{SUSP} = \text{SUSP} + (\text{SCRCONC} * \text{VOL}) \quad (15)$$

If the amount of scour calculated is greater than available storage in the bed, the bed scour is set equal to the bed storage, and the bed storage is set equal to zero. Since the value specified for TAUCS should be greater than that for TAUCD, only one process (deposition or scour) occurs during each simulation interval.

4.2(3).5.2 Simulate Behavior of Sand/Gravel (subroutine SANDLD)

Purpose

SANDLD simulates the deposition, scour, and transport processes of the sand fraction of inorganic sediment.

Method

Erosion and deposition of sand, or noncohesive sediment, is affected by the amount of sediment the flow is capable of carrying. If the amount of sand being transported is less than the flow can carry for the hydrodynamic conditions of the RCHRES, sand will be scoured from the bed. This occurs until the actual sand transport rate becomes equal to the carrying capacity of the flow or until the available bed sand is all scoured. Conversely, deposition occurs if the sand transport rate exceeds the flow's capacity to carry sand.

Subroutine SANDLD allows the user to calculate sand transport capacity for a RCHRES by any one of three methods. Depending on the value of SANDFG specified in the User's Control Input, either the Toffaleti equation (SANDFG=1), the Colby method (SANDFG=2), or an input power function of velocity (SANDFG=3) is used. If sand transport capacity is calculated using the Toffaleti or Colby methods, the potential sandload concentration is determined by the following conversion:

$$PSAND = (GSI * TWIDE * 10.5) / ROM \quad (16)$$

where:

PSAND = potential sandload (mg/l)
 GSI = sand transport capacity (tons/day/ft of width)
 (calculated in COLBY or TOFFAL)
 TWIDE = width of RCHRES (ft)
 10.5 = conversion factor
 ROM = total rate of outflow of water from the RCHRES (m3/sec)

If carrying capacity is a power function of velocity, PSAND is calculated as:

$$PSAND = KSAND * AVVELE ** EXPSND \quad (17)$$

where:

KSAND = coefficient in the sandload suspension equation (input parameter)
 EXPSND = exponent in sandload suspension equation (input parameter)
 AVVELE = average velocity (ft/sec)

The potential outflow of sand during the interval is:

$$PROSND = (SANDS * SROVOL) + (PSAND * EROVOL) \quad (18)$$

where:

PROSND = potential sand outflow
 SANDS = concentration of sand at start of interval (mg/l)
 SROVOL and EROVOL are as defined in Section 4.2(3).2

The potential scour from, or deposition to, the bed storage is found using the continuity equation:

$$PSCOUR = (VOL * PSAND) - (VOLS * SANDS) + PROSND - ISAND \quad (19)$$

where:

PSCOUR = potential scour (+) or deposition (-)
 VOL = volume of water in RCHRES at the end of the interval (ft3 or m3)
 VOLS = volume of water in RCHRES at the start of interval (ft3 or m3)
 ISAND = total inflow of sand into RCHRES during interval

The terms in Equations 18 and 19 have the units of concentration. The potential scour is compared to the amount of sand material on the bottom surface available for resuspension. If scour demand is less than available bottom sands, the demand is satisfied in full, and the bed storage is adjusted accordingly. The new suspended concentration is PSAND. If the potential scour cannot be satisfied by bed storage, all of the available bed sand is suspended, and bed storage is exhausted. The concentration of suspended sandload is calculated as:

$$SAND = (ISAND + SCOUR + SANDS*(VOLS - SROVOL))/(VOL + EROVOL) \quad (20)$$

where:

SAND = concentration of sand at end of interval
 SCOUR = sand scoured from, or deposited to, the bottom
 SANDS = concentration of sand at start of interval

The total amount of sand leaving the RCHRES during the interval is:

$$ROSAND = SROVOL*SANDS + EROVOL*SAND \quad (21)$$

If a RCHRES goes dry during an interval, or if there is no outflow from the RCHRES, all the sand in suspension at the beginning of the interval is assumed to settle out, and the bed storage is correspondingly increased.

4.2(3).5.2.1 Calculate Sand Transport Capacity by Using Toffaleti's Method (subroutine TOFFAL)

Purpose

TOFFAL uses Toffaleti's method to calculate the capacity of the RCHRES flow to transport sand.

Method

In Toffaleti's methodology, the actual stream for which the sand discharge is to be calculated is assumed to be equivalent to a two-dimensional stream of width equal to that of the real stream and of depth equal to the hydraulic radius of the real stream (FHRAD).

For the purposes of calculation, the depth, FHRAD, of the hypothetical stream is divided into four zones shown in Figure 4.2(3).5-2. These are: (1) the bed zone of relative thickness $Y/FHRAD = 2*FDIAM/FHRAD$; (2) the lower zone extending from $Y/FHRAD = 2*FDIAM/FHRAD$ to $Y/FHRAD = 1/11.24$; (3) the middle zone extending from $Y/FHRAD = 1/11.24$ to $Y/FHRAD = 1/2.5$; and (4) the upper zone extending from $Y/FHRAD = 1/2.5$ to the surface. (FDIAM is the median bed sediment diameter). The velocity profile is represented by the power relation:

$$U = (1 + CNV)*V*(Y/FHRAD)**CNV \quad (22)$$

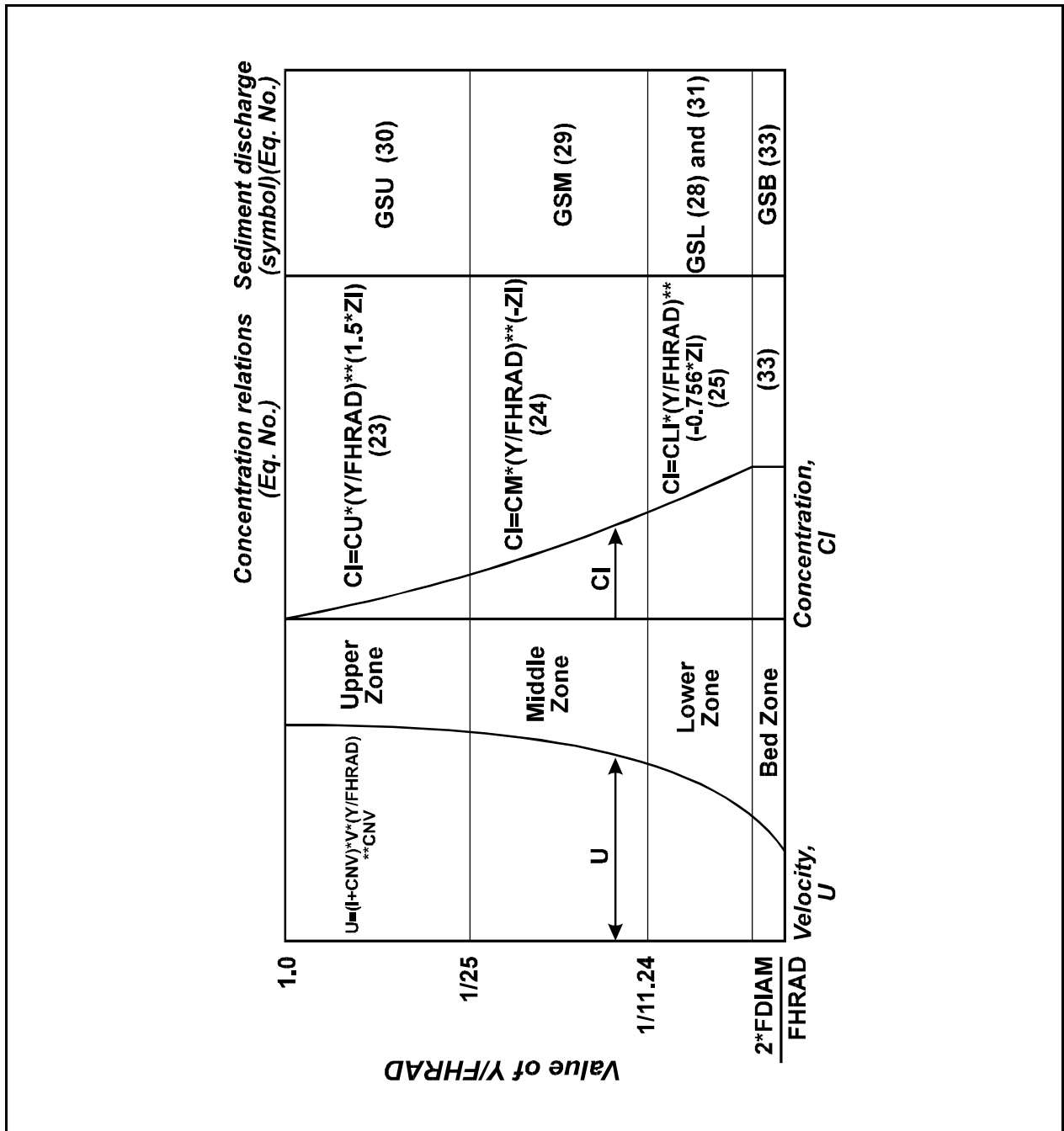


Figure 4.2(3).5-2 Toffaleti's velocity, concentration, and sediment discharge relations

where:

U = flow velocity at distance Y above the bed (ft/sec)
 V = mean stream velocity (ft/sec)
 CNV = exponent derived empirically as a function of water temperature ($0.1198 + 0.00048 \cdot \text{TMPR}$)
 TMPR = water temperature (degrees F)

The concentration distribution of sand is given by a power relation for each of the three upper zones; i.e., by Equations 23-25 in Figure 4.2(3).5-2. The exponent, ZI, in Equations 23-25 is given by:

$$\text{ZI} = (\text{VSET} \cdot \text{V}) / (\text{CZ} \cdot \text{FHRAD} \cdot \text{SLOPE}) \quad (26)$$

where:

VSET = settling velocity for sand (ft/s)
 SLOPE = slope of RCHRES (ft/ft)
 CZ = empirical factor derived as a function of water temperature ($260.67 - 0.667 \cdot \text{TMPR}$)

Expressions for the sand transport capacity of the lower (GSL), middle (GSM), and upper (GSU) zones are obtained by substituting U from Equation 22 and the appropriate value for sand particle concentration (CI) for each zone into the following equation and integrating between the vertical limits of the zone:

$$\text{GSI} = \text{INT} [\text{LLI to ULI}] (\text{CI} \cdot \text{Udy}) \quad (27)$$

where:

GSI = sand transport capacity for zone I
 INT = integral of function in () over limits in []
 ULI = depth Y at upper limit of zone I
 LLI = depth Y at lower limit of zone I
 CI = concentration of sand in zone I

The resulting equations for sand transport capacity in the three zones are:

$$\text{GSL} = \text{CMI} \cdot ((\text{HRAD}/11.24)^{(1.0 + \text{CNV} - 0.758 \cdot \text{ZI})} - (2 \cdot \text{FDIAM})^{(1.0 + \text{CNV} - 0.756 \cdot \text{ZI})}) / (1.0 + \text{CNV} - 0.756 \cdot \text{ZI}) \quad (28)$$

$$\text{GSM} = \text{CMI} \cdot ((\text{HRAD}/11.24)^{(0.244 \cdot \text{ZI})} \cdot ((\text{HRAD}/2.5)^{(1.0 + \text{CNV} - \text{ZI})} - (\text{HRAD}/11.24)^{(1.0 + \text{CNV} - \text{ZI})})) / (1.0 + \text{CNV} - \text{ZI}) \quad (29)$$

$$\text{GSU} = \text{CMI} \cdot ((\text{HRAD}/11.24)^{(0.244 \cdot \text{ZI})} \cdot (\text{HRAD}/2.5)^{(0.5 \cdot \text{ZI})} \cdot (\text{HRAD}^{(1.0 + \text{CNV} - 1.5 \cdot \text{ZI})} - (\text{HRAD}/2.5)^{(1.0 + \text{CNV} - 1.5 \cdot \text{ZI})})) / (1.0 + \text{CNV} - 1.5 \cdot \text{ZI}) \quad (30)$$

in which

$$\text{CMI} = 43.2 \cdot \text{CLI} \cdot (1.0 + \text{CNV}) \cdot \text{V} \cdot \text{HRAD}^{(0.758 \cdot \text{ZI} - \text{CNV})} \quad (31)$$

A value for CLI, the concentration of sand in the lower zone, can be obtained by setting the expression for GSL in Equation 28 equal to the following empirical expression and solving for CLI:

$$GSL = 0.6 / ((TT * AC * K4 / V^{**2})^{**}(1.67) * FDIAM / 0.00058)^{**}(1.67)) \quad (32)$$

where:

- GSL = sand transport capacity
- TT = empirical factor derived as a function of water temperature ($1.10 * (0.051 + 0.00009 * TMPR)$)
- AC = empirical factor derived as a function of the kinematic viscosity of water (VIS) and shear velocity based on shear stress due to sand grain roughness (USTAR)
- K4 = empirical factor derived as a function of AC, slope of the RCHRES (SLOPE), and particle diameter for which 65% by weight of sediment is finer (D65).
- V = mean stream velocity (ft/sec)
- FDIAM = median bed sediment diameter (ft)

Values for factors AC and K4 are given in Figure 4.2(3).5-3. The dimensions of AC are such that GSL is expressed in tons per day per foot of width. Consequently, when CLI is evaluated and substituted back into Equations 28-30 the resulting units of sand transport capacity for all three zones are tons per day per foot of width.

Prior to calculation of sand transport capacity for the zones, Equation 25 is solved to be sure that the value for concentration at $Y=2*FDIAM$ does not exceed 100 lbs/ft³. If it does, the concentration at this depth is set equal to 100 lbs/ft³ and an adjusted value of CLI is calculated and used in Equations 28-30. The transport capacity of the final zone, the bed zone (Figure 4.2(3).5-2), is also determined using the adjusted value of CLI and the following equation:

$$GSB = CMI * (2 * FDIAM)^{**}(1.0 + CNV - 0.758 * ZI) \quad (33)$$

The total sand transport capacity (GSI) for the RCHRES is the sum of the transport capacities for the four zones:

$$GSI = GSB + GSL + GSM + GSU \quad (34)$$

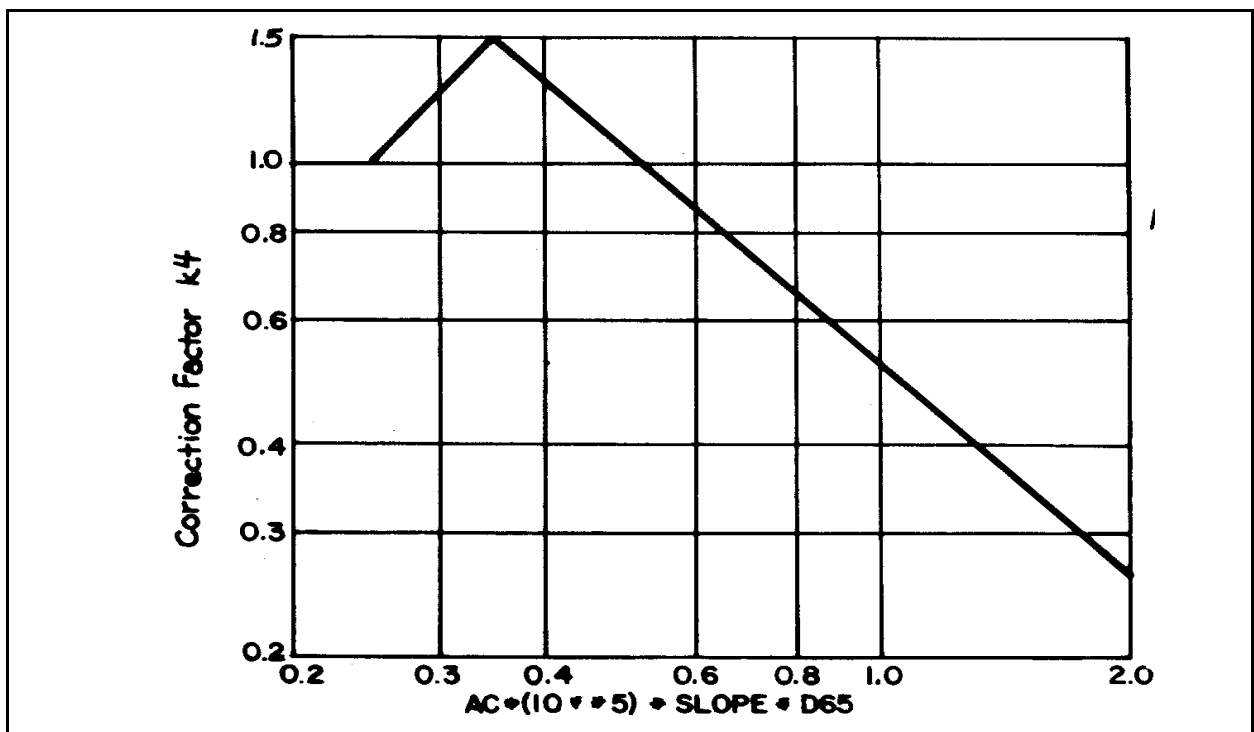
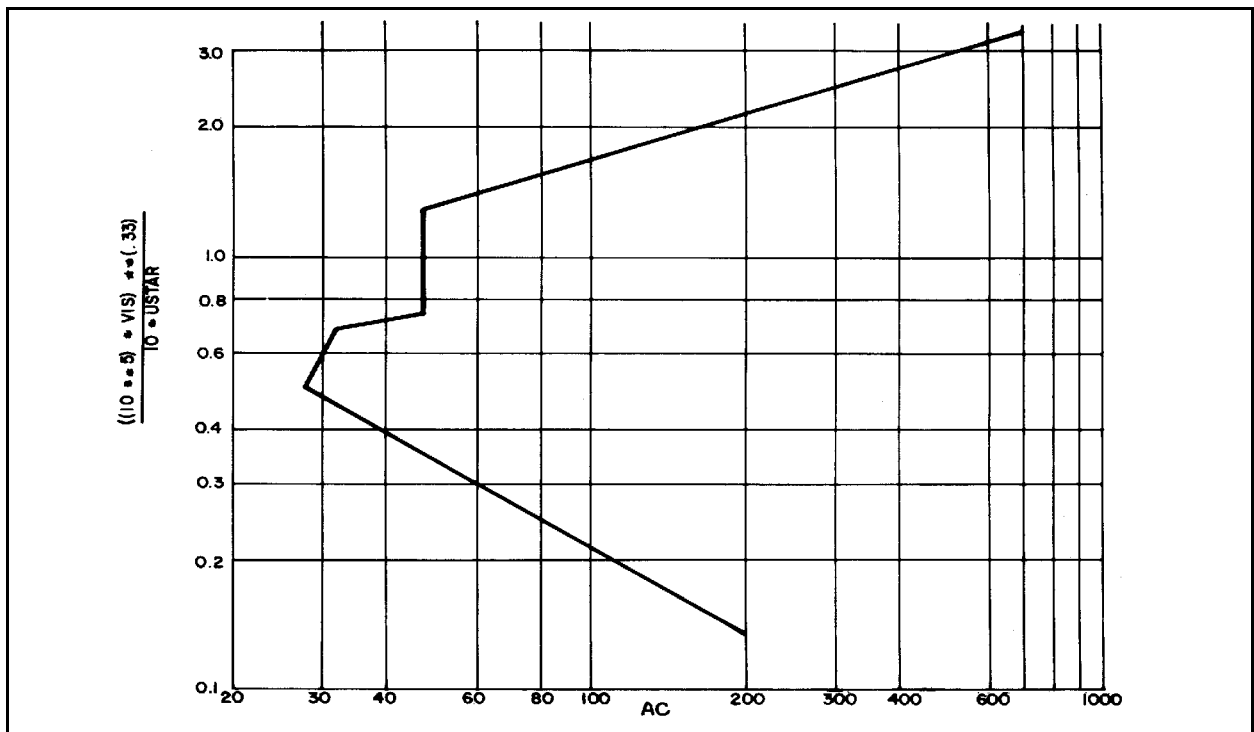


Figure 4.2(3).5-3 Factors in Toffaleti relations

4.2(3).5.2.2 Calculate Sand Transport Capacity by Using Colby's Method (subroutine COLBY)

Purpose

COLBY calculates the capacity of the RCHRES to transport sand based on the median bed sediment diameter (DB50), average stream velocity (V), hydraulic radius (HRAD), fine sediment load concentration (FSL), and water temperature (TEMPR).

Method

The solution technique used in this subroutine is based on empirical relationships developed from Figures 4.2(3).5-4 and 4.2(3).5-5. In general terms, the solution consists of three operations:

1. Obtain one value for sediment transport capacity from a matrix of values by interpolation. The dimensions of the matrix (G) are 4x8x6 and correspond to ranges of hydraulic radius, velocity, and mean diameter of bed sediment, respectively. Since Colby's curves were developed on a log-log scale, it is necessary to perform a series of three linear interpolations of logarithmic values to derive the value for sediment transport appropriate for the hydraulic parameters in the RCHRES. This value (GTUC) is not corrected for the effects of fine sediment concentration or water temperature.
2. Correct sand transport capacity value to account for water temperature in RCHRES. A multiplier is obtained from a matrix of values by interpolation. The dimensions of the matrix (T) are 7x4 and correspond to ranges of water temperature and hydraulic radius, respectively. A linear interpolation of logarithmic values is performed to derive the appropriate temperature correction factor. Generally speaking sand transport capacity, measured in tons per day per foot of stream width, decreases with increasing stream width (see Figure 4.2(3).5-5).
3. Correct sand transport capacity value to account for fine sediment load in RCHRES. A multiplier is obtained from a matrix of values by interpolation. The dimensions of the matrix (F) are 5x9 and correspond to ranges of fine sediment load concentration and hydraulic radius, respectively. Again, a linear interpolation of logarithmic values is performed to derive the appropriate correction factor. Sand transport capacity increases with increasing fine sediment load and with increasing stream width (Figure 4.2(3).5-5). It should be noted, however, that the correction factor is not large for typical stream conditions. For example, the multiplier corresponding to a fine sediment load of 10,000 ppm (with hydraulic radius of 1 foot) is 1.17.

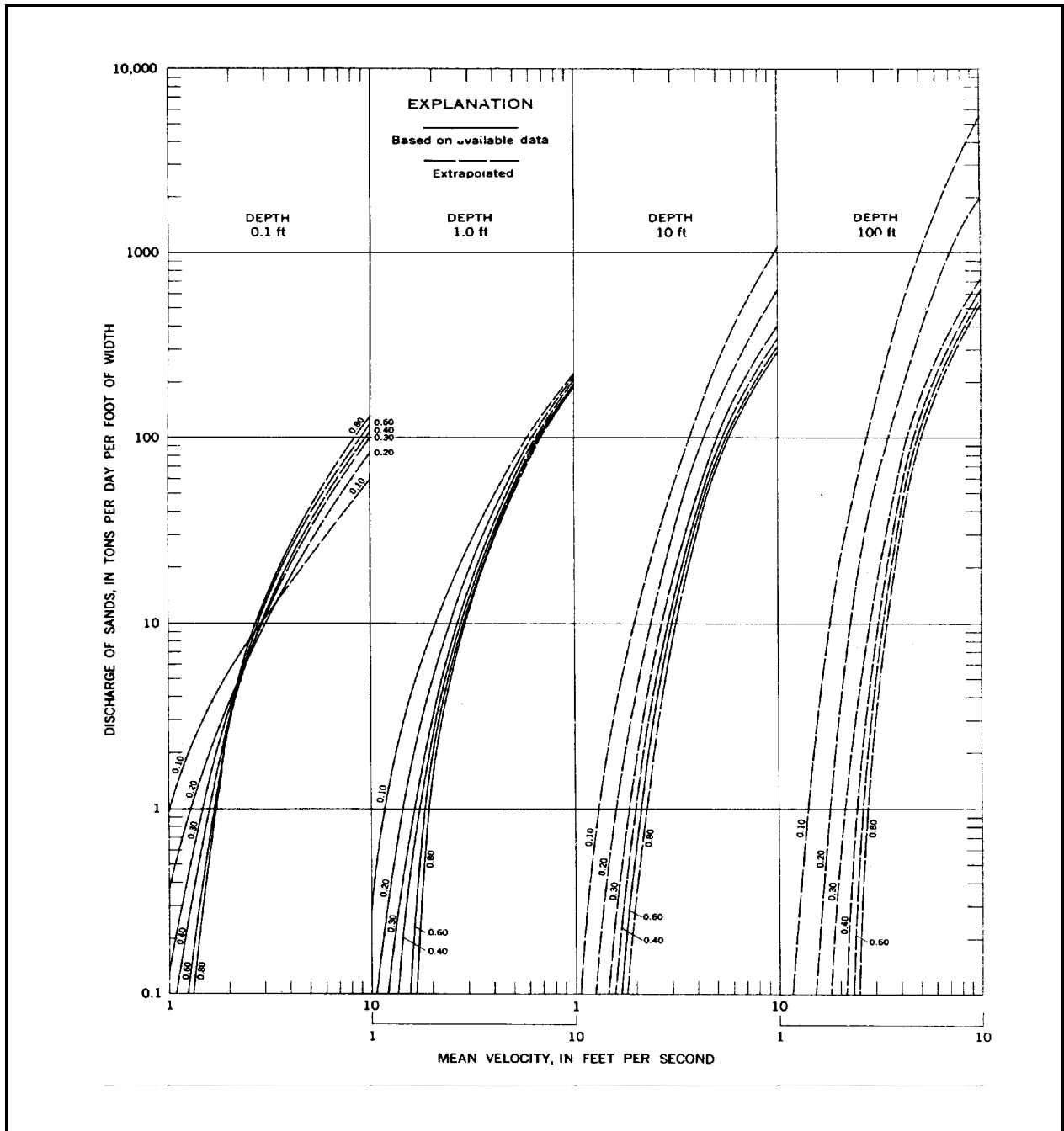


Figure 4.2(3).5-4 Colby's relationship for discharge of sands in terms of mean velocity for six median sizes of bed sands, four depths of flow, and water temperature of 60 F

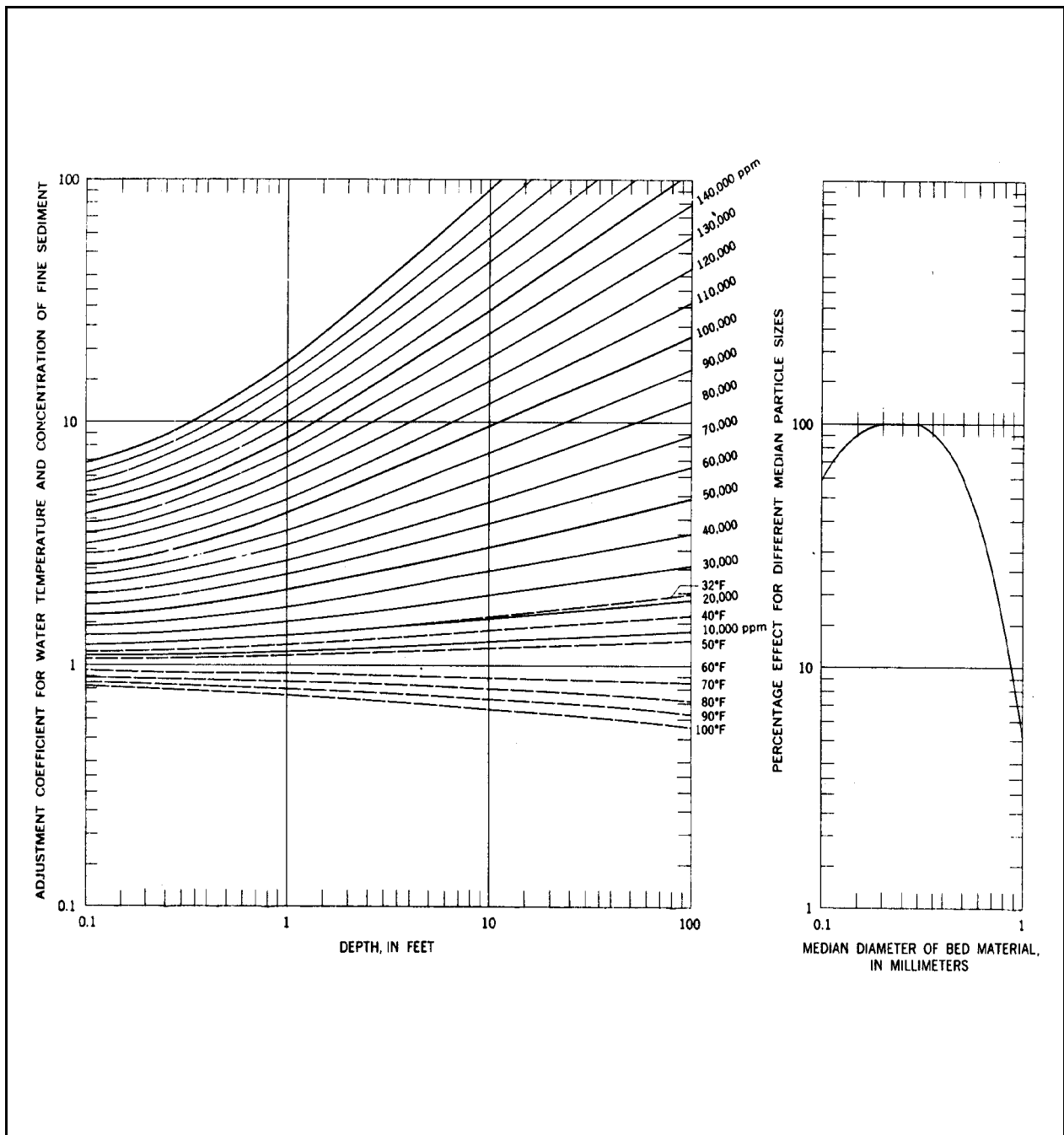


Figure 4.2(3).5-5 Colby's correction factors for effect of water temperature, concentration of fine sediment, and sediment size; applied to uncorrected discharge of sand given by Figure 4.2(3).5-4

The following additional comments are important to understanding and using the COLBY subroutine in HSPF:

1. Fine sediment load is defined as the sum of suspended silt and clay.
2. If the value for median bed sediment diameter, hydraulic radius, or average velocity for the RCHRES for a given simulation interval falls outside the range of values considered in Colby's graphs, a solution for sand transport capacity cannot be obtained by the Colby method. In this case, an error message is printed which specifies which parameter is out of range, and subroutine TOFFAL is automatically called to obtain a solution using the Toffaleti method.

Acceptable ranges of parameter values for COLBY are:

- | | |
|----------------------------------|---------------|
| (a) median bed sediment diameter | 0.1-0.8 mm |
| (b) hydraulic radius | 0.1-100 ft |
| (c) average velocity | 1.0-10.0 ft/s |
3. Both the Colby and Toffaleti formulations equate depth of flow to hydraulic radius. This approximation is best for wide rivers. Subroutines COLBY and TOFFAL were obtained and modified from Battelle Northwest Laboratories' SERATRA model (Onishi and Wise, 1979). In this model, the depth of flow values in Figures 4.2(3).5-4 and 4.2(3).5-5 are equated to hydraulic radius values, and the HSPF version of COLBY has done the same. To the best of our knowledge the accuracy of this approximation for narrow streams has not been documented.

4.2(3).6 Simulate the Behavior of a Generalized Quality Constituent (Module Section GQUAL)

Purpose

The purpose of this code is to enable the model user to simulate the behavior of a generalized constituent. The constituent which is modeled may be present in the RCHRES only in a dissolved state, or it may also be sediment-associated. If the generalized quality constituent, which will be called a "qual" throughout this discussion, is not associated with sediment, module section GQUAL only considers the following processes:

1. Advection of dissolved material
2. Decay processes. One or more of the following can be modeled:
 - a. hydrolysis
 - b. oxidation by free radical oxygen
 - c. photolysis
 - d. volatilization
 - e. biodegradation
 - f. generalized first-order decay
3. Production of one generalized quality constituent as a result of decay of another generalized quality constituent by any of the listed decay processes except volatilization. This capability is included to allow for situations in which the decay products of a chemical are of primary interest to the user.

The following additional processes are considered if the generalized quality constituent being modeled is sediment-associated:

4. Advection of adsorbed suspended material
5. Deposition and scour of adsorbed material with sediment
6. Decay of suspended and bed material
7. Adsorption/desorption between dissolved and sediment-associated phase.

Schematic View of Fluxes and Storage

Figure 4.2(3).6-1 illustrates the fluxes and storages modeled in section GQUAL. Note that the arrows indicating fluxes from each of the sediment fraction storages are not all labeled. For instance, although deposition and scour transfer materials between the suspended storage and bed storage of all three sediment fractions (sand, silt, clay), only the flux arrow for deposition/scour of clay is labeled. Deposition/scour flux arrows for sand and silt are left unlabeled so that the flow diagram does not become overly cluttered and incomprehensible. The same convention is used for the other fluxes contained in the flow diagram (i.e., an unlabeled flux arrow indicates that a flux of the same nature as a parallel labeled flux occurs).

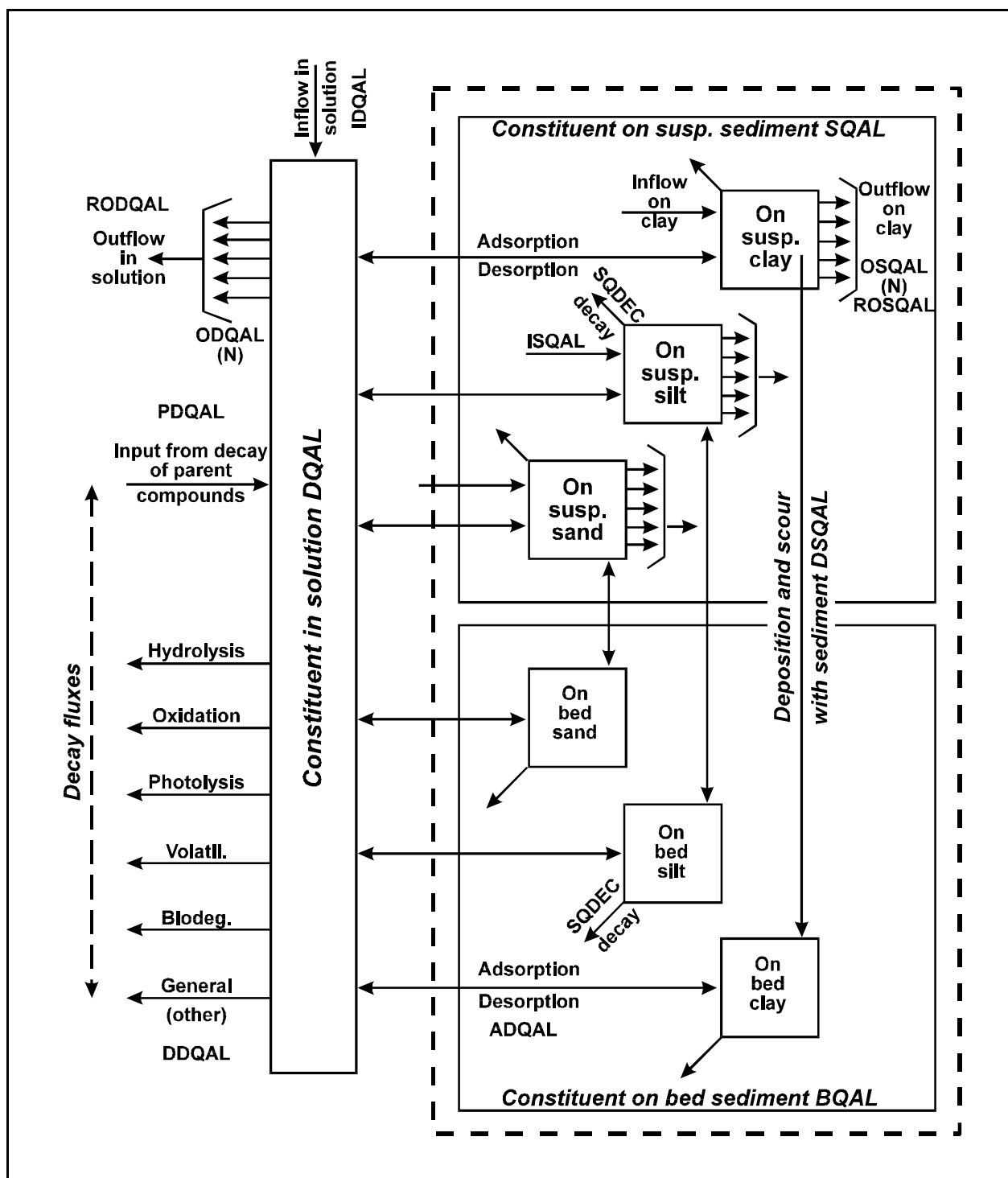


Figure 4.2(3).6-1 Flow diagram for generalized quality constituent in the GQUAL section of the RCHRES Application Module

Approach

The first portion of GQUAL evaluates the nature of the data which will be used for the GQUAL simulation. Since it is anticipated that some users of section GQUAL will be using this section independently of many of the other sections of the RCHRES application module, a variety of data types are allowed. In particular, most data required for simulation of individual decay processes can be supplied in the form of a single constant, 12 monthly constants, a time series value from the INPAD, or in cases where the data value is calculated in another active section of RCHRES, the last computed value may be used. Data types which may be obtained from any one of these sources include:

1. water temperature
2. pH (for hydrolysis)
3. free radical oxygen (for oxidation)
4. total suspended sediment (for photolysis)
5. phytoplankton (for photolysis)
6. cloud cover (for photolysis)
7. wind (for volatilization on lakes)

GQUAL utilizes six routines to perform the simulation of a generalized quality constituent. These six routines and their functions are:

1. OXREA: compute oxygen reaeration rate (used to simulate volatilization)
2. ADVECT: simulate advection of dissolved material
3. DDECAY: simulate decay of dissolved material
4. ADVQAL: advect sediment-associated material
5. ADECAY: simulate decay of qual adsorbed to suspended and bed sediment
6. ADSDES: simulate exchange of materials due to adsorption and desorption

Details on the methods used by these routines are provided in functional descriptions 4.2(3)3.1, 4.2(3).7.1.2, and 4.2(3).6.1 through 4.2(3).6.4, respectively.

Before ADVECT is called, GQUAL sums the inputs of dissolved qual from upstream reaches, tributary land areas, and atmospheric deposition:

$$\text{INDQAL} = \text{IDQAL} + \text{SAREA} * \text{ADFX} + \text{SAREA} * \text{PREC} * \text{ADCN} \quad (1)$$

where:

INDQAL = total input of dissolved qual to reach
 IDQAL = input of dissolved qual from upstream reaches and tributary land
 SAREA = surface area of reach
 ADFX = dry or total atmospheric deposition flux in mass/area per interval
 PREC = precipitation depth
 ADCN = concentration for wet atmospheric deposition in mass/volume

Atmospheric deposition inputs can be specified in two possible ways depending on the form of the available data. If the deposition is in the form of a flux (mass per area per time), then it is considered "dry deposition". If the deposition is in the form of a concentration in rainfall, then it is considered "wet deposition", and the program automatically combines it with the input rainfall time series to compute the resulting flux. Either type of deposition data can be input as a time series, which covers the entire simulation period, or as a set of monthly values that is used for each year of the simulation. The specific atmospheric deposition time series are documented in the EXTNL table of the Time Series Catalog for RCHRES, and are specified in the EXT SOURCES block of the UCI. The monthly values are input in the MONTH-DATA block in the UCI.

GQUAL is also responsible for the calculation of increases in qual resulting from decay of a "parent" chemical. The HSPF code is designed so that a user may specify that a "daughter" chemical is produced by any or all of the six decay processes (except volatilization) which degrade a parent qual. However, certain restrictions are placed on the daughter/parent relationship. Simulation of up to three generalized quality constituents is allowed. Qual #2 may be produced by decay of qual #1. Qual #3 may be produced by decay of qual #1 and/or qual #2. Other relationships are not allowed. The user should sequence quality constituents accordingly. The amount of daughter qual produced by decay of a parent by a particular decay process is computed as:

$$PDQAL(I) = DDQAL(K,J)*C(I,J,K) \quad (1)$$

where:

PDQAL(I) = amount of daughter qual I produced by decay of parent qual J through process K (concu/l)*(ft3/ivl) or (concu/l)*(m3/ivl)
 DDQAL(K,J) = amount of parent material decayed by process K expressed in same units as PDQAL(I)
 C(I,J,K) = amount of qual I produced per unit of qual J degraded by process K in units of concu I/concu J

After the amount of decay resulting from all active decay processes and the amount of input of qual produced by decay of parent qual(s) have been calculated, the new dissolved concentration of a qual is computed as:

$$DQAL(I) = DQAL(I) + (PDQAL(I) - DDQAL(7,I))/VOL \quad (2)$$

where:

DQAL(I) = concentration of dissolved qual I
 PDQAL(I) = amount of qual I produced by decay of parent qual(s)
 DDQAL(7,I) = total amount of qual I degraded by the decay processes
 VOL = volume of water in the RCHRES

Additional Requirements

HSPF allows a maximum of 3 general quality constituents. The user selects the units for each constituent; thus, different constituents may have different units. For example, the user may simulate fecal and total coliforms expressed in organisms per ml and a pesticide expressed in milligrams per liter in the same simulation. In order to provide this flexibility, additional input is required. For each constituent the following information must be provided in the User's Control Input:

- GQID: the name of the constituent (up to 20 characters long)
- QTYID: this string (up to 8 characters) contains the units used to describe the quantity of constituent entering or leaving the RCHRES, and the total quantity of material stored in it. Examples of possible units for QTYID are 'Morg' for millions of organisms or 'lbs' for pounds
- CONCID: the concentration units for each decay constituent (up to 4 characters long); examples are '#' or 'mg'. It is implied that these units are "per l".
- CONV: conversion factor from QTYID/VOL to desired concentration units: $CONC = CONV * (QTY / VOL)$ (in English system, VOL is expressed in ft³; in metric system, VOL is expressed in m³)

For example, if:
 CONCID is mg/l,
 QTYID is kg, and
 VOL is m³,
 then $CONV = 1000$.

4.2(3).6.1 Simulate Decay of Dissolved Material (subroutine DDECAY)

Purpose

DDECAY simulates the degradation of generalized quality constituents by chemical and/or biological means. Six processes are considered:

1. hydrolysis
2. oxidation by free radical oxygen
3. photolysis
4. volatilization
5. biodegradation
6. generalized first-order decay

Discussion

HSPF includes detailed degradation methods only for the dissolved state of the quality constituent (qual); decay of qual material in the adsorbed state is handled by a lumped first-order decay function in subroutine ADECAY. Formulations of the degradation processes are based on studies conducted by Smith et al. (1977, 1979), Zepp and Cline (1977), Falco et al. (1976), and Mill et al. (1980). Most formulations are similar to those included in the SERATRA model (Onishi and Wise, 1979). All degradation processes modeled in DDECAY contain a temperature correction factor.

Methods

Hydrolysis

Hydrolysis is defined as any reaction that takes place in water, without the aid of light or microorganisms, in which a compound is transformed to a different compound as a result of reaction with water. The rate of change of dissolved qual concentration due to hydrolysis is sensitive to changes in pH and water temperature. In HSPF, the equation presented by Smith et al. (1977) is modified to include a temperature correction factor and rewritten as:

$$\text{KHYD} = (\text{KA} \cdot 10.0^{(-\text{PHVAL})} + \text{KB} \cdot 10.0^{(\text{PHVAL} - 14.0)} + \text{KN}) \cdot \text{THHYD}^{**\text{TW20}} \quad (3)$$

where:

KHYD = hydrolysis rate constant for qual adjusted for pH
and water temperature conditions of RCHRES
KA = hydrolysis rate coefficient for qual in acidic solution (pH5)
KB = hydrolysis rate coefficient for qual in basic solution (pH9)
KN = hydrolysis rate coefficient for qual in neutral solution (pH7)
PHVAL = pH of water in RCHRES
THHYD = temperature correction parameter for hydrolysis
TW20 = TW (water temperature in degrees C) - 20.0

The hydrolysis rate coefficients (KA, KB, KN) for a particular qual are determined by standard laboratory tests (ASTM, 1980). Depending on the availability of data and the needs of the model user, pH information for the hydrolysis equation can be supplied as (1) one constant value, (2) twelve monthly values, or (3) a time series. The time series can either be an input time series or the results of pH simulation if section RQUAL is active and pH is simulated.

Oxidation by Free Radical Oxygen

Two general types of oxidation reactions can be distinguished for evaluating chemical oxidation processes in an aquatic environment (Mill et al., 1980):

1. Reaction of an excited state of a molecule with oxygen, in which the excited state is produced by direct photolysis or by interaction with a photosensitizer; this process is termed photo-oxidation.

2. Reaction of the ground state of the chemical with oxidants in solution, in which the oxidants are formed by reactions of dissolved or suspended natural materials in solution; these reactions are termed thermal oxidation, autoxidation, or simply oxidation. The ultimate driving force for oxidant formation may, however, often be photochemical reactions of the natural materials.

In HSPF, photo-oxidation is considered as one of the photo-initiated degradation processes collectively labelled as photolysis. Consequently, only thermal oxidation is considered in the following formulation. The rate of oxidation of dissolved qual is expressed as a function of free radical oxygen concentration (ROC) and water temperature:

$$KROX = KOX * ROC * (THOX ** TW20) \quad (4)$$

where:

KROX = oxidation rate constant for qual adjusted for free radical oxygen concentration and water temperature
 KOX = base oxidation rate coefficient for qual
 ROC = free radical oxygen concentration (moles/l (M))
 THOX = temperature correction parameter for oxidation
 TW20 = TW (water temperature in degrees C) - 20.0

The oxidation rate coefficient (KOX) for a qual is determined from laboratory tests. Mill et al. (1980) cites two groups of oxidants which are likely to be important in natural waters: alkylperoxy radicals and singlet molecular oxygen. The overall free radical oxygen concentration can be specified by the user as a constant value, twelve monthly values, or a time series.

Photolysis

Photochemical transformation of chemicals can occur when energy in the form of light is absorbed by a molecule, placing it in an excited state from which reaction can occur. Direct photolysis of chemicals occurs when the chemical molecule itself absorbs light and undergoes reaction from its excited state. Indirect photolysis occurs when another chemical species, called a sensitizer, absorbs light and the sensitizer transfers energy from its excited state to another chemical, which then undergoes reaction. There are many types of photochemical reactions, including oxidation, reduction, hydrolysis, substitution, and rearrangement. In practice it is possible to measure the rate constant for photochemical reaction or a reaction quantum yield without knowing the types of reactions which are occurring (Mill et al., 1980). The formulation of photolysis developed for HSPF is intended to measure the net degradation of a generalized quality constituent which results from photochemical reactions.

The basic equation for rate of loss of a qual in dilute solution in an environmental water body due to absorbance of light of wavelength lambda is given by:

$$KPHOL = ((PHI * INLITL) / DEP) * FSLAM * FQLAM \quad (5)$$

where:

KPHOL = rate of loss of qual due to photolysis by light of wavelength lambda
 PHI = reaction quantum yield for photolysis of qual (moles/einstein)
 INLITL = incident light intensity of wavelength lambda (einsteins/cm2.day)
 DEP = depth of water
 FSLAM = fraction of light absorbed by the system
 FQLAM = fraction of absorbed light that is absorbed by qual

The solution technique outlined by Mill and implemented in HSPF uses seasonal day-averaged, 24-hour light intensity values (LLAM) for 18 wavelength intervals from 300 nm to 800 nm. In order to use these values, the relationship between the light intensity variable (INLITL) in Equation 5 and the tabulated values for LLAM must be defined. The relationship derived by Mill for relatively clear water or shallow depths can be written as:

$$INLITL = LLAM / 2.3 * BETA \quad (6)$$

where:

BETA = LLIT/DEP
 LLIT = path length of light through water
 DEP = depth of water

Further, the effects of cloud cover on light intensity are introduced by adding factor CLDLAM:

$$INLITL = (LLAM / 2.3 * BETA) * CLDLAM \quad (7)$$

where:

CLDLAM = fraction of total light intensity of wavelength
 lambda which is not absorbed or scattered by clouds

CLDLAM is calculated as:

$$CLDLAM = (10.0 - CC * KCLDL) / 10.0 \quad (8)$$

where:

CC = cloud cover in tenths
 KCLDL = efficiency of cloud cover in intercepting light
 of wavelength lambda, a user supplied parameter (default value 0.0)

By substitution of Equation 7 into Equation 5, the general equation for the photolysis rate of a qual due to absorbance of light of wavelength lambda can be expressed as:

$$KPHOL = ((PHI * LLAM * CLDLAM) / 2.3 * BETA * DEP) * FSLAM * FQLAM \quad (9)$$

The general mathematical expression for the fraction of light absorbed by the water system (FSLAM) is:

$$FSLAM = 1.0 - 10^{**(-K_{LAM} * LLIT)} \quad (10)$$

The exponential coefficient, KLAM, in this equation has two components for laboratory conditions:

$$KLAM = ALPHL + EPSLAM * C \quad (11)$$

where:

ALPHL = base absorbance term for light of wavelength lambda
for the system (/cm)
EPSLAM = absorbance term for light of wavelength lambda
absorbed by qual (l/mole.cm)
C = concentration of qual (moles/l)

For environmental systems, the effects of light absorbance by suspended sediment and phytoplankton are introduced to the formulation, and KLAM is expanded to:

$$KLAM = ALPHL + EPSLAM * C + GAMLAM * SED + DELLAM * PHYTO \quad (12)$$

where:

GAMLAM = absorbance term for light absorbed by suspended sediment (l/mg/cm)
SED = total suspended sediment (mg/l)
DELLAM = absorbance term for light absorbed by phytoplankton (l/mg/cm)
PHYTO = phytoplankton concentration (mg/l)

Because the concentration of qual is assumed small, the fraction of total absorbance of light in the water system resulting from absorbance by the qual is assumed negligible, and the term (EPSLAM*C) is dropped from Equation 12. By substituting the modified value of KLAM into Equation 9, setting LLIT = BETA*DEP (from Equation 6), and assuming that BETA = 1.2 (Mill, 1980), the final form of the expression for FSLAM is obtained:

$$FSLAM = 1.0 - 10^{**}(-1.2 * KLAM * DEP) \quad (13)$$

The remaining term of the general equation for photolysis (Equation 9) which must be evaluated is FQLAM, the fraction of total absorbed light that is absorbed by the qual. This term is evaluated as:

$$FQLAM = (EPSLAM * C) / KLAM \quad (14)$$

Equation 9 can be rewritten as:

$$PHOFXL = ((PHI * LLAM * CLDLAM) / 2.3 * BETA * DEP) * (1.0 - 10^{**}(-1.2 * KLAM * DEP)) * (EPSLAM * C / KLAM) \quad (15)$$

To obtain the rate of loss of qual due to photolysis from absorption of light of all wavelength intervals, Equation 15 must be summed over LLAM:

$$KPHO = (PHI / (2.76 * DEP)) * (SUM [1 to 18] ((LLAM * CLDLAM * EPSLAM / KLAM) * (1.0 - EXP(-2.76 * KLAM * DEP))) \quad (16)$$

The equation for the degradation rate due to photolysis used in HSPF is further complicated by correction factors for surface shading and water temperature. The final rearranged and expanded formulation is:

$$KPHO = (CF * DELT60 / 24.) * PHI * (SUM [1 \text{ to } 18] ((LLAM * CLDLAM / 2.76 * KLAM * DEP) * (1.0 - EXP(-2.76 * KLAM * DEP)) * EPSLAM)) * THPHO * TW20 \quad (17)$$

where:

SUM = summation of function in () over limits in []
 CF = factor accounting for surface shading
 DELT60/24 = conversion from day to interval
 THPHO = temperature correction parameter for photolysis
 TW20 = TW (water temperature in degrees C) - 20.0

For simulation intervals of less than 24 hours, photolysis is assumed to occur only between 6:00 AM and 6:00 PM during approximate daylight hours. In order to obtain a solution which is reasonably consistent with the input seasonal, day-averaged, 24-hour light intensity values, the daily light intensity is assumed to be uniformly distributed over the 12 hours from 6:00 AM to 6:00 PM. Consequently, calculated photolysis rates are doubled during daylight hours and set equal to zero for non-daylight hours. It should be noted that five look-up tables for solar intensity values (LLAM) are incorporated into HSPF. Tables 4.2(3).6-1 through 4.2(3).6-5 show the values for seasonal day-averaged, 24 hour light intensity at 10, 20, 30, 40, and 50 degrees latitude. The Run Interpreter checks the input latitude for the study area and selects the appropriate table from which to extract values. Additional input required to simulate photolysis in subroutine DDECAY include:

1. Molar absorption coefficients for each of the 18 wavelengths
2. Reaction quantum yield for qual (PHI)
3. Temperature correction parameter for photolysis (THPHO)
4. 18 values for base absorbance term for water system (ALPHL)
5. 18 values for absorbance for light absorbed by suspended sediment (GAMLAM)
6. 18 values for absorbance for light absorbed by phytoplankton (DELLAM)
7. Cloud cover values. Either a time series or 12 monthly values may be supplied.
8. Total suspended sediment values. Either a time series or 12 monthly values.
9. Phytoplankton values. Either a time series or 12 monthly.

Table 4.2(3).6-1 Solar Intensity Values for Latitude 10 N

Wavelength, Nanometers	Solar Intensity, milli-einsteins/cm ² /day			
	Spring	Summer	Fall	Winter
300	1.02E-2	4.66E-4	4.19E-4	3.20E-4
303.75	1.78E-2	3.16E-3	2.87E-3	2.39E-3
308.75	2.85E-2	9.37E-3	8.51E-3	7.26E-3
313.75	3.27E-2	1.90E-2	1.73E-3	1.51E-2
318.75	4.18E-2	2.91E-2	2.66E-2	2.38E-2
323.1	3.70E-2	2.65E-2	2.91E-2	2.36E-2
346	3.39E-1	3.29E-1	2.99E-1	2.92E-1
370	4.33E-1	4.38E-1	3.85E-1	3.44E-1
400	8.40E-1	8.37E-1	7.64E-1	6.96E-1
430	1.16	1.17	1.07	9.80E-1
460	1.47	1.47	1.36	1.23
490	1.50	1.50	1.37	1.27
536.25	2.74	2.69	2.46	2.26
587.5	2.90	2.79	2.52	2.35
637.5	2.90	2.80	2.60	2.43
687.5	2.80	2.80	2.60	2.30
756	2.70	2.70	2.50	2.40
800	3.00	2.50	2.30	2.10

Table 4.2(3).6-2 Solar Intensity Values for Latitude 20 N

Wavelength, Nanometers	Solar Intensity, milli-einsteins/cm ² /day			
	Spring	Summer	Fall	Winter
300	3.51E-4	4.44E-4	2.74E-4	1.47E-4
303.75	2.51E-3	3.15E-3	2.20E-3	1.47E-3
308.75	8.09E-3	9.61E-3	6.89E-3	5.34E-3
313.75	1.81E-2	1.97E-2	1.48E-2	1.15E-2
318.75	2.82E-2	3.02E-2	2.33E-2	1.88E-2
323.1	2.83E-2	3.03E-2	2.33E-2	1.88E-2
340	3.29E-1	3.47E-1	2.68E-1	2.21E-1
370	4.24E-1	4.47E-1	3.45E-1	2.86E-1
406	8.41E-1	8.83E-1	6.96E-1	5.97E-1
430	1.17	1.23	9.80E-1	8.40E-1
460	1.47	1.55	1.24	1.06
490	1.50	1.58	1.26	1.09
536.25	2.68	2.81	2.30	1.95
587.5	2.80	2.96	2.35	2.03
637.5	2.80	2.90	2.42	2.07
687.5	2.80	3.00	2.40	2.10
750	2.76	2.80	2.20	2.36
800	2.50	2.70	2.26	1.60

Table 4.2(3).6-3 Solar Intensity Values for Latitude 30 N

Wavelength, Nanometers	Solar Intensity, milli-einsteins/cm ² /day			
	Spring	Summer	Fall	Winter
300	2.30E-4	3.65E-4	1.35E-4	4.10E-5
303.75	2.13E-3	2.32E-3	1.44E-3	6.50E-4
308.73	7.26E-3	9.02E-3	4.84E-3	2.76E-3
313.75	1.65E-2	1.92E-2	1.16E-2	7.55E-3
318.75	2.64E-2	3.02E-2	1.89E-2	1.31E-2
323.1	2.69E-2	3.04E-2	2.30E-2	1.34E-2
340	3.20E-1	3.74E-1	2.23E-1	1.70E-1
370	4.14E-1	4.37E-1	2.84E-1	2.19E-1
400	8.27E-1	9.07E-1	6.23E-1	4.75E-1
430	1.15	1.34	8.50E-1	6.69E-1
460	1.45	1.59	1.09	8.50E-1
490	1.48	1.62	1.11	8.80E-1
536.25	2.64	2.89	2.00	1.57
587.5	2.74	3.03	2.07	1.63
637.5	2.76	3.00	2.09	1.67
687.5	2.80	3.00	2.10	1.73
750	2.70	2.90	2.10	1.63
800	2.50	2.80	1.90	1.60

Table 4.2(3).6-4 Solar Intensity Values for Latitude 40 N

Wavelength, Nanometers	Solar Intensity, milli-einsteins/cm ² /day			
	Spring	Summer	Fall	Winter
300	1.09E-4	2.49E-4	1.09E-4	5.38E-6
303.75	1.37E-3	2.32E-3	1.37E-3	1.56E-4
308.75	2.96E-3	7.93E-3	5.35E-3	1.02E-3
313.75	7.99E-3	1.81E-2	1.38E-2	3.79E-3
318.75	1.38E-2	2.91E-2	2.319E-2	7.53E-3
323.1	1.42E-2	2.97E-2	2.39E-2	8.10E-3
340	1.78E-1	3.54E-1	1.08E-1	7.52E-2
370	2.30E-1	4.58E-1	3.84E-1	1.47E-1
400	5.26E-1	9.71E-1	7.91E-1	3.38E-1
430	6.76E-1	1.28	1.11	4.80E-1
460	8.90E-1	1.43	1.39	6.10E-1
490	9.23E-1	1.63	1.42	6.20E-1
536.25	1.69	2.92	2.52	1.12
587.5	1.73	3.05	2.62	1.16
637.5	1.78	3.00	2.60	1.19
687.5	1.50	3.10	4.70	1.39
750	1.70	2.90	2.60	1.20
800	1.60	2.90	2.50	1.16

Table 4.2(3).6-5 Solar Intensity Values for Latitude 50 N

Wavelength, Nanometers	Solar Intensity, milli-einsteins/cm ² /day			
	Spring	Summer	Fall	Winter
300	3.71E-5	7.88E-6	1.52E-4	4.00E-7
303.75	7.10E-4	1.75E-3	2.25E-4	1.57E-5
308.75	3.55E-3	6.53E-3	1.29E-3	1.78E-4
313.75	7.30E-3	1.63E-2	4.39E-3	1.20E-3
318.75	1.84E-3	2.67E-2	8.64E-3	2.93E-3
323.1	1.96E-2	2.77E-2	9.20E-3	3.68E-3
340	2.66E-1	3.43E-1	1.24E-1	6.29E-2
370	3.48E-1	4.44E-1	1.66E-1	8.21E-2
400	7.24E-1	9.04E-1	3.65E-1	1.96E-1
430	1.02	1.26	5.17E-1	2.75E-1
460	1.29	1.60	6.60E-1	3.51E-1
470	1.32	1.63	6.80E-1	3.55E-1
536.25	2.34	2.90	1.22	6.30E-1
587.5	2.40	3.04	1.25	6.40E-1
637.5	2.44	3.00	1.31	6.90E-1
687.5	2.50	3.10	1.34	7.10E-1
750	2.50	2.90	1.31	7.10E-1
800	2.30	2.90	1.24	6.90E-1

Volatilization

Volatilization of a chemical that is dissolved in water is defined as the transport of the chemical from the water to the atmosphere. The concentration of the chemical in water decreases even though a transformation does not occur. Thus, volatilization is not a degradation process in the strict sense, since the chemical which leaves a water body by volatilization is not biologically or chemically degraded. Current evidence suggests that volatilization is likely to be the major aquatic fate of low molecular weight, nonpolar compounds that are not rapidly biodegraded or chemically transformed. Volatilization rates of higher molecular weight compounds can also be significant under certain conditions (Smith, 1979).

In HSPF, the volatilization rate of a qual is tied to the oxygen reaeration coefficient:

$$KVOL = KOREA * CFGAS \quad (18)$$

where:

KVOL = rate of loss of qual from water due to volatilization
 KOREA = oxygen reaeration coefficient calculated by subroutine OXREA
 CFGAS = ratio of volatilization rate of qual to oxygen reaeration rate, an input parameter.

The value for input parameter CFGAS can be determined as the ratio of the molecular diameter of oxygen to the molecular diameter of the qual.

Biodegradation

Biodegradation is one of the most important processes for transformation of chemical compounds when they enter natural environments. Many organic chemicals are used by living cells for carbon and energy sources. Microorganisms metabolize a wide variety of organic compounds, including many man-made chemicals (Chou, 1980). The rate of biodegradation of a dissolved qual is expressed as a function of the concentration of biomass which degrades the qual (BIO) and water temperature:

$$KBIO = KBMASS * BIO * (THBIO ** TW20) \quad (19)$$

where:

KBIO = biodegradation rate constant for qual adjusted for biomass concentration and water temperature
 BIOCON = base biodegradation rate coefficient for qual
 BIO = concentration of biomass that is involved in qual degradation
 THBIO = temperature correction parameter for biodegradation
 TW20 = TW (water temperature in degrees C) - 20.0

Biomass data may be supplied as a constant, 12 monthly values, or a time series. HSPF allows for the fact that a different population of microorganisms can be involved in the biodegradation of each different generalized quality constituent by requiring the user to specify a unique set of biomass data for each constituent which is simulated.

Generalized First-order Decay

Generalized first-order decay of dissolved qual may be simulated in addition to, or instead of, the individual decay processes outlined above. The equation used to calculate rate of decay is:

$$K_{GEN} = K_{GEND} * T_{HGEN}^{**TW20} \quad (20)$$

where:

K_{GEN} = generalized first-order decay rate for a qual
corrected for temperature
 K_{GEND} = base first-order decay rate for a qual
 T_{HGEN} = temperature correction parameter for first-order decay

After decay rates for all of the processes which are active for a qual have been calculated, they are summed to determine a total decay rate. At this point the total loss of qual material resulting from decay is evaluated:

$$DDQALT = DQAL * (1.0 - \exp(-KTOTD)) * VOL \quad (21)$$

where:

$DDQALT$ = loss of qual due to all forms of degradation,
expressed in (concu/l)*(ft³/ivl) or (concu/l)*(m³/ivl)
 $DQAL$ = concentration of dissolved qual (concu/l)
 $KTOTD$ = total decay rate of qual per interval
 VOL = volume of water in the RCHRES

Finally, to determine the amount of material degraded by each individual process, a linear proration is performed based on the total decay of material:

$$DDQAL(I) = (K(I)/KTOTD) * DDQALT \quad (22)$$

where:

$DDQAL(I)$ = loss of qual due to decay by process I, expressed
in (concu/l)*(ft³/ivl) or (concu/l)*(m³/ivl)
 $K(I)$ = decay rate due to process I (/ivl)

4.2(3).6.2 Simulate Advection of Material on Sediment (subroutine ADVQAL)

Purpose

ADVQAL simulates the advective processes for the quality constituent attached to one sediment size fraction. Processes handled in this subroutine include:

1. Inflow to the RCHRES of qual attached to suspended sediment.
2. Migration of qual from suspension in the water to the bed as a result of deposition of the sediment to which the qual is adsorbed.
3. Migration of qual from the bed into suspension in the water as a result of scour of the bed sediments to which the qual is adsorbed.
4. Outflow from the RCHRES of qual attached to suspended sediment.

Method

The movement of adsorbed qual is completely determined by the movement of the sediment to which it is attached. All fluxes of adsorbed qual are expressed as the product of the flux of a sediment fraction (sand, silt, or clay) and the concentration of qual associated with that fraction (expressed in concu per mg of sediment). Likewise, storages of adsorbed qual are expressed as the product of the sediment fraction storage and the associated concentration of qual. A simplified flow diagram of sediment and associated qual fluxes and storages is provided in Figure 4.2(3).6-2 to facilitate the following discussion. Note that ADVQAL is designed to operate on one sediment fraction and one qual each time it is called by GQUAL.

If the sediment simulation in module section SEDTRN indicates that scour of bed storage of a sediment fraction occurs, the following actions are taken in ADVQAL:

1. Bed storage of adsorbed qual is updated.
2. Flux of qual from bed to suspension (DSQAL) is set equal to the bed storage of the qual (BQAL) if the entire bed storage of the sediment fraction is scoured.
3. If only part of the bed storage of the sediment fraction is scoured, the flux of qual from bed to suspension is calculated as:

$$DSQAL = BQAL * DEPSCR \quad (23)$$

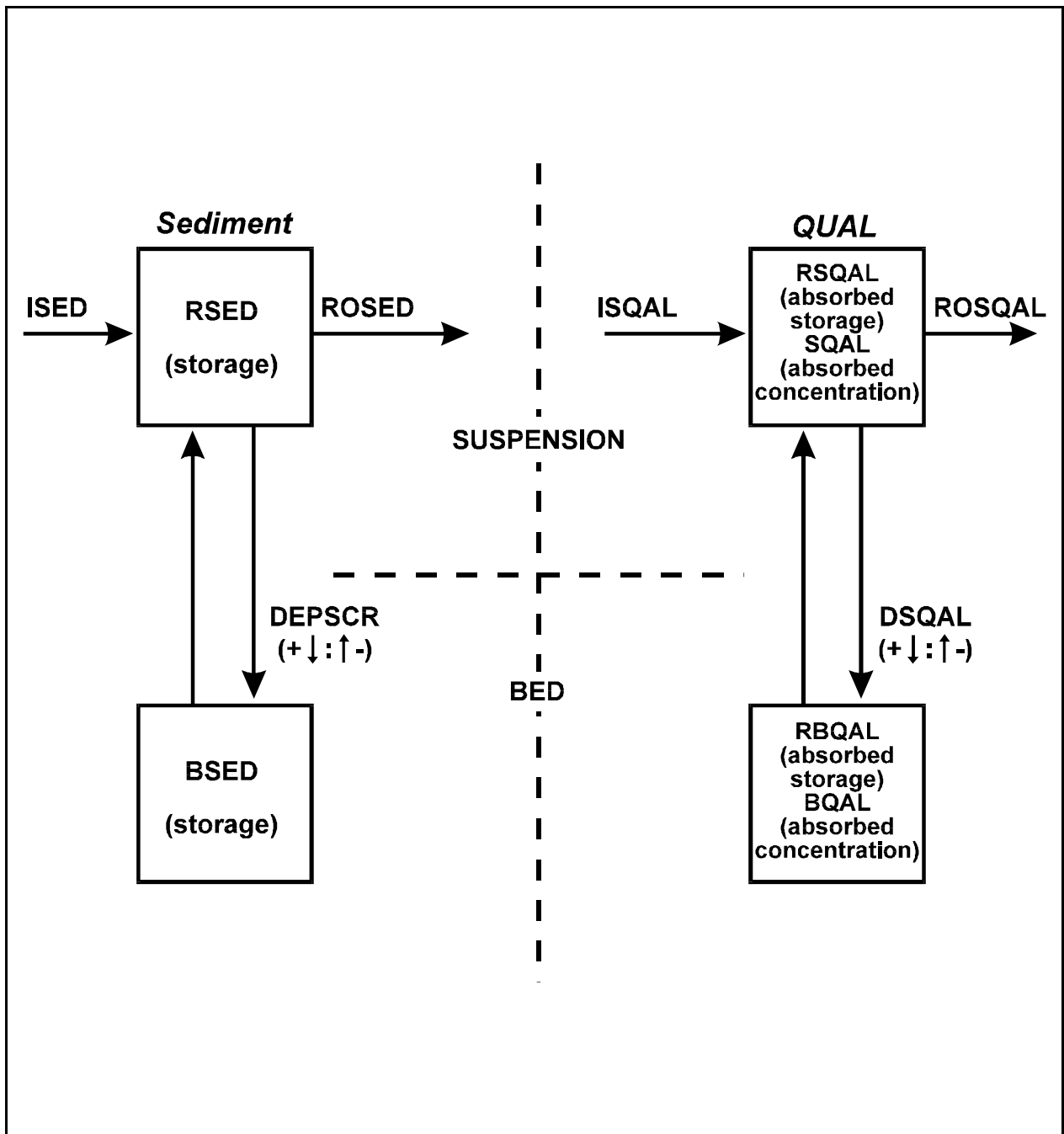


Figure 4.2(3).6-2 Simplified flow diagram for important fluxes and storages of sediment and associated qual used in subroutine ADVQAL

where:

DSQAL = amount of qual scoured from bed and added to suspension
expressed in (concu/l)*(ft3/ivl) or (concu/l)*(m3/ivl)
BQAL = concentration of qual on bed sediment fraction
under consideration in concu/mg sediment
DEPSCR = amount of sediment fraction which is scoured from
the bed expressed in mg.ft3/l.ivl or mg.m3/l.ivl

4. Concentration of adsorbed qual in suspension is updated to account for scour:

$$SQAL = (ISQAL + RSQALS - DSQAL)/(RSED + ROSED) \quad (24)$$

where:

SQAL = concentration of adsorbed qual in suspension
expressed as concu/mg suspended sediment fraction
ISQAL = inflow of qual to the RCHRES as a result of inflowing sediment
fraction, expressed as (concu/l)*(ft3/ivl) or (concu/l)*(m3/ivl)
RSQALS = storage of qual on suspended sediment fraction
expressed in (concu/l)*ft3 or (concu/l)*m3
RSED = amount of sediment fraction in suspension at end of interval
expressed in mg.ft3/l or mg.m3/l
ROSED = amount of sediment fraction contained in outflow from the RCHRES
during the interval expressed in mg.ft3/l.ivl or mg.m3/l.ivl

5. Amount of qual leaving the RCHRES as outflow is determined as:

$$ROSQAL = ROSED * SQAL \quad (25)$$

If the sediment simulation in module section SEDTRN indicates that deposition of suspended sediment occurs, ADVQAL performs the following operations:

1. Concentration of qual on total suspended sediment fraction (inflow + suspended storage) for the RCHRES is calculated:

$$SQAL = (ISQAL + RSQALS)/(RSED + DEPSCR + ROSED) \quad (26)$$

2. Amount of qual leaving the RCHRES due to outflow of sediment fraction is determined:

$$ROSQAL = ROSED * SQAL \quad (27)$$

3. Amount of qual leaving suspension due to deposition of the sediment to which it is adsorbed is found by:

$$DSQAL = DEPSCR * SQAL \quad (28)$$

4. The concentration of qual on sediment in suspension is set equal to zero if the suspended storage of sediment is zero.
5. The concentration of qual on bed sediment is set equal to zero if the storage of bed sediment at the end of the interval is zero.
6. If there is bed sediment at the end of the interval, the bed storage of qual associated with the sediment fraction is calculated as:

$$RBQAL = DSQAL + RBQALS \quad (29)$$

7. The concentration of qual on bed sediment is determined:

$$BQAL = RBQAL/BSED \quad (30)$$

where:

BSED = storage of sediment fraction (sand, silt, or clay)
in the bed, expressed as mg.ft³/l or mg.m³/l

The final operation which ADVQAL performs is the computation of outflow of adsorbed qual through individual exits (when more than one exit is specified). The algorithm is:

$$OSQAL(I) = ROSQAL * OSED(I) / ROSED \quad (31)$$

where:

OSQAL(I) = outflow of adsorbed qual through exit gate I
ROSQAL = total outflow of adsorbed qual from RCHRES
OSED(I) = outflow of sediment fraction through exit gate I

4.2(3).6.3 Simulate Decay of Adsorbed Material (subroutine ADECAY)

Purpose

ADECAY is a generalized subroutine which calculates the amount of decay experienced by a generalized quality constituent (qual) adsorbed to inorganic sediment. This subroutine is called twice (once for decay on suspended sediment and once for decay on bed sediment) for each generalized quality constituent which is sediment-associated. (The user specifies that a qual is sediment-associated by setting QALFG(7)=1 for the qual in the User's Control Input.) HSPF assumes that the decay rate of a particular adsorbed qual is the same for all fractions of sediment (sand, silt, and clay), but may be different for suspended sediment than it is for bed sediment.

Method

Necessary information which must be supplied to the subroutine includes:

1. ADDCPM(1) - decay rate for qual on sediment being considered (suspended or bed)
2. ADDCPM(2) - temperature correction coefficient for decay
3. RSED(1-3) - the storage of each sediment fraction expressed in mg.ft3/l or mg.m3/l (for either suspended or bed sediment)
4. SQAL(1-3) - the concentration of qual associated with the 3 fractions of sediment (concu/mg)

First, the temperature-adjusted decay rate is calculated:

$$DK = \text{ADDCPM}(1) * \text{ADDCPM}(2) ** \text{TW20} \quad (32)$$

where:

$$\text{TW20} = \text{TW (water temperature)} - 20.0 \text{ in degrees C.}$$

Next, the fraction of adsorbed qual which decays during the simulation interval (FACT) is calculated using the general form for first-order decay:

$$\text{FACT} = 1.0 - \text{EXP}(-DK) \quad (33)$$

The concentration of qual decayed from each sediment fraction (DCONC) is determined, and the concentration of qual associated with each fraction is updated:

$$\text{DCONC} = \text{SQAL}(I) * \text{FACT} \quad (34)$$

$$\text{SQAL}(I) = \text{SQAL}(I) - \text{DCONC} \quad (35)$$

Finally, the mass of qual decayed from each sediment fraction is calculated:

$$\text{SQDEC}(I) = \text{DCONC} * \text{RSED}(I) \quad (36)$$

where:

SQDEC(I) = amount of qual decayed from sediment fraction I expressed in (concu/l)*(ft3/ivl) or (concu/l)*(m3/ivl)

DCONC = concentration of qual decayed from sediment fraction (concu/mg)

RSED(I) = storage of sediment fraction I (mg.ft3/l or mg.m3/l)

4.2(3).6.4 Simulate Adsorption/Desorption of a Generalized Quality Constituent (subroutine ADSDES)

Purpose

ADSDES simulates the exchange of a generalized quality constituent (qual) between the dissolved state and adsorbed state. Kinetic equilibrium between dissolved state and six adsorption sites is modeled: suspended sand, silt, and clay, and bed sand, silt, and clay.

Method

The basic equation (Onishi and Wise, 1979) for the transfer of a chemical between the dissolved state and an adsorbed state on sediment type J is:

$$-d(RSEDJ*SQALJ)/dt + RSEDJ*KJT*(KDJ*DQAL - SQALJ) = 0 \quad (37)$$

where:

RSEDJ = total quantity of sediment type J in the RCHRES
(mg.ft³/l or mg.m³/l)
SQALJ = concentration of qual on sediment type J (concu/mg)
DQAL = concentration of dissolved qual (concu/l)
KDJ = distribution coefficient between dissolved state and sediment type J (liters/mg) (adsorbed concentration/dissolved concentration)
KJT = temperature corrected transfer rate between dissolved state and sediment type J

Thus, adsorption of a qual by sediment or desorption from sediment is assumed to occur toward an equilibrium condition with transfer rate KJT if the particulate qual concentration differs from its equilibrium value. Equation 37 is actually 6 equations (one for each sediment type J) with 7 unknowns (DQAL and 6 values of SQALJ). The necessary seventh equation is that of conservation of material. The following relation gives the total quantity of qual in the RCHRES, both before and after exchange due to adsorption/desorption:

$$\text{SUM [1 to 6]}(RSEDJ*SQALJ) + \text{VOL}*DQAL = \text{TOT} \quad (38)$$

where:

VOL = volume of water in the RCHRES

To solve numerically, Equation 37 is expressed in finite difference form:

$$\begin{aligned} & -RSEDJ*(SQALJ - SQALJO) + RSEDJ*KJT*KDJ*DQAL*DELT \\ & - RSEDJ*KJT*SQALJ*DELT = 0 \end{aligned} \quad (39)$$

where:

SQALJ = concentration of qual on sediment type J at end of simulation interval (subsequent to adsorption/desorption)
SQALJO = concentration of qual on sediment type J at start of interval
DELT = simulation time step

The product of the transfer rate for sediment type J and the simulation time step is calculated ($AKJ = KJT \cdot DELT$), and the resulting value is substituted into Equations 38 and 39. Two forms of Equation 38 are written. Equation 40 expresses conservation of material at the beginning of the simulation interval and Equation 41 expresses conservation of material at the end of the interval:

$$- \text{SUM [1 to 6]} ((RSEDJ \cdot SQALJO) - VOL \cdot DQALO) = -TOT \quad (40)$$

$$- \text{SUM [1 to 6]} ((RSEDJ \cdot SQALJ) - VOL \cdot DQAL) = -TOT \quad (41)$$

Equation 39 is rewritten as:

$$RSEDJ((1.0 + AKJ)/(AKJ \cdot KDJ)) \cdot SQALJ - RSEDJ \cdot DQAL = (RSEDJ \cdot SQALJO)/(AKJ \cdot KDJ) \quad (42)$$

Equations 41 and 42 can be written in matrix form and solved for unknowns $SQALJ$ and $DQAL$ using standard procedures such as Gaussian elimination or the Crout reduction. The solutions are:

$$DQAL = (TOT - \text{SUM [1 to 6]} (RSEDJ \cdot CJ)/AJJ) / (VOL + \text{SUM [1 to 6]} (RSEDJ/AJJ)) \quad (43)$$

$$SQALJ = (CJ/AJJ) + (DQAL/AJJ) \quad (44)$$

where:

$$\begin{aligned} DQAL &= \text{concentration of dissolved qual after adsorption/desorption} \\ SQALJ &= \text{concentration of qual on sediment type J after adsorption/desorption} \\ AJJ &= (1 + AKJ)/(AKJ \cdot KDJ) \\ CJ &= (SQALJO/AKJ \cdot KDJ) \end{aligned}$$

By combining Equations 40 and 43, TOT can be eliminated, and a final solution for $DQAL$ can be obtained:

$$DQAL = (VOL \cdot DQALO + \text{SUM [1 to 6]} (SQALJO - CJ/AJJ) \cdot RSEDJ) / (VOL + \text{SUM [1 to 6]} (RSEDJ/AJJ)) \quad (45)$$

In subroutine ADSDES, the following variables are used to facilitate the evaluation of Equations 44 and 45:

$$AINVJ = 1.0/AJJ = (AKJ \cdot KDJ)/(1.0 + AKJ) \quad (46)$$

$$CAINVJ = CJ/AJJ = (SQALJO/(1.0 + AKJ)) \quad (47)$$

4.2(3).7 Simulate Constituents Involved in Biochemical Transformations (Section RQUAL of Module RCHRES)

RQUAL is the parent routine to the four subroutine groups which simulate constituents involved in biochemical transformations. Within module section RQUAL the following constituents may be simulated:

dissolved oxygen
 biochemical oxygen demand
 ammonia
 nitrite
 nitrate
 orthophosphorus
 phytoplankton
 benthic algae
 zooplankton
 dead refractory organic nitrogen
 dead refractory organic phosphorus
 dead refractory organic carbon
 total inorganic carbon
 pH
 carbon dioxide

Four additional quantities are estimated from simulation of these constituents. These quantities are total organic nitrogen, total organic phosphorus, total organic carbon, and potential biochemical oxygen demand. The definition of these quantities is determined by their method of calculation:

$$\begin{aligned} \text{TORN} &= \text{ORN} + \text{CVBN} * (\text{ZOO} + \text{PHYTO} + \text{BOD}/\text{CVBO}) & (1) \\ \text{TORP} &= \text{ORP} + \text{CVBP} * (\text{ZOO} + \text{PHYTO} + \text{BOD}/\text{CVBO}) & (2) \\ \text{TORC} &= \text{ORC} + \text{CVBC} * (\text{ZOO} + \text{PHYTO} + \text{BOD}/\text{CVBO}) & (3) \\ \text{POTBOD} &= \text{BOD} + \text{CVNRBO} * (\text{ZOO} + \text{PHYTO}) & (4) \end{aligned}$$

where:

TORN = total organic nitrogen (mg N/l)
 TORP = total organic phosphorus (mg P/l)
 TORC = total organic carbon (mg C/l)
 POTBOD = potential BOD (mg O/l)
 ORN = dead refractory organic nitrogen (mg N/l)
 ORP = dead refractory organic phosphorus (mg P/l)
 ORC = dead refractory organic carbon (mg C/l)
 BOD = biochemical oxygen demand from dead nonrefractory organic materials (mg O/l)
 CVBN = conversion from mg biomass to mg nitrogen
 CVBP = conversion from mg biomass to mg phosphorus
 CVBC = conversion from mg biomass to mg carbon
 CVNRBO = conversion from mg biomass to mg biochemical oxygen demand (with allowance for non-refractory fraction)
 CVBO = conversion from mg biomass to mg oxygen
 ZOO = zooplankton (mg biomass/l)
 PHYTO = phytoplankton (mg biomass/l)

Subroutine RQUAL performs two tasks. First, RQUAL is responsible for calling the four subroutine groups which simulate the constituents listed above. These four groups and their functions are:

1. OXRX: simulate primary dissolved oxygen and biochemical oxygen demand balances
2. NUTRX: determine inorganic nitrogen and phosphorus balances
3. PLANK: simulate plankton populations and associated reactions
4. PHCARB: simulate pH and inorganic carbon species

The four groups are listed in their order of execution, and the execution of a group is dependent upon the execution of the groups listed above it. For example, subroutine group PHCARB cannot be activated unless OXRX, NUTRX, and PLANK are active. On the other hand, the reactions in OXRX can be performed without the reactions contained in the other three subroutine groups.

The other function of RQUAL is to determine the values for variables which are used jointly by the four subroutine groups. The following variables are evaluated:

1. AVVELE: the average velocity of water in the RCHRES (ft/s)
2. AVDEPE: the average depth of water in the RCHRES (ft)
3. DEPCOR: conversion factor from square meters to liters
(used for changing areal quantities from the benthal surface to equivalent volumetric values based on the depth of water in the RCHRES)
4. SCRFAC: scouring factor to be used for calculation of benthal release rates of inorganic nitrogen, orthophosphorus, carbon dioxide, and biochemical oxygen demand

SCRFAC has one of two values depending on the average velocity (AVVELE) of the water in the RCHRES. AVVELE is compared to the value of parameter SCRVEL, the user-specified velocity at and above which scouring occurs. If AVVELE is less than the value of parameter SCRVEL, then SCRFAC is set equal to 1.0, and there is no increase of benthal release rates due to scouring. If AVVELE is greater than SCRVEL, SCRFAC is set equal to the value of parameter SCRMUL, which is a constant multiplication factor applied directly to the release rates to account for scouring by rapidly moving water.

4.2(3).7.1 Simulate Primary DO and BOD Balances
(Subroutine Group OXRX of Module RCHRES)

Purpose

The purpose of this code is to simulate the primary processes which determine the dissolved oxygen concentration in a reach or mixed reservoir. Dissolved oxygen concentration is generally viewed as an indicator of the overall well-being of streams or lakes and their associated ecological systems. In relatively unpolluted waters, sources and sinks of oxygen are in approximate balance, and the concentration remains close to saturation. By contrast, in a stream receiving untreated waste waters, the natural balance is upset, bacteria predominate, and a significant depression of dissolved oxygen results (O'Connor and DiToro, 1970).

Schematic View of Fluxes and Storages

Figures 4.2(3).7.1-1 and 4.2(3).7.1-2 illustrate the fluxes and storages modeled in this subroutine group. In order to account for temporal variations in oxygen balance, state variables for both dissolved oxygen and biochemical oxygen demand must be maintained. The state variable DOX represents the oxygen dissolved in water and immediately available to satisfy the oxygen requirements of the system. The BOD state variable represents the total quantity of oxygen required to satisfy the first-stage (carbonaceous) biochemical oxygen demand of dead nonrefractory organic materials in the water.

Subroutine OXRX considers the following processes in determining oxygen balance:

1. longitudinal advection of DOX and BOD
2. sinking of BOD material
3. benthic oxygen demand
4. benthic release of BOD material
5. reaeration
6. oxygen depletion due to decay of BOD materials

Additional sources and sinks of DOX and BOD are simulated in other sections of the RCHRES module. If module section NUTRX (Section 4.2(3).7.2) is active, the effects of nitrification on dissolved oxygen and denitrification on BOD balance can be considered. If module section PLANK (Section 4.2(3).7.3) is active, the dissolved oxygen balance can be adjusted to account for photosynthetic and respiratory activity by phytoplankton and/or benthic algae and respiration by zooplankton. Adjustments to the BOD state variable in section PLANK include increments due to death of plankton and nonrefractory organic excretion by zooplankton.

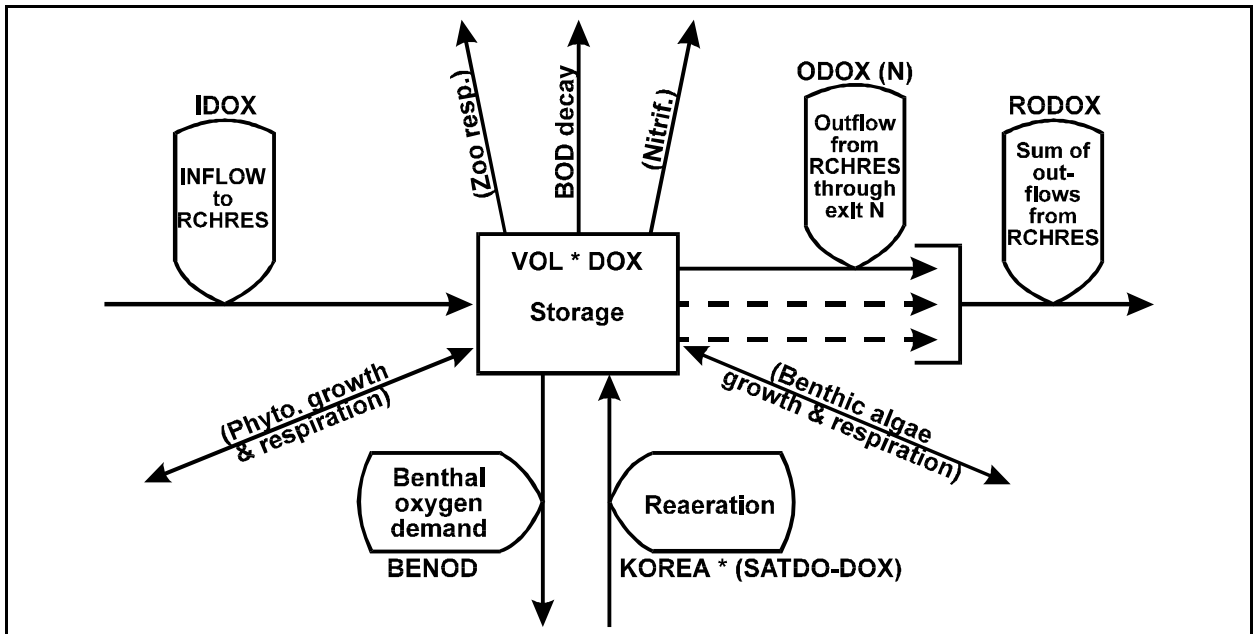


Figure 4.2(3).7.1-1 Flow diagram for dissolved oxygen in the OXRX subroutine group of the RCHRES Application Module

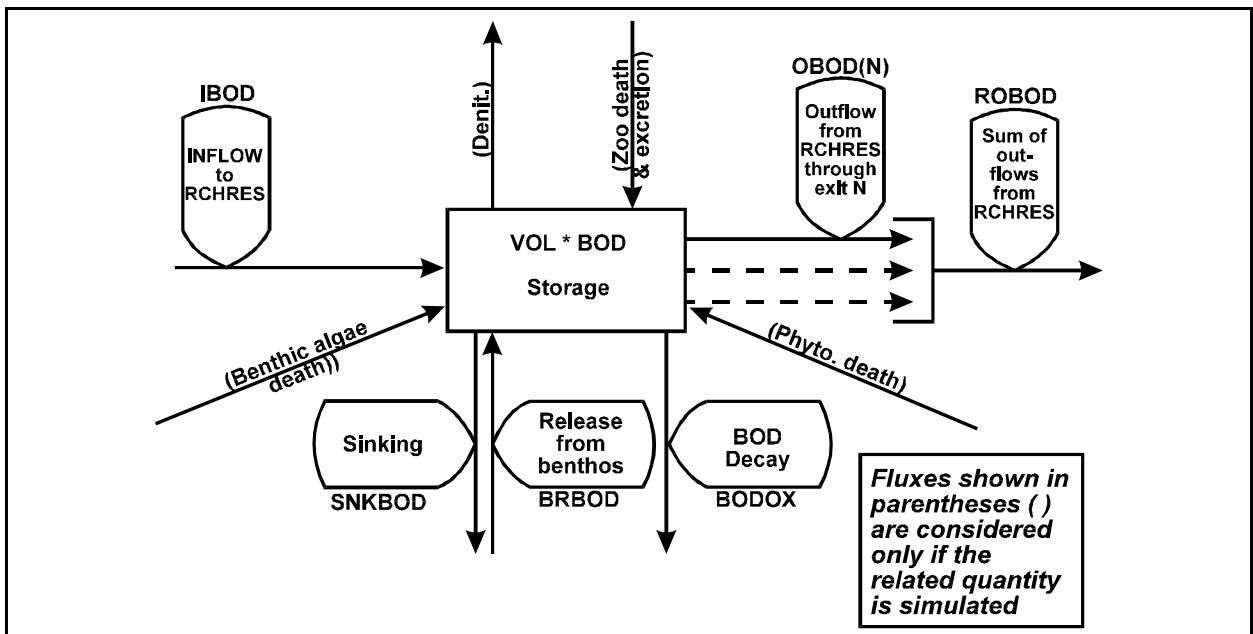


Figure 4.2(3).7.1-2 Flow diagram for biochemical oxygen demand in the OXRX subroutine group of the RCHRES Application Module

Subroutine Group OXRX

Subroutine OXRX uses five subroutines to simulate dissolved oxygen and biochemical oxygen demand. Advection of DOX and BOD is performed by ADVECT. Sinking of BOD material is carried out by SINK. OXBEN calculates benthal oxygen demand and benthal release of BOD materials. The oxygen reaeration coefficient is determined by utilizing OXREA, and BOD decay calculations are performed in BODDEC.

Since subroutine OXREA may also be called by module section GQUAL to obtain the oxygen reaeration coefficient (KOREA) for calculation of volatilization rates for generalized quality constituents, the change in dissolved oxygen concentration in water due to reaeration is calculated in OXRX rather than OXREA. The equation for reaeration is:

$$\text{DOX} = \text{DOXS} + \text{KOREA} * (\text{SATDO} - \text{DOXS}) \quad (1)$$

where:

DOX = dissolved oxygen concentration after reaeration (mg/l)
DOXS = dissolved oxygen concentration at start of interval (mg/l)
KOREA = reaeration coefficient calculated in OXREA
SATDO = saturated concentration of dissolved oxygen (mg/l)

The saturation concentration of dissolved oxygen is computed at prevalent atmospheric conditions by the equation:

$$\text{SATDO} = (14.652 + \text{TW} * (-0.41022 + \text{TW} * (0.007991 - 0.7777\text{E-}4 * \text{TW}))) * \text{CFPRES} \quad (2)$$

where:

SATDO = saturated concentration of dissolved oxygen (mg/l)
TW = water temperature (deg C)
CFPRES = ratio of site pressure to sea level pressure
(CFPRES is calculated by the Run Interpreter dependent upon mean elevation of RCHRES)

4.2(3).7.1.1 Simulate Benthic Oxygen Demand and Benthic Release of BOD (subroutine OXBEN)

Purpose

OXBEN accounts for two possible demands exerted on available oxygen by the benthos. These two demands are categorized as benthic oxygen demand and benthic release of BOD materials. Benthic oxygen demand results from materials in the bottom muds which require oxygen for stabilization. This process results in a direct loss of oxygen from the RCHRES. The second demand on oxygen caused by the release and suspension of BOD materials is a less direct form of oxygen demand. This process increases the pool of BOD present in the RCHRES and exerts a demand on the dissolved oxygen concentration at a rate determined by the BOD decomposition kinetics.

Benthic Oxygen Demand

The user approximates the oxygen demand of the bottom muds at 20 degrees Celsius by assigning a value to BENOD for each RCHRES. The effects of temperature and dissolved oxygen concentration on realized benthic demand are determined by the following equation:

$$\text{BENOX} = \text{BENOD} * (\text{TCBEN} ** \text{TW20}) * (1.0 - \text{Exp}(-\text{EXPOD} * \text{DOX})) \quad (3)$$

where:

BENOX = amount of oxygen demand exerted by benthic muds (mg/m²/interval)
 BENOD = reach dependent benthic oxygen demand at 20 degrees C
 (mg/m²/interval)
 TCBEN = temperature correction factor for benthic oxygen demand
 TW20 = water temperature - 20.0 (deg C)
 EXPOD = exponential factor to benthic oxygen demand function
 (default value = 1.22)
 DOX = dissolved oxygen concentration (mg/l)

The first portion of the above equation adjusts the demand at 20 degrees Celsius to a demand at any temperature. The second portion of the equation indicates that low concentrations of dissolved oxygen suppress realized oxygen demand. For example, 91 percent of BENOD may be realized at a dissolved oxygen concentration of 2 mg/l, 70 percent at 1 mg/l, and none if the waters are anoxic.

After the value of BENOX has been calculated, the dissolved oxygen state variable is updated:

$$\text{DOX} = \text{DOX} - \text{BENOX} * \text{DEPCOR} \quad (4)$$

where:

DEPCOR = factor which converts from mg/m² to mg/l, based on the average depth of water in the RCHRES during the simulation interval
 (DEPCOR is calculated in subroutine RQUAL)

Benthic Release of BOD

Bottom releases of BOD are a function of scouring potential and dissolved oxygen concentration. The equation used to calculate BOD release is:

$$RELBOB = (BRBOB(1) + BRBOB(2)*Exp(-EXPREL*DOX))*SCRFAC \quad (5)$$

where:

RELBOB = BOD released by bottom muds (mg/m² per interval)
 BRBOB(1) = base release rate of BOD materials (aerobic conditions)
 (mg/m²/interval)
 BRBOB(2) = increment to bottom release rate due to decreasing
 dissolved oxygen concentration
 EXPREL = exponential factor to BOD benthic release function
 (default value = 2.82)
 DOX = dissolved oxygen concentration (mg/l)
 SCRFAC = scouring factor dependent on average velocity of water
 (SCRFAC is calculated in subroutine RQUAL)

The above equation accounts for the fact that benthic releases are minimal during conditions of low velocity and ample dissolved oxygen. Under these conditions a thin layer of hardened, oxidized material typically retards further release of materials from the benthos. However, anaerobic conditions or increased velocity of overlying water disrupts this layer, and release rates of BOD and other materials are increased. Solution of Equation 3 indicates that 6 percent of the incremental release rate (BRBOB(2)) occurs when 1 mg/l of dissolved oxygen is present, 75 percent occurs when 0.1 mg/l is present, and the entire increment occurs under anoxic conditions.

4.2(3).7.1.2 Calculate Oxygen Reaeration Coefficient (subroutine OXREA)

Purpose

Various methods have been used to calculate atmospheric reaeration coefficients, and experience has shown that the most effective method of calculation in any given situation depends upon the prevalent hydraulic characteristics of the system (Covar, 1976). Based upon user instructions, subroutine OXREA calculates oxygen reaeration by using one of four built-in solution techniques.

Approach

The general equation for reaeration is:

$$DOX = DOXS + KOREA*(SATDO - DOXS) \quad (6)$$

where:

DOX = dissolved oxygen concentration after reaeration (mg/l)
 KOREA = reaeration coefficient (greater than zero and less than one)
 SATDO = oxygen saturation level for given water temperature (mg/l)
 DOXS = dissolved oxygen concentration at start of interval (mg/l)

Lake Reaeration

In a lake or reservoir, calculation of reaeration is dependent upon surface area, volume, and wind speed. The wind speed factor is determined using the following empirical relationship:

$$\text{WINDF} = \text{WINDSP} * (-0.46 + 0.136 * \text{WINDSP}) \quad (7)$$

where:

WINDF = wind speed factor in lake reaeration calculation
WINDSP = wind speed (m/sec)

For low wind speeds, less than 6.0 m/s, WINDF is set to 2.0. The reaeration coefficient for lakes is calculated as:

$$\text{KOREA} = (.032808 * \text{WINDF} * \text{CFOREA} / \text{AVDEPE}) * \text{DELT60} \quad (8)$$

where:

CFOREA = correction factor to reaeration coefficient for lakes; for lakes with poor circulation characteristics, CFOREA may be less than 1.0, and lakes with exceptional circulation characteristics may justify a value greater than 1.0
AVDEPE = average depth of water in RCHRES during interval (ft)
DELT60 = conversion from hourly time interval to simulation interval

Stream Reaeration

One of three approaches to calculating stream reaeration may be used:

1. Energy dissipation method (Tsivoglou-Wallace, 1972). Oxygen reaeration is calculated based upon energy dissipation principles:

$$\text{KOREA} = \text{REACT} * (\text{DELTHE} / \text{FLOTIM}) * (\text{TCGINV} ** (\text{TW} - 20.)) * \text{DELTS} \quad (9)$$

where:

REACT = escape coefficient with a typical value between 0.054/ft and 0.110/ft.
DELTHE = drop in energy line along length of RCHRES (ft)
FLOTIM = time of flow through RCHRES (seconds)
TCGINV = temperature correction coefficient for gas invasion rate with a default value of 1.047
DELTS = conversion factor from units of /second to units of /interval

DELTHE, the drop in elevation over the length of the RCHRES, is supplied by the user. REACT, the escape coefficient, referred to in Tsivoglou's work, is also supplied by the user. The value for FLOTIM is calculated by dividing the length of the RCHRES by the average velocity for the simulation interval. Tsivoglou's method of calculation is activated by setting the reaeration method flag (REAMFG) to 1.

2. Covar's method of determining reaeration (Covar, 1976). Reaeration is calculated as a power function of hydraulic depth and velocity. The general equation is:

$$KOREA = REAK * (AVVELE^{EXPREV}) * (AVDEPE^{EXPRED}) * (TCGINV^{(TW - 20.)}) * DELT60 \quad (10)$$

where:

KOREA = reaeration coefficient (per interval)
 REAK = empirical constant for reaeration equation (/hour)
 AVVELE = average velocity of water (ft/s)
 EXPREV = exponent to velocity function
 AVDEPE = average water depth (ft)
 EXPRED = exponent to depth function
 TCGINV = temperature correction coefficient for reaeration
 defaulted to 1.047
 DELT60 = conversion factor from units of per hour to units of per interval

Depending on current depth and velocity, one of three sets of values for REAK, EXPREV, and EXPRED is used. Each set corresponds to an empirical formula which has proven accurate for a particular set of hydraulic conditions. The three formulas and their associated hydraulic conditions and coefficients are:

1. Owen's formula (Owen et al., 1964). This formula is used for depths of less than 2 ft. For this formula, REAK = 0.906, EXPREV = 0.67, and EXPRED = -1.85.
2. Churchill's formula (1962). This formula is used for high velocity situations in depths of greater than 2 ft. For this formula, REAK = 0.484, EXPREV = 0.969, and EXPRED = -1.673.
3. O'Connor-Dobbins formula (1958). This formula is used for lower velocity situations in depths of greater than 2 ft. The coefficient values are: REAK = 0.538, EXPREV = 0.5, and EXPRED = -1.5.

This method of calculation of reaeration is activated by setting the reaeration method flag (REAMFG) to 2.

3. Users may select their own power function of hydraulic depth and velocity for use under all conditions of depth and velocity. In this case, the user supplies values for REAK, EXPREV, and EXPRED. This option is selected by setting the reaeration method flag (REAMFG) to 3.

Reaeration may be modeled as a constant process for any given temperature. In this case, the user must supply a value for REAK, and a value of zero for both EXPREV and EXPRED. Note that subroutine OXREA requires input values for REAK, EXPREV, and EXPRED only if REAMFG is 3.

4.2(3).7.1.3 Calculate BOD Decay (subroutine BODDEC)

Purpose

Subroutine BODDEC adjusts the dissolved oxygen concentration of the water to account for the oxygen consumed by microorganisms as they break down complex materials to simpler and more stable products. Only carbonaceous BOD is considered in this subroutine. The BOD decay process is assumed to follow first-order kinetics and is represented by:

$$\text{BODOX} = (\text{KBOD20} * (\text{TCBOD} ** (\text{TW} - 20.))) * \text{BOD} \quad (11)$$

where:

BODOX = quantity of oxygen required to satisfy BOD decay (mg/l per interval)

KBOD20 = BOD decay rate at 20 degrees C (/interval)

TCBOD = temperature correction coefficient, defaulted to 1.075

TW = water temperature (degrees C)

BOD = BOD concentration (mg/l)

If there is not sufficient dissolved oxygen available to satisfy the entire demand exerted by BOD decay, only the fraction which can be satisfied is subtracted from the BOD state variable, and the DOX variable is set to zero.

4.2(3).7.2 Simulate Primary Inorganic Nitrogen and Phosphorus Balances (Subroutine Group NUTRX of Module RCHRES)

Purpose

This code simulates the primary processes which determine the balance of inorganic nitrogen and phosphorus in natural waters. When modeling the water quality of an aquatic system, consideration of both nitrogen and phosphorus is essential. Nitrogen, in its various forms, can deplete dissolved oxygen levels in receiving waters, stimulate aquatic growth, exhibit toxicity toward aquatic life, or present a public health hazard (EPA, 1975). Phosphorus is vital in the operation of energy transfer systems in biota, and in many cases is the growth limiting factor for algal communities. Consequently, it is necessary to model phosphorus in any study concerned with eutrophication processes.

Schematic View of Fluxes and Storages

Figures 4.2(3).7.2-1 and 4.2(3).7.2-2 illustrate the fluxes and storages of four constituents which are introduced into the RCHRES modeling system in subroutine group NUTRX. In addition to these constituents, the state variables for dissolved oxygen and BOD are also updated. If subroutine group NUTRX is active (NUTFG = 1), nitrate will automatically be simulated; the user must specify whether or not nitrite, total ammonia, and/or orthophosphorus are to be simulated in addition to nitrate by assigning appropriate values to NO2FG, TAMFG, and PO4FG in the User's Control Input. In addition, if ammonia or orthophosphorus is simulated, the user may specify whether to simulate the adsorbed (particulate) forms of ammonia and orthophosphorus. If either adsorbed nutrient is simulated, Section SEDTRN must be active to provide the inorganic sediment (sand, silt, and clay) concentrations and fluxes. If all possible constituents are simulated, subroutine NUTRX considers the following processes:

1. longitudinal advection of dissolved NO₃, NO₂, NH₃, and PO₄
2. benthic release of inorganic nitrogen (NH₃) and PO₄ (if BENRFG = 1)
3. ammonia ionization (NH₃/NH₄⁺ equilibrium)
4. ammonia vaporization (if AMVFG = 1)
5. nitrification of NH₃ and NO₂
6. denitrification of NO₃ (if DENFG = 1)
7. ammonification due to degradation of BOD materials
8. adsorption/desorption of NH₃ and PO₄ to inorganic sediment in the water column (if ADNHF = 1 or ADPOFG = 1)
9. deposition/scour and longitudinal advection of adsorbed NH₃ and PO₄ (if ADNHF = 1 or ADPOFG = 1)

Additional sources and sinks of NO₃, NH₃, and PO₄ are simulated in the PLANK section (4.2(3).7.3) of this module. If section PLANK is active, the state variables for these three constituents can be adjusted to account for nutrient uptake by phytoplankton and/or benthic algae, and for respiration and inorganic excretion by zooplankton.

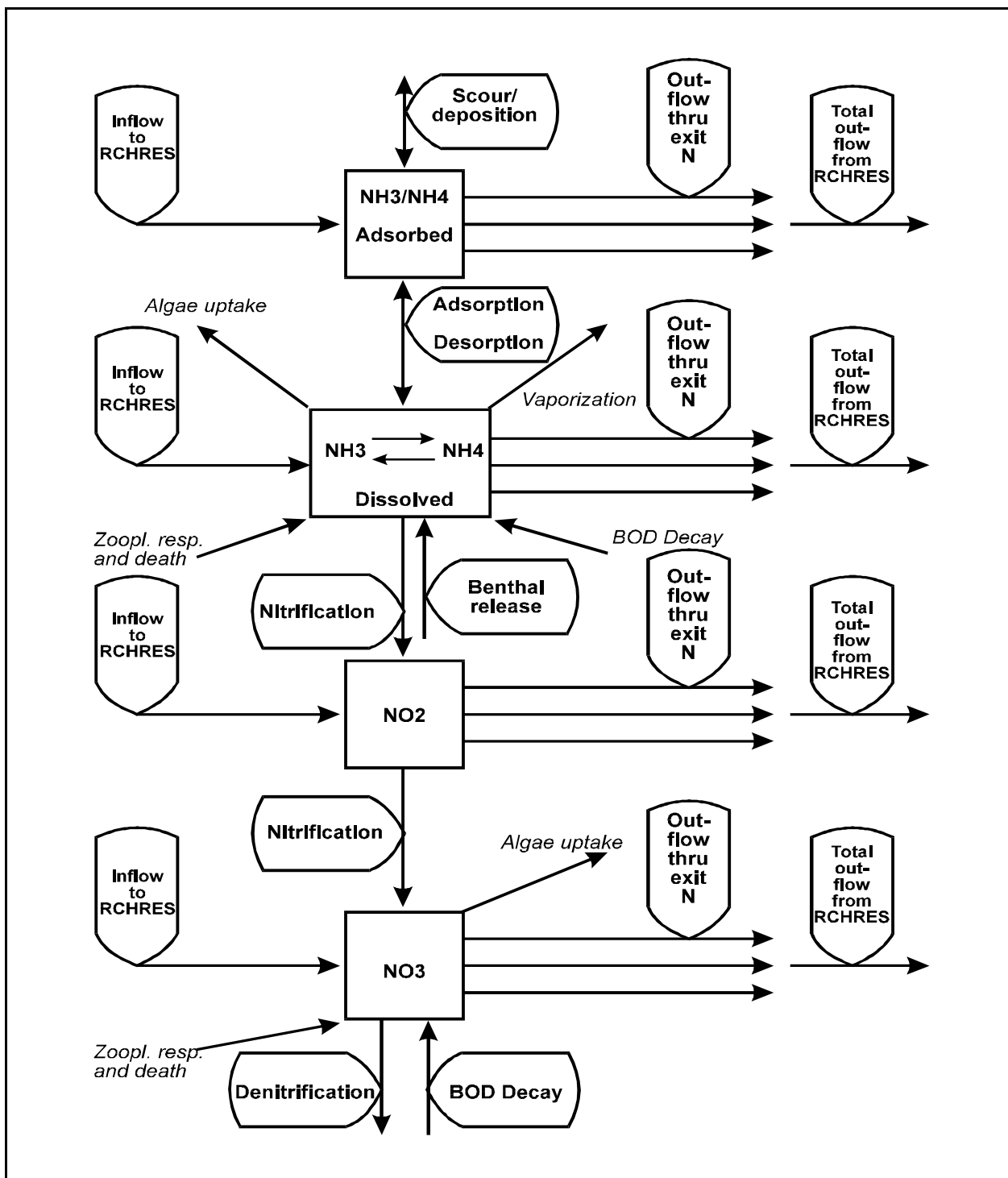


Figure 4.2(3).7.2-1 Flow diagram for inorganic nitrogen in the NUTRX subroutine group of the RCHRES Application Module

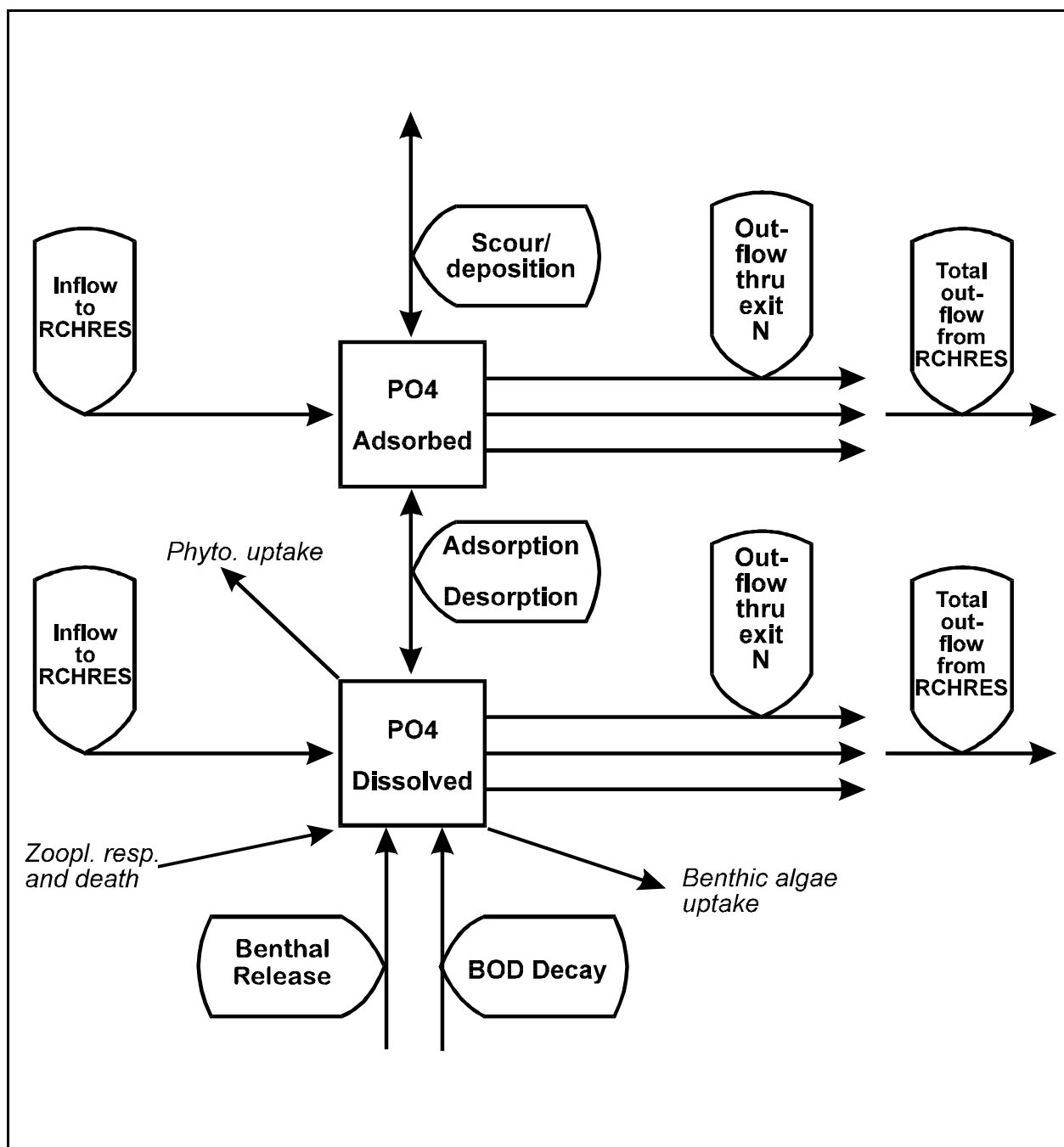


Figure 4.2(3).7.2-2 Flow diagram for ortho-phosphate in the NUTRX subroutine group of the RCHRES Application Module

Subroutine NUTRX utilizes nine principal routines to simulate inorganic nitrogen and phosphorus. Advection of dissolved NO₃, NO₂, NH₃, and PO₄ is performed by ADVECT. BENTH determines the amount of inorganic nitrogen and phosphorus which is released to the overlying waters from the benthos. The nitrification and denitrification processes are simulated by NITRIF and DENIT, respectively. Adsorption/desorption of NH₃ and PO₄ is computed by ADDSNU, and the advection and deposition/scour of the adsorbed forms are simulated in ADVNUT. The ammonia ionization and volatilization calculations are performed in AMMION and NH3VOL, respectively. Finally, the production of inorganic nitrogen and phosphorus resulting from decay of BOD materials is simulated by DECBAL.

Before ADVECT is called, NUTRX sums the inputs of dissolved NO₃, NH₃, and PO₄ from upstream reaches, tributary land areas, and atmospheric deposition (deposition of NO₂ is not considered):

$$\text{INNUT} = \text{INUT} + \text{SAREA} * \text{ADFX} + \text{SAREA} * \text{PREC} * \text{ADCN} \quad (1)$$

where:

INNUT = total input of dissolved nutrient to reach
 INUT = input of dissolved nutrient from upstream reaches and tributary land
 SAREA = surface area of reach
 ADFX = dry or total atmospheric deposition flux in mass/area per interval
 PREC = precipitation depth
 ADCN = concentration for wet atmospheric deposition in mass/volume

Atmospheric deposition inputs can be specified in two possible ways depending on the form of the available data. If the deposition is in the form of a flux (mass per area per time), then it is considered "dry deposition". If the deposition is in the form of a concentration in rainfall, then it is considered "wet deposition", and the program automatically combines it with the input rainfall time series to compute the resulting flux. Either type of deposition data can be input as a time series, which covers the entire simulation period, or as a set of monthly values that is used for each year of the simulation. The specific atmospheric deposition time series are documented in the EXTNL table of the Time Series Catalog for RCHRES, and are specified in the EXT SOURCES block of the UCI. Monthly values are input in the MONTH-DATA block in the UCI.

4.2(3).7.2.1 Simulate Benthic Release of Constituents (subroutine BENTH)

Purpose

This subroutine checks to see whether present water conditions are aerobic or anaerobic, calculates benthic release for a constituent based on this check, and updates the concentration of the constituent.

Approach

The equation used to calculate release is:

$$\text{RELEAS} = \text{BRCON}(\text{I}) * \text{SCRFAC} * \text{DEPCOR} \quad (1)$$

where:

RELEAS = amount of constituent released (mg/l per interval)
 BRCON(I) = benthic release rate (BRTAM or BRPO4) for constituent
 (mg/m² per interval)
 SCRFAC = scouring factor, dependent on average velocity of the water
 (SCRFAC is computed in RQUAL)
 DEPCOR = conversion factor from mg/m² to mg/l (computed in RQUAL)

The dissolved oxygen concentration below which anaerobic conditions are considered to exist is determined by the input parameter ANAER. Two release rates are required for each of the constituents: one for aerobic conditions and one for anaerobic conditions. Typically, the aerobic release rate is less than the anaerobic rate, because a layer of oxidized materials forms on the benthic surface during aerobic periods, and this layer retards the release rate of additional benthic materials. BRCON(1) is the aerobic release rate and BRCON(2) is the anaerobic rate. The choice of which release rate is used is determined by comparing the current value of DOX to ANAER.

If ammonia is simulated, the inorganic nitrogen release from the benthos is assumed to be in the form of ammonia, and the NH₃ (TAM) state variable is updated. If ammonia is not simulated, benthic release of inorganic nitrogen is assumed to not occur. If orthophosphate is simulated, an additional call is made to BENTH to account for release of PO₄.

Simulation of benthic release processes is activated by assigning a value of one to BENRFG in the User's Control Input for RQUAL.

4.2(3).7.2.2 Simulate Nitrification (subroutine NITRIF)

Purpose

NITRIF simulates the oxidation of ammonium and nitrite by chemoautotrophic bacteria. This oxidation provides energy for bacteria much the same way that sunlight provides energy for photosynthetic algae. The Nitrosomonas genera are responsible for conversion of ammonium to nitrite, and Nitrobacter perform oxidation of nitrite to nitrate. Oxidation of inorganic nitrogen is dependent upon a suitable supply of dissolved oxygen; subroutine NITRIF does not simulate nitrification if the DO concentration is below 2 mg/l.

Method

The rate of nitrification is represented by a first order equation in which nitrification is directly proportional to the quantity of reactant present, either ammonia or nitrite. The equation used to calculate the amount of NH₃ oxidized to NO₂ is:

$$TAMNIT = KTAM20 * (TCNIT ** (TW - 20.)) * TAM \quad (2)$$

where:

TAMNIT = amount of NH₃ oxidation (mg N/l per interval)
 KTAM20 = ammonia oxidation rate coefficient at 20 degrees C (/interval)
 TCNIT = temperature correction coefficient, defaulted to 1.07
 TW = water temperature (degrees C)
 TAM = total ammonia concentration (mg N/l)

Similarly, if nitrite is simulated, the amount of nitrite oxidized to nitrate is determined by the equation:

$$NO2NIT = KNO220 * (TCNIT ** (TW - 20.)) * NO2 \quad (3)$$

where:

NO2NIT = amount of NO₂ oxidation (mg N/l/interval)
 KNO220 = NO₂ oxidation rate coefficient at 20 degrees C (/interval)
 NO2 = nitrite concentration (mg N/l)

The amount of oxygen used during nitrification is 3.43 mg oxygen per mg NH₃-N oxidized to NO₂-N, and 1.14 mg oxygen per mg NO₂-N oxidized to NO₃-N. In the RCHRES module, these figures are adjusted to 3.22 mg and 1.11 mg, respectively, to account for the effects of carbon dioxide fixation by bacteria (Wezerak and Gannon, 1968). Thus, the oxygen demand due to nitrification is evaluated as:

$$DODEMD = 3.22 * TAMNIT + 1.11 * NO2NIT \quad (4)$$

where:

DODEMD = loss of dissolved oxygen from the RCHRES due to nitrification
 (mg O/l per interval)

If the value of DODEMD is greater than available dissolved oxygen, the amounts of oxidation from NH₃ to NO₂ and from NO₂ to NO₃ are proportionally reduced, so that the state variable DOX maintains a non-negative value. If nitrite is not simulated, the calculated amount of oxidized ammonia is assumed to be fully oxidized to nitrate.

4.2(3).7.2.3 Simulate Denitrification (subroutine DENIT)

Purpose

DENIT simulates the reduction of nitrate by facultative anaerobic bacteria such as Pseudomonas, Micrococcus, and Bacillus. These bacteria can use NO₃ for respiration in the same manner that oxygen is used under aerobic conditions. Facultative organisms use oxygen until the environment becomes nearly or totally anaerobic, and then switch over to NO₃ as their oxygen source. In HSPF, the end product of denitrification is assumed to be nitrogen gas.

Approach

Denitrification does not occur in the RCHRES module unless the dissolved oxygen concentration is below a user-specified threshold value (DENOXT). If that situation occurs, denitrification is assumed to be a first-order process based on the NO₃ concentration. The amount of denitrification for the interval is calculated by the following equation:

$$\text{DENNO3} = \text{KNO320} * (\text{TCDEN}^{*(\text{TW}-20)}) * \text{NO3} \quad (5)$$

where:

DENNO3 = amount of NO₃ denitrified (mg N/l per interval)
 KNO320 = NO₃ denitrification rate coefficient at 20 degrees C (/interval)
 TCDEN = temperature correction coefficient for denitrification
 NO3 = nitrate concentration (mg N/l)

4.2(3).7.2.4 Simulate Adsorption/Desorption of Ammonia and Orthophosphorus (subroutine ADDSNU)

Purpose

This subroutine simulates the exchange of nutrient (ammonium and orthophosphorus) between the dissolved state and adsorption on suspended sediment. The sorbents considered are suspended sand, silt, and clay, which are simulated in section SEDTRN. The adsorption/desorption process is not simulated in bed sediments.

Approach

The adsorption/desorption for each sediment fraction is represented with an equilibrium, linear isotherm, i.e., a standard K_d approach, which is described as follows:

$$\text{SNUT}(J) = \text{DNUT} * \text{ADPM}(J) \quad (6)$$

where:

SNUT(J) = equilibrium concentration of adsorbed nutrient on sediment fraction J (mg/kg)
 DNUT = the equilibrium concentration of dissolved nutrient (mg/l)
 ADPM(J) = adsorption parameter (or Kd) for sediment fraction J (l/kg)

This expression for SNUT(J) is substituted into the following mass balance expression for total nutrient in the reach:

$$\text{NUM} = \text{DNUT} * \text{VOL} + \sum_{J=1,3} 3 [\text{SNUT}(J) * \text{RSED}(J)] = \text{total nutrient in reach} \quad (7)$$

where:

NUM = variable used to represent total nutrient mass in the reach (mg)
 VOL = volume of reach (l)
 RSED(J) = mass of sediment fraction J in suspension (kg)

After substituting, rearranging, and solving for DNUT, the following expression is obtained:

$$\text{DNUT} = \frac{\text{NUM}}{\text{VOL} + \sum_{J=1,3} 3 [\text{RSED}(J) * \text{ADPM}(J)]} \quad (8)$$

In the above equation, the value of NUM is obtained from a "non-equilibrium" version of Equation (7) in which temporary DNUT and SNUT values include the effects of other processes such as advection, scour/deposition, nitrification, etc, that have occurred during the interval. Therefore, the overall procedure involves performing all processes that affect the nutrient concentrations, and then partitioning (equilibrating) the total mass of nutrient among the four phases, i.e., dissolved phase and three sediment fractions.

Note, the units listed for some variables in the preceding discussion are simplified from the internal (code) HSPF units.

4.2(3).7.2.5 Simulate Advection and Deposition/Scour of Adsorbed Ammonia and Orthophosphorus (subroutine ADVNUT)

Purpose

ADVNUT simulates the advective processes for a nutrient (NH₃ or PO₄) attached to one sediment size fraction. Processes handled in this routine include:

1. Inflow to the RCHRES of nutrient attached to suspended sediment.
2. Migration of nutrient from suspension in the water to the bed as a result of deposition of the sediment to which the nutrient is adsorbed.

3. Migration of nutrient from the bed into suspension in the water as a result of scour of the bed sediments to which the nutrient is adsorbed.
4. Outflow from the RCHRES of nutrient attached to suspended sediment.

Method

The movement of adsorbed nutrient is completely determined by the movement of the sediment to which it is attached. All fluxes of adsorbed nutrient are expressed as the product of the flux of a sediment fraction (sand, silt, or clay) and the concentration of nutrient associated with that fraction (expressed in mg per kg of sediment). Likewise, storages of adsorbed nutrient are expressed as the product of the sediment fraction storage and the associated concentration of nutrient. Note that the nutrient storage in the bed is essentially infinite. Nutrients that deposit to the bed are assumed to be lost from the RCHRES, and scoured sediment is assumed to have a constant (user-specified) adsorbed nutrient concentration; thus the scoured nutrient flux is limited only by the storage of sediment in the bed. A simplified flow diagram of sediment and associated nutrient fluxes and storages is provided in Figure 4.2(3).7.2-3 to facilitate the following discussion. ADVNUT is designed to operate on one sediment fraction and one nutrient each time it is called by subroutine NUTRX.

If the sediment simulation in module section SEDTRN indicates that scour of bed storage of a sediment fraction occurs, the following actions are taken in ADVNUT:

1. The flux of nutrient from bed to suspension is calculated as:

$$DSNUT = BNUT * DEPSCR \quad (9)$$

where:

DSNUT = amount of nutrient scoured from bed and added to suspension
(mg/l)*(ft³/ivl) or (mg/l)*(m³/ivl)
 BNUT = constant concentration of nutrient on bed sediment fraction
under consideration (mg/mg sediment)
 DEPSCR = amount of sediment fraction which is scoured from
the bed (mg.ft³/l.ivl or mg.m³/l.ivl)

2. The concentration of adsorbed nutrient in suspension is updated to account for scour:

$$SNUT = (ISNUT + RSNUTS - DSNUT) / (RSED + ROSED) \quad (10)$$

where:

SNUT = concentration of adsorbed nutrient in suspension
(mg/mg suspended sediment)
 ISNUT = inflow of nutrient to the RCHRES as a result of inflowing
sediment fraction ((mg/l)*(ft3/ivl) or (mg/l)*(m3/ivl))
 RSNUTS = storage of nutrient on suspended sediment fraction
((mg/l)*ft3 or (mg/l)*m3)
 RSED = amount of sediment fraction in suspension
at end of interval (mg.ft3/l or mg.m3/l)
 ROSED = amount of sediment fraction contained in outflow from the RCHRES
during the interval (mg.ft3/l.ivl or mg.m3/l.ivl)

3. The concentration of nutrient on bed sediment is set equal to zero if the storage of bed sediment at the end of the interval is zero.

5. Amount of nutrient leaving the RCHRES as outflow is determined as:

$$\text{ROSNOT} = \text{ROSED} * \text{SNUT} \quad (11)$$

If the sediment simulation in module section SEDTRN indicates that deposition of suspended sediment occurs, ADVNUT performs the following operations:

1. Concentration of nutrient on total suspended sediment fraction (inflow + suspended storage) for the RCHRES is calculated:

$$\text{SNUT} = (\text{ISNUT} + \text{RSNUTS}) / (\text{RSED} + \text{DEPSCR} + \text{ROSED}) \quad (12)$$

2. Amount of nutrient leaving the RCHRES due to outflow of sediment fraction is determined:

$$\text{ROSNOT} = \text{ROSED} * \text{SNUT} \quad (13)$$

3. Amount of nutrient leaving suspension due to deposition of the sediment to which it is adsorbed is found by:

$$\text{DSNUT} = \text{DEPSCR} * \text{SNUT} \quad (14)$$

4. The concentration of nutrient on sediment in suspension is set equal to zero if the suspended storage of sediment is zero.

The final operation which ADVNUT performs is the computation of outflow of adsorbed nutrient through individual exits (when more than one exit is specified). The algorithm is:

$$\text{OSNUT}(I) = \text{ROSNOT} * \text{OSED}(I) / \text{ROSED} \quad (15)$$

where:

OSNUT(I) = outflow of adsorbed nutrient through exit gate I
 ROSNOT = total outflow of adsorbed nutrient from RCHRES
 OSED(I) = outflow of sediment fraction through exit gate I

4.2(3).7.2.6 Simulate Ionization of Ammonia to Ammonium (subroutine AMMION)

Approach

The total dissolved ammonia state variable (TAM) consists of two forms, NH_4^+ and NH_3 . The ionized form is dominant at typical pH's and temperatures found in nature; however, the un-ionized form is toxic to aquatic species at fairly low concentrations, and may be significant at some extreme environmental pH's. Therefore, while the process formulations in HSPF are based on the total ammonia, the un-ionized form is computed and output.

The fraction (FRAC) of total ammonia that is present as un-ionized ammonia is calculated as:

$$\text{FRAC} = \frac{10^{\text{pH}}}{10^{\text{pH}} + \text{RATIO}} \quad (16)$$

where:

RATIO = ratio of ionization products for water k_w and ammonia (k_b)

RATIO is computed using an empirical relationship based on pH and temperature as described by Loehr et al. (1973):

$$\text{RATIO} = -3.39753 \log_e(0.02409 \text{ TW}) 10^9 \quad (17)$$

The pH used in Equation 16 may be obtained from Section PHCARB (if it is active) or specified by the user in the form of a constant value, 12 monthly values, or an input time series.

4.2(3).7.2.7 Simulate Ammonia Volatilization (subroutine NH3VOL)

Approach

The amount of total ammonia lost from the RCHRES due to ammonia volatilization is calculated by a standard two-layer model of mass transfer across the air-water interface; this is based on Henry's Law and the flux of mass through the water and air films. The inverse of the overall mass transfer coefficient is given by the following expression:

$$\frac{1}{K_R} = K_{RINV} = \frac{1}{\text{NH3KL}} + \frac{8.21 \times 10^{-5} * \text{TWKELV}}{\text{HCNH3} * \text{NH3KG}} \quad (18)$$

where:

KR = overall mass transfer coefficient (cm/hr)
 KRINV = inverse of coefficient (hr/cm)
 NH3KL = liquid film mass transfer coefficient (cm/hr)
 NH3KG = gas film mass transfer coefficient (cm/hr)
 HCNH3 = Henry's Law Constant for ammonia (atm-m³/mole)
 8.21E-5 = the ideal gas constant (atm-m³/K/mole)
 TWKELV = water temperature (degrees K)

Computation of the liquid-film coefficient is based on correlation with the reaeration rate (i.e., the rate of transfer of oxygen gas across the interface). The proportionality constant is a function of the ratio of the molecular weights. Therefore, the liquid-film coefficient is given by:

$$\text{NH3KL} = [\text{KOREA} * \text{AVDEPM} * 100/\text{DELT60}] * [1.878^{**}(\text{EXPNVL}/2.)] \quad (19)$$

where:

KOREA = the oxygen reaeration rate (per interval)
 AVDEPM = average depth of the reach (m)
 100 = conversion from meters to centimeters
 DELT60 = conversion from units of per interval to units of per hour
 1.878 = ratio of molecular weight of oxygen (32) to ammonia (17)
 EXPNVL = user-specified exponential factor

Note that in the first part of the above equation, KOREA is being converted to the same units as NH3KL, i.e., cm/hr.

In a similar manner to the liquid-film coefficient, the gas-film coefficient is computed from the water evaporation rate which is primarily driven by the wind. The gas film coefficient is computed as:

$$\text{NH3KG} = 700. * \text{WINDSP} * 1.057^{**}(\text{EXPNVG}/2.) \quad (20)$$

where:

700 = an empirical constant relating the wind speed in m/s and the evaporation rate in cm/hr
 WINDSP = wind speed (m/s)
 1.057 = ratio of water molecular weight to that of ammonia
 EXPNVG = user-specified exponential factor

The Henry's constant for ammonia (HCNH3) is interpolated from a table of values based on temperature and pH.

The reach-specific, first-order rate constant for volatilization is computed by:

$$\text{KNVOL} = \text{KR} * \text{DELT60}/(\text{AVDEPM} * 100) \quad (21)$$

where:

KNVOL = first-order rate constant for volatilization (/interval)
 100 = conversion from units of 1/cm to 1/m

Finally, the volatilization loss is computed as:

$$\text{NH3VLT} = \text{KNVOL} * \text{TAM} \quad (22)$$

where:

NH3VLT = volatilization loss during the interval (mg N/l)
 TAM = concentration of total ammonia (mg N/l)

Simulation of ammonia volatilization is activated by setting AMVFG equal to one in the User's Control Input. Of course, total ammonia simulation must also be activated by setting TAMFG equal to 1.

4.2(3).7.2.8 Perform Materials Balance for Transformation from Organic to Inorganic Material (subroutine DECBAL)

Purpose

DECBAL adjusts the inorganic nitrogen and orthophosphorus state variables to account for decomposition of organic materials.

Method

In subroutine NUTRX the total BOD decay for the time interval is used to compute the corresponding amounts of inorganic nitrogen and orthophosphorus produced by the decay are determined as:

$$\text{DECNIT} = \text{BODOX} * \text{CVON} \quad (23)$$

$$\text{DECP04} = \text{BODOX} * \text{CVOP} \quad (24)$$

where:

BODOX = total BOD decay (mg O/l per interval)
 CVON = stoichiometric conversion factor from mg oxygen to mg nitrogen
 CVOP = stoichiometric conversion factor from mg oxygen to mg phosphorus

The values for DECNIT and DECP04 are passed to subroutine DECBAL. If ammonia is simulated, the value of DECNIT is added to the NH3 (TAM) state variable; if not, DECNIT is added to the NO3 state variable. If orthophosphorus is simulated, the value of DECP04 is added to the PO4 state variable.

4.2(3).7.3 Simulate Plankton Populations and Associated Reactions (Subroutine Group PLANK of Module RCHRES)

Purpose

PLANK simulates phytoplankton, zooplankton, and/or benthic algae.

Schematic View of Fluxes and Storages

Figures 4.2(3).7.3-1 through 4.2(3).7.3-4 illustrate the fluxes and storages of the six constituents which are introduced into the RCHRES modeling system in subroutine PLANK. In addition to these constituents, the state variables for dissolved oxygen, biochemical oxygen demand, nitrate, total ammonia, and orthophosphorus are also updated. If subroutine group PLANK is active (PLKFG = 1), dead refractory organics will automatically be simulated. The state variables for these organics are ORN (dead refractory organic nitrogen), ORP (dead refractory organic phosphorus), and ORC (dead refractory organic carbon). The user must specify whether or not phytoplankton, zooplankton, and/or benthic algae are simulated by assigning appropriate values to PHYFG, ZOOFG, and BALFG in the User's Control Input. The state variable PHYTO represents the free floating photosynthetic algae, ZOO represents the zooplankton which feed on PHYTO, and BENAL is the state variable for algae attached to the benthic surface.

Subroutine group PLANK is a large and complex code segment. It uses twelve subroutines to perform simulation of the three types of plankton. Longitudinal advection of PHYTO and ZOO is performed by ADVPLK, a special advection routine for plankton. ORN, ORP, and ORC are advected by ADVECT. The sinking of PHYTO, ORN, ORP, and ORC is performed by subroutine SINK. The user controls the sinking rate of these constituents by assigning values to parameters PHYSET and REFSET in the User's Control Input. PHYSET is the rate of phytoplankton settling, and REFSET is the settling rate for all three of the dead refractory organic constituents. Advection and sinking are performed every interval.

Before ADVECT is called, PLANK sums the inputs of ORN, ORP, and ORC from upstream reaches, tributary land areas, and atmospheric deposition:

$$\text{INORG} = \text{IORG} + \text{SAREA} \cdot \text{ADFX} + \text{SAREA} \cdot \text{PREC} \cdot \text{ADCN} \quad (1)$$

where:

INORG = total input of organic to reach
 IORG = input of organic from upstream reaches and tributary land
 SAREA = surface area of reach
 ADFX = dry or total atmospheric deposition flux in mass/area per interval
 PREC = precipitation depth
 ADCN = concentration for wet atmospheric deposition in mass/volume

Atmospheric deposition inputs can be specified in two possible ways depending on the form of the available data. If the deposition is in the form of a flux (mass per area per time), then it is considered "dry deposition". If the deposition is in the form of a concentration in rainfall, then it is considered "wet deposition", and the program automatically combines it with the input rainfall time series to

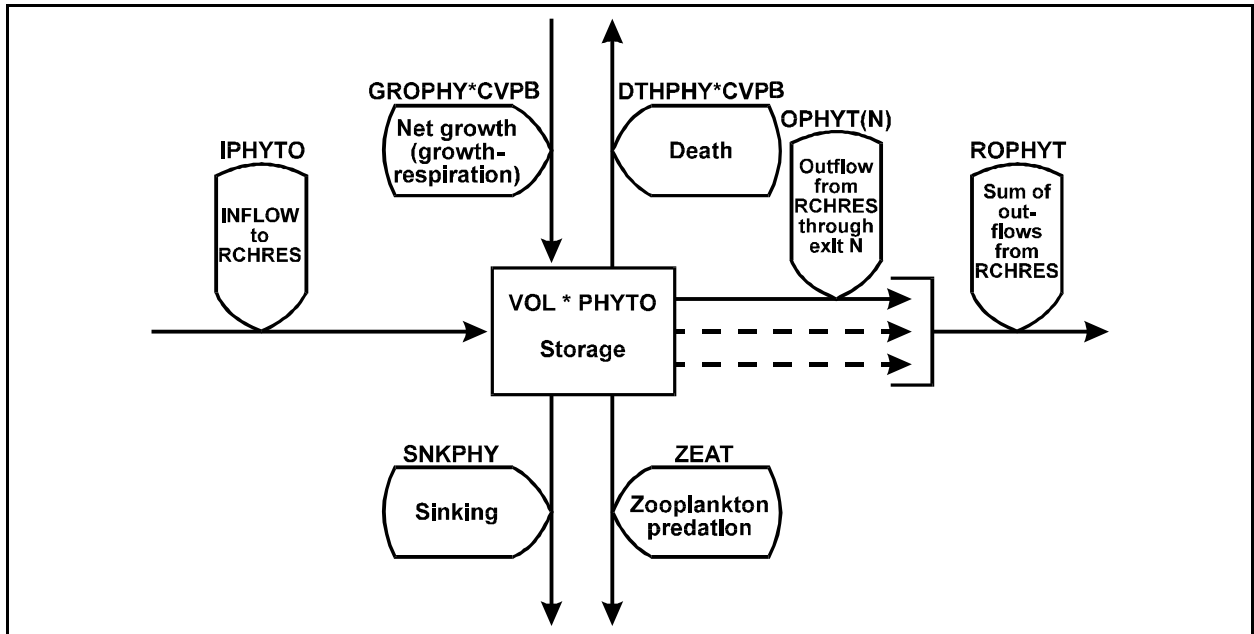


Figure 4.2(3).7.3-1 Flow diagram for phytoplankton in the PLANK section of the RCHRES Application Module

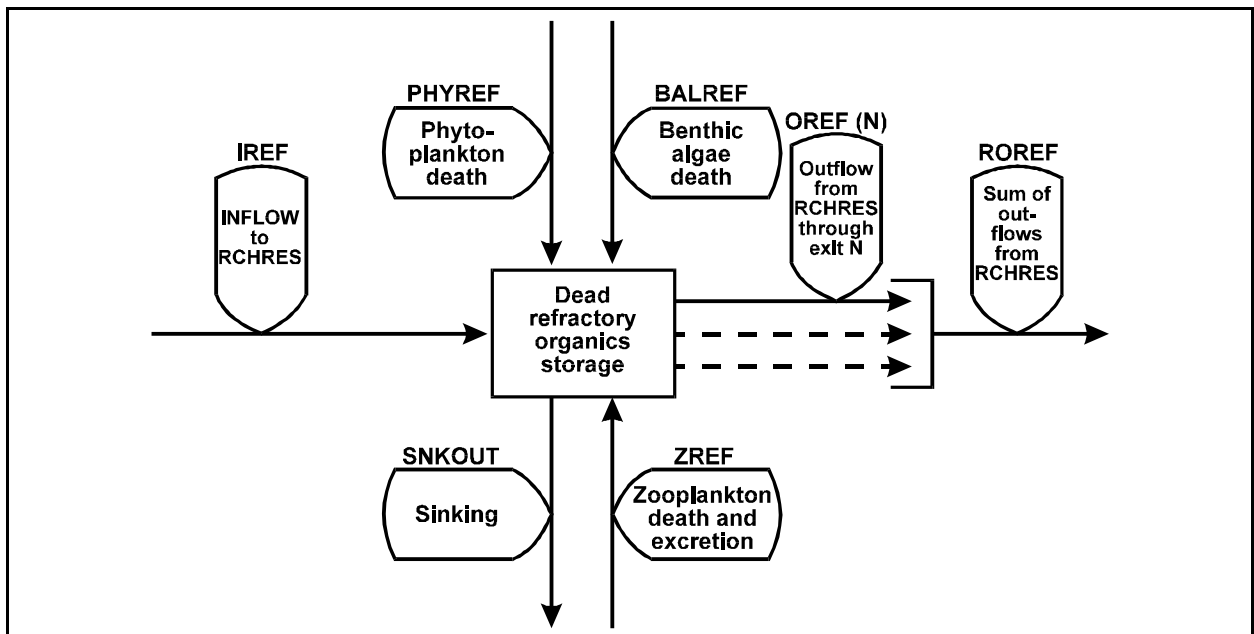


Figure 4.2(3).7.3-2 Flow diagram for dead refractory organics in the PLANK section of the RCHRES Application Module

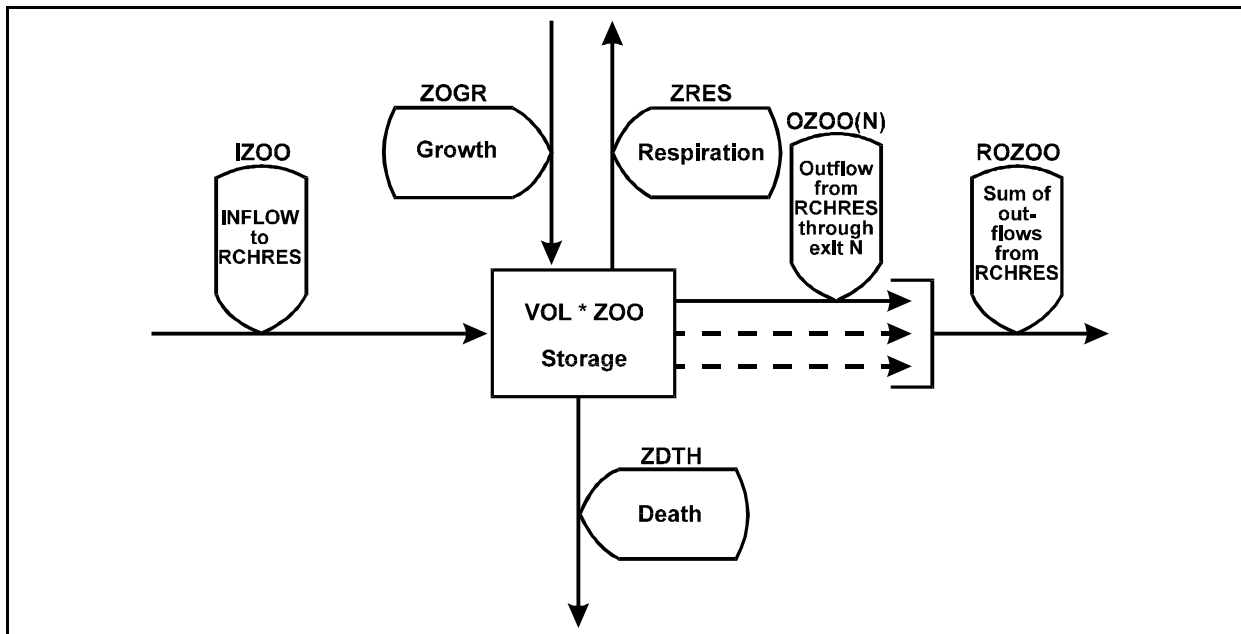


Figure 4.2(3).7.3-3 Flow diagram for zooplankton in the PLANK section of the RCHRES Application Module

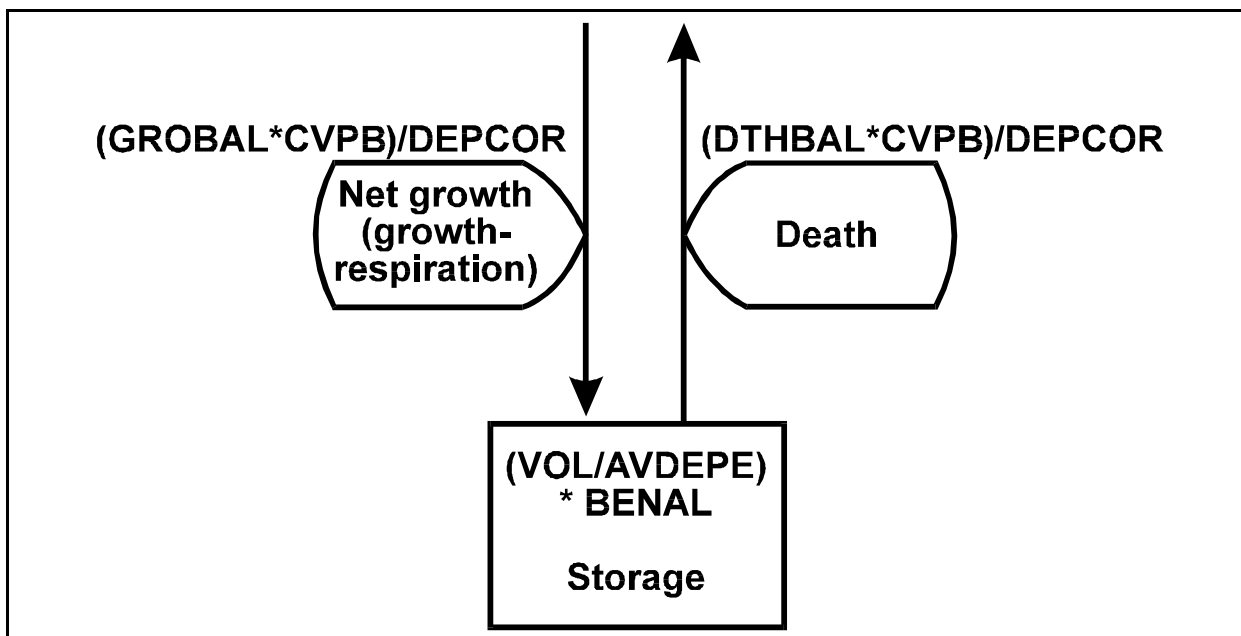


Figure 4.2(3).7.3-4 Flow diagram for benthic algae in the PLANK section of the RCHRES Application Module

compute the resulting flux. Either type of deposition data can be input as a time series, which covers the entire simulation period, or as a set of monthly values that is used for each year of the simulation. The specific atmospheric deposition time series for NUTRX are documented in the EXTNL table of the Time Series Catalog for RCHRES, and are specified in the EXT SOURCES block of the UCI. The monthly values are input in the MONTH-DATA block in the UCI.

The remainder of the processes modeled in PLANK are only performed when the average depth of water in the RCHRES is at least 2 inches. Experience has shown that the algorithms used to represent these processes are not accurate for excessively shallow waters. If 2 inches or more of water is present in the RCHRES, PLANK performs a series of operations which are necessary to determine the availability of light to support algal growth. First the light intensity at the RCHRES surface is calculated by the following equation:

$$\text{INLIT} = 0.97 * \text{CFSAX} * \text{SOLRAD} / \text{DELT} \quad (1)$$

where:

INLIT = light intensity immediately below water surface (langleys/min)
 0.97 = correction factor for surface reflection (assume 3 percent)
 CFSAX = input parameter that specifies the ratio of radiation at water surface to gage radiation values. This factor also accounts for shading of the water body, e.g. by trees and streambanks
 SOLRAD = solar radiation (langleys/interval)
 DELT = conversion from units of per interval to per minute

After the light intensity at the water surface has been calculated, PLANK determines the factors which diminish the intensity of light as it passes through the water. In addition to the natural extinction due to passage through water, extinction may result from interference caused by suspended sediment or phytoplankton. If SDLTFG is assigned a value of one, the contribution of total suspended sediment to light extinction is calculated as:

$$\text{EXTSED} = \text{LITSED} * \text{SSED} \quad (2)$$

where:

EXTSED = increment to base extinction coefficient due to total suspended sediment (/ft)
 LITSED = multiplication factor to total suspended sediment conc. (supplied in User's Control Input)
 SSED = total suspended sediment (sand + silt + clay) (mg/l)

The contribution of suspended phytoplankton to light extinction is determined by the empirical relationship:

$$\text{EXTCLA} = 0.00452 * \text{PHYCLA} \quad (3)$$

where:

EXTCLA = increment to base extinction coefficient due to phytoplankton (/ft)
 0.00452 = multiplication factor to phytoplankton chlorophyll a concentration
 PHYCLA = phytoplankton concentration (micromoles/l of chlorophyll a)

Subroutine Group PLANK

After values for INLIT, EXTSER, and EXTCLA have been calculated, PLANK calls subroutine LITRCH to determine the light correction factor to algal growth and the amount of light available to phytoplankton and benthic algae. Once these calculations have been completed, PLANK checks a series of flags to determine which types of plankton are to be simulated. If PHYFG is assigned a value of one, simulation of phytoplankton is performed. Zooplankton are simulated if ZOOFG is given a value of one. Zooplankton simulation can be performed only if the phytoplankton section is active. Finally, a value of one for BALFG activates benthic algae simulation.

4.2(3).7.3.1 Advect Plankton (subroutine ADVPLK)

Purpose

ADVPLK performs the advection of phytoplankton and zooplankton. The normal advection method (subroutine ADVECT) used in the RCHRES module assumes that each constituent concentration is uniform throughout the RCHRES. This assumption is not valid for plankton. Both phytoplankton and zooplankton locate their breeding grounds near the channel boundaries. Since the water near the boundaries moves downstream much more slowly than the mean water velocity, the plankton populations have a much longer residence time in the RCHRES than would be indicated by the mean flowtime. The geographical extent of the plankton breeding grounds is inversely related to the flow rate. At low flows, large areas of slow moving waters which are suitable for breeding exist along the channel boundaries. As flowrates increase, more and more of these areas are subject to flushing. The special advection routine is critical to plankton simulation, because the only source of plankton is within the reach network. Thus an upstream RCHRES with no plankton inflows can maintain a significant plankton population only if the growth rate of plankton exceeds the rate at which plankton are advected out of the RCHRES. Since biological growth rates are typically much slower than "normal" advection rates, few free-flowing RCHRES's could maintain a plankton population without the use of the special advection routine.

Method

Figure 4.2(3).7.3-5 illustrates the relationships used to perform plankton advection.

ADVPLK assumes that a certain concentration of plankton (STAY) is not subject to advection, but any excess of organisms will be advected in the normal way. A small population (SEED) of plankton are never subject to advection, even during the periods of greatest flow. The maximum concentration of plankton which is not subject to advection (MXSTAY) occurs during low flow conditions. Each simulation interval ADVPLK calculates STAY based on the values of these two parameters and OREF. OREF is the outflow rate at which STAY has a value midway between SEED and MXSTAY. First, the average flow rate through the RCHRES for the interval is calculated:

$$OFLO = (SROVOL + EROVOL)/DELTS \quad (4)$$

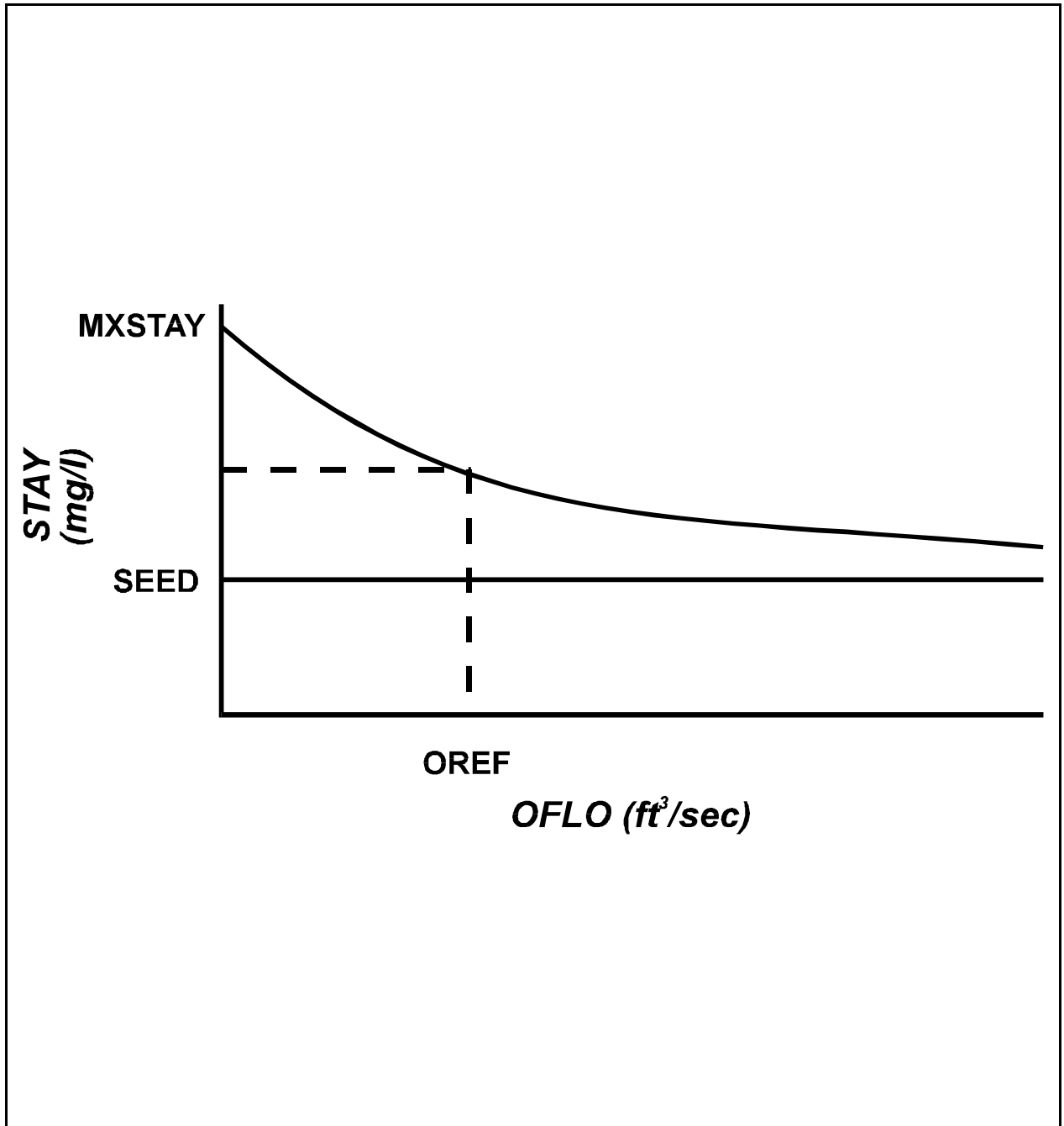


Figure 4.2(3).7.3-5 Relationship of parameters for special advection of plankton

where:

OFLO = average flow rate (ft³/s or m³/s)
 DELTS = number of seconds per interval
 SROVOL and EROVOL are as defined in Section 4.2(3).2

The concentration of plankton which is not subject to advection is then determined:

$$STAY = (MXSTAY - SEED) * (2.0 ** (-OFLO / OREF)) + SEED \quad (5)$$

where:

STAY = plankton concentration not advected (mg/l)
 MXSTAY = maximum concentration not subject to advection
 SEED = concentration of plankton never subject to advection
 OREF = outflow rate at which STAY has a value midway between
 SEED and MXSTAY (ft³/s or m³/s)

The amount of plankton not subject to advection is converted to units of mass (MSTAY) by multiplying STAY by the volume in the RCHRES at the start of the interval (VOLS). The concentration of plankton which is advected is:

$$PLNKAD = PLANK - STAY \quad (6)$$

ADVPLK calls subroutine ADVECT to perform longitudinal advection of the quantity PLNKAD. The updated value of PLNKAD is then added to the amount of plankton which did not undergo advection to determine the concentration of plankton in the RCHRES at the end of the interval:

$$PLANK = PLNKAD + MSTAY / VOL \quad (7)$$

where:

PLANK = concentration of plankton at end of interval
 PLNKAD = concentration of advected plankton which remain in RCHRES
 MSTAY = mass of plankton not advected
 VOL = volume in RCHRES at end of interval

If the concentration of plankton in the RCHRES at the start of the interval is less than the value assigned to SEED, advection of plankton is not performed in the RCHRES, and the value of PLANK at the end of the interval is calculated as:

$$PLANK = (MSTAY + IPLANK) / VOL \quad (8)$$

where:

IPLANK = mass of plankton which enters RCHRES during interval

4.2(3).7.3.2 Calculate Light-related Information Needed for Algal Simulation (subroutine LITRCH)

Purpose

Subroutine LITRCH determines the light correction factor to algal growth and the amount of light available to phytoplankton and benthic algae.

Method

The overall light extinction factor for the interval is obtained by adding EXTSED and EXTCLA to the base extinction coefficient (EXTB). The value of EXTB is assumed constant for a particular RCHRES and must be assigned in the User's Control Input. The resulting sum (EXTCO) is used to calculate the euphotic depth, which is the distance below the surface of the water body at which 1 percent of the light incident on the surface is still available:

$$EUDEP = 4.60517/EXTCO \quad (9)$$

where:

EUDEP = euphotic depth (ft)

EXTCO = total light extinction coefficient (/ft)

HSPF assumes that growth of algae occurs only in the euphotic zone (that is, the water above euphotic depth). When EUDEP has been calculated, it is possible to assign a value to CFLIT, the light correction factor to algal growth. A value of 1.0 is assigned to CFLIT if the calculated euphotic zone includes all the water of the RCHRES. $CFLIT = EUDEP/AVDEPE$, if the euphotic depth is less than the average depth of water (AVDEPE). CFLIT is used in subroutine ALGRO, to adjust the computed rate of algal growth.

Finally, the amount of light available to phytoplankton and benthic algae is calculated. The equation used to calculate the amount of light available to phytoplankton assumes that all phytoplankton are at mid-depth in the RCHRES or the middle of the euphotic zone, whichever is closer to the surface:

$$PHYLIT = INLIT * \text{Exp}(-EXTCO * (.5 * \text{Min}(EUDEP, AVDEPE))) \quad (10)$$

where:

PHYLIT = light available to phytoplankton (langleys/min)

INLIT = light available at water surface (langleys/min)

EXTCO = light extinction coefficient (/ft)

AVDEPE = average depth of water in the RCHRES (ft)

Exp = Fortran exponential function

Min = Fortran minimum function

The equation used to calculate the amount of light available to benthic algae assumes that all benthic algae are at AVDEPE below the surface of the RCHRES:

$$BALLIT = INLIT * \text{Exp}(-EXTCO * AVDEPE) \quad (11)$$

4.2(3).7.3.3 Simulate Phytoplankton (subroutine PHYRX)

Purpose

PHYRX simulates the algae which float in the water of a RCHRES. Because these organisms use energy from light to produce organic matter, they are called primary producers and are considered the first trophic level in the aquatic ecosystem. The biological activity of the ecosystem depends upon the rate of primary production by these photosynthetic organisms. The activities of the phytoplankton are in turn affected by the physical environment. Through the process of photosynthesis, phytoplankton consume carbon dioxide and release oxygen back into the water. At the same time, algal respiration consumes oxygen and releases carbon dioxide. Phytoplankton reduce the concentration of nutrients in the water by consuming phosphates, nitrate, and ammonia. Through assimilation these nutrients are transformed into organic materials which serve as a food source for higher trophic levels. A portion of the organic matter that is not used for food decomposes, which further affects the oxygen and nutrient levels in the water. Where the phytoplankton population has grown excessively, much of the available oxygen supply of the water may be depleted by decomposition of dead algae and respiration. In this situation, phytoplankton place a serious stress upon the system.

Approach

To describe quantitatively the dynamic behavior of phytoplankton populations, a number of assumptions must be made. PHYRX treats the entire phytoplankton population as if it were one species, and the mean behavior of the population is described through a series of generalized mathematical formulations. While such an approach obscures the behavior of individual species, the overall effect of the phytoplankton population on the water quality can be modeled with reasonable accuracy.

The HSPF system assumes that biomass of all types (phytoplankton, zooplankton, benthic algae, dead organic materials) has a consistent chemical composition. The user specifies the biomass composition by indicating the carbon:nitrogen:phosphorus ratio and the percent-by-weight carbon. This is done by assigning values to the following parameters:

1. CVBPC: number of moles of carbon per mole of phosphorus in biomass (default = 106)
2. CVBPN: number of moles of nitrogen per mole of phosphorus in biomass (default = 16)
3. BPCNTC: percentage of biomass weight which is carbon (default = 49)

The algorithms used in PHYRX and its subroutines require that the phytoplankton population be expressed in units of micromoles of phosphorus per liter. PHYRX converts the value for state variable PHYTO in milligrams biomass per liter into micromoles phosphorus per liter and assigns this value to the internal state variable STC (standing crop).

Subroutine Group PLANK

PHYRX uses five routines to simulate phytoplankton. ALGRO computes unit growth and respiration rates and determines the growth limiting factor for the phytoplankton. If the amount of growth exceeds the amount of respiration for the interval, GROCHK adjusts growth to account for nutrient limitations. PHYDTH calculates the amount of death occurring during the interval. State variables ORN, ORP, ORC, and BOD are updated by ORGBAL to account for materials resulting from phytoplankton death. Finally, NUTRUP adjusts the values for PO₄, NO₃, and TAM (total ammonia) to account for uptake of nutrients by phytoplankton. In addition to these updates, the dissolved oxygen state variable is adjusted in PHYRX to account for the net effect of phytoplankton photosynthesis and respiration:

$$DOX = DOX + (CVPB*CVBO*GROPHY) \quad (12)$$

where:

CVPB = conversion factor from micromoles phosphorus to mg biomass
CVBO = conversion factor from mg biomass to mg oxygen
GROPHY = net growth of phytoplankton (micromoles phosphorus/l per interval)

After all the operations in PHYRX and its subroutines have been performed, the value of STC is converted back into units of milligrams biomass per liter and becomes the updated value of PHYTO.

4.2(3).7.3.3.1 Calculate Unit Growth and Respiration Rates for Algae (subroutine ALGRO)

Purpose

ALGRO calculates the unit growth rate of algae based on light, temperature, and nutrients. Each time step, ALGRO determines the rate limiting factor for growth, and passes a label which identifies the limiting factor to the subroutines responsible for printed output. The labels and their meanings are as follows:

'LIT' Growth is light limited.
'NON' Insufficient nutrients are available to support growth.
'TEM' Water temperature does not allow algal growth.
'NIT' Growth is limited by availability of inorganic nitrogen.
'PO4' Growth is limited by availability of orthophosphorus.
'NONE' There is no limiting factor to cause less than maximal growth.
'WAT' Insufficient water is available to support growth.

ALGRO is also responsible for calculating the unit respiration rate for algae. This routine is used in the simulation of both phytoplankton and benthic algae.

Approach

ALGRO performs a series of initial checks to determine whether or not conditions are suitable for growth during the interval. If the light intensity for the interval is less than 0.001 langley/min, insufficient light is available for growth, and growth is not calculated. Likewise, if the concentration of either inorganic nitrogen or orthophosphorus is less than 0.001 mg/l, no growth occurs. If these checks indicate that conditions are suitable for growth, ALGRO next determines the effects of water temperature on the growth potential.

Temperature Control

The user specifies the temperature preferences of the algae by assigning values to three parameters: TALGRL, TALGRM, and TALGRH. If the water temperature is less than the value assigned to TALGRL or greater than the value assigned to TALGRH, no growth occurs. For water temperatures between TALGRL and TALGRH, a correction factor to maximum growth rate (MALGR) is calculated. This correction factor increases in value linearly from 0.0 at TALGRL to 1.0 at TALGRM. Thus, TALGRM specifies the minimum temperature at which growth can occur at a maximum rate. ALGRO assumes that there is no temperature retardation of maximum growth rate for temperatures between TALGRM and TALGRH. The temperature corrected maximum growth rate is:

$$\text{MALGRT} = \text{MALGR} * \text{TCMALG} \quad (13)$$

where:

MALGRT = temperature corrected maximum algal growth rate (/interval)

MALGR = maximum unit growth rate for algae

TCMALG = temperature correction to growth (TCMALG ranges between 0 and 1)

Once the temperature correction to potential growth rate has been made, ALGRO uses Monod growth kinetics with respect to orthophosphorus, inorganic nitrogen, and light intensity to determine the actual growth rate. The procedure taken in ALGRO is to consider each possible limiting factor separately to determine which one causes the smallest algal growth rate during each simulation interval. This method does not preclude that interactions between factors affect the actual growth rate; in cases where it has been established that there is such an interaction, as in the uptake of phosphate, the phenomena are included in the model. If none of the factors considered is limiting, growth will be maximal and temperature dependent.

Phosphorus Limited Growth

Algae are dependent upon uptake of orthophosphorus to provide the continual supply of phosphorus necessary for ordinary cellular metabolism and reproductive processes. In phosphorus-limited situations, the resultant growth rate has been shown to be dependent not only on the concentration of phosphate ions, but on nitrate concentration as well (DiToro, et al., 1970). The phosphorus limited growth rate is determined by:

$$\text{GROP} = \text{MALGRT} * \text{PO4} * \text{NO3} / ((\text{PO4} + \text{CMMP}) * (\text{NO3} + \text{CMMNP})) \quad (14)$$

where:

GROP = unit growth rate based on phosphorus limitation (/interval)
 MALGRT = temperature corrected maximum algal growth rate
 PO4 = orthophosphorus concentration (mg P/l)
 NO3 = nitrate concentration (mg N/l)
 CMMP = orthophosphorus Michaelis-Menten constant for phosphorus limited growth (mg P/l) (CMMP is defaulted to 0.015 mg P/l)
 CMMNP = nitrate Michaelis-Menten constant for phosphorus limited growth (mg N/l) (CMMNP is defaulted to 0.0284 mg N/l)

Nitrogen Limited Growth

Nitrogen is essential to algae for assimilation of proteins and enzymes. In the form of nitrate, nitrogen serves as the essential hydrogen acceptor in the metabolic pathways which enable organisms to grow. ALGRO allows for two different sources of inorganic nitrogen. If ammonia is being simulated and a value of one is assigned to the nitrogen source flag (NSFG), both ammonia and nitrate are used by algae to satisfy their nitrogen requirements. Otherwise, only nitrate is considered in the kinetics formulations. High ratios of ammonia to nitrate have been found to retard algal growth. If a value of one is assigned to the ammonia retardation flag (AMRFG), this phenomenon is simulated by the equation:

$$MALGN = MALGRT - 0.757 \cdot TAM + 0.051 \cdot NO3 \quad (15)$$

where:

MALGN = maximum unit growth rate corrected for ammonia retardation (/interval)
 MALGRT = temperature corrected maximum unit growth rate

Nitrogen limitation on growth is calculated by the equation:

$$GRON = MALGN \cdot MMN / (MMN + CMMN) \quad (16)$$

where:

GRON = unit growth rate based on nitrogen limitation (per interval)
 MALGN = maximum unit growth rate (MALGN has the same value as MALGRT if AMRFG is set to zero)
 MMN = total pool of inorganic nitrogen considered available for growth
 CMMN = Michaelis-Menten constant for nitrogen limited growth (mg N/l) (CMMN is defaulted to 0.045 mg N/l)

Light Limited Growth

The equation used to determine the limitation on growth rate imposed by light intensity was derived by Dugdale and Macisaac (1971) based on uptake rates of inorganic nitrogen under varying light intensities:

$$GROL = MALGRT \cdot LIGHT / (CMMLT + LIGHT) \quad (17)$$

where:

GROL = unit growth rate based on light limitation (/interval)
 MALGRT = temperature corrected maximum unit growth rate (/interval)
 LIGHT = light intensity available to algae in RCHRES (langleys/min)
 CMMLT = Michaelis-Menten constant for light limited growth (langleys/min)
 (CMMLT is defaulted to 0.033 langleys/min)

Algal Respiration

Algal respiration is dependent upon water temperature and is calculated by the equation:

$$RES = ALR20 * (TW/20.) \quad (18)$$

where:

RES = unit algal respiration rate (/interval)
 ALR20 = unit respiration rate at 20 degrees C
 TW = water temperature (deg C)

4.2(3).7.3.3.2 Check Nutrients Required for Computed Growth (subroutine GROCHK)

GROCHK assures that a minimum concentration of 0.001 mg/l of each nutrient remains in the RCHRES waters after growth occurs. If this condition is not satisfied, the computed growth rate is adjusted accordingly. Orthophosphorus and inorganic nitrogen are always considered as nutrients. If pH is simulated (PHFG = 1), the user may specify that carbon dioxide concentration also be considered as a limiting nutrient by setting the value of DECFG equal to zero.

4.2(3).7.3.3.3 Calculate Phytoplankton Death (subroutine PHYDTH)

Purpose

PHYDTH calculates algal death each interval by using one of two unit death rates specified in the User's Control Input. ALDL, the low unit death rate, is used when environmental conditions encourage sustained life. In situations where nutrients are scarce or the phytoplankton population becomes excessive, ALDH, the high algal death rate, is used.

Method

The high algal death rate, which has a default value of 0.01/hr, is used if any one of three conditions exists:

1. the concentration of PO₄ is less than the value of parameter PALDH
2. the concentration of inorganic nitrogen is less than the value of parameter NALDH
3. the concentration of phytoplankton is greater than the value of parameter CLALDH

Regardless of whether these tests indicate that ALDH or ALDL should be used, an additional increment to death occurs if anaerobic conditions prevail during the interval. The increment to death rate due to anaerobic conditions is determined by the value of parameter OXALD. The amount of phytoplankton death which occurs during the interval is calculated as:

$$DTHPHY = ALD * STC \quad (19)$$

where:

DTHPHY = amount of phytoplankton death (micromoles P/l per interval)
 ALD = unit algal death rate determined by environmental conditions
 (/interval)
 STC = concentration of phytoplankton (micromoles P/l)

4.2(3).7.3.3.4 Perform Materials Balance for Transformation from Living to Dead Organic Material (subroutine ORGBAL)

Purpose

ORGBAL increments the concentrations of dead organics to account for plankton death. Plankton death may either be algal death, zooplankton death, or phytoplankton ingested by zooplankton but not assimilated. In each case in which ORGBAL is called, the increments to ORP, ORN, ORC, and BOD are calculated in the subroutine which makes the call and passed on to ORGBAL. ORGBAL is merely a service program which performs the additions to these state variables.

4.2(3).7.3.3.5 Perform Materials Balance for Transformation from Inorganic to Organic Materials (subroutine NUTRUP)

Purpose

NUTRUP adjusts the concentrations of inorganic chemicals to account for net growth of algae. Net growth may be either positive or negative depending on the relative magnitude of growth and respiration. The state variables which are updated by NUTRUP include PO4, NO3, TAM, and CO2.

Method

The adjustments to PO4 and CO2 are straightforward. The PO4 state variable is always updated; the CO2 state variable is only updated if pH is simulated (PHFG = 1) and carbon dioxide is considered as a limiting nutrient (DECFG = 0). Adjustment of the inorganic nitrogen state variables is more complex. If ammonia is not specified as a source of inorganic nitrogen for growth (NSFG = 0), only the NO3 state variable is updated to account for net growth. If ammonia is considered a nutrient (NSFG = 1), negative net growth is accounted for by adding the total flux of nitrogen to the TAM state variable. If net growth is positive, a portion of the nitrogen flux is subtracted from both the NO3 and TAM state variables. The relative proportions of NO3 and TAM are governed by the value of parameter ALNPR, which is the fraction of nitrogen requirements for growth which are preferably satisfied by nitrate.

4.2(3).7.3.4 Simulate Zooplankton (subroutine ZORX)

Purpose

ZORX simulates the growth and death of zooplankton, and the resultant changes in the biochemical balance of the RCHRES. Zooplankton play an important role in determining the water quality of rivers and lakes. By feeding on the algal, bacterial, and detrital mass, they are a natural regulator in the aquatic environment. At the same time zooplankton are a source of food material for higher trophic levels such as fish. Through excretion, zooplankton provide nutrients for phytoplankton growth. HSPF is only concerned with those zooplankton which feed on phytoplankton, although in reality zooplankton may be herbivores, omnivores, or carnivores.

Schematic View of Fluxes and Storages

Figure 4.2(3).7.3-3 illustrates the fluxes and storage of zooplankton modeled in ZORX. In addition to zooplankton, the state variables for dissolved oxygen, biochemical oxygen demand, total ammonia, nitrate, orthophosphate, and refractory organics are also updated. Subroutine ZORX considers the following processes:

1. filtering and ingestion of phytoplankton by zooplankton
2. assimilation of ingested materials to form new zooplankton biomass
3. zooplankton respiration
4. inorganic and organic zooplankton excretion
5. zooplankton death

Filtering and Ingestion

The amount of phytoplankton ingested per milligram zooplankton is calculated by the equation:

$$\text{ZOEAT} = \text{ZFIL20} * (\text{TCZFIL} ** (\text{TW} - 20.)) * \text{PHYTO} \quad (20)$$

where:

ZOEAT = unit ingestion rate (mg phyto/mg zoo per interval)
 ZFIL20 = zooplankton filtering rate at 20 degrees C
 (liters filtered/mg zoo per interval)
 TCZFIL = temperature correction coefficient for filtering
 TW = water temperature (deg C)
 PHYTO = phytoplankton concentration (mg phyto/l)

The filtering rate is dependent upon water temperature and phytoplankton concentration. Rates for most biological activities double for every 10 degrees Centigrade increase in temperature. The filtering rate meets this criterion if the default value of 1.17 is used for the temperature correction coefficient TCZFIL.

When the phytoplankton biomass is below a critical concentration, the unit filtering rate will be maximal and constant. As the phytoplankton biomass increases above the critical concentration, the limiting rate is dependent on ingestive and digestive capabilities, and not on the concentration of the food source. Under these conditions, the filtering rate decreases proportionally such that the algal biomass ingested remains constant at the value of the parameter MZOEAT, which is defaulted to 0.055 mg phytoplankton/mg zooplankton per hour. The code simulates this by reducing ZOEAT to MZOEAT, if Equation 20 gives a value greater than MZOEAT. HSPF assumes that the filtering activities of zooplankton are 100 percent efficient; that is, the zooplankton ingest all of the food which is contained in the water which they filter. The total amount of phytoplankton ingested by the zooplankton is calculated as:

$$ZEAT = ZOEAT * ZOO \quad (21)$$

where:

ZEAT = ingested phytoplankton (mg biomass/l per interval)

ZOEAT = unit ingestion rate

ZOO = zooplankton concentration (mg biomass/l)

ZORX checks that the calculated amount of ingestion does not reduce the phytoplankton population to less than 0.0025 micromoles of phosphorus per liter; if it does, the ingestion rate is adjusted to maintain a phytoplankton concentration at this level.

Assimilation

Assimilation is the process by which ingested phytoplankton are converted to new zooplankton mass. The process of assimilation is never 100 percent efficient in biological systems. Unassimilated food is excreted as organic and inorganic waste products. Zooplankton assimilation efficiency is dependent upon quality and concentration of food. High quality food is assimilated at high efficiency, whereas low quality food is mostly excreted as waste resulting in low assimilation efficiency. The relationship between food concentration and assimilation efficiency is more complex. If the concentration of available food and the filtering rate of an organism are such that the organism ingests more food than can be readily used for growth and metabolism, the organism's assimilation efficiency decreases. The model represents the effect of food quality and concentration on assimilation as shown in Figure 4.2(3).7.3-6.

The quality of the zooplankton food is assigned in the User's Control Input by the parameter ZFOOD. Three qualities of food are allowed. From these, one type must be chosen to represent the overall food source available to the zooplankton:

1 = high quality food
ZFOOD = 2 = medium quality
3 = low quality

Depending on the value assigned to ZFOOD, the assimilation efficiency ZEFF is calculated by one of the following equations:

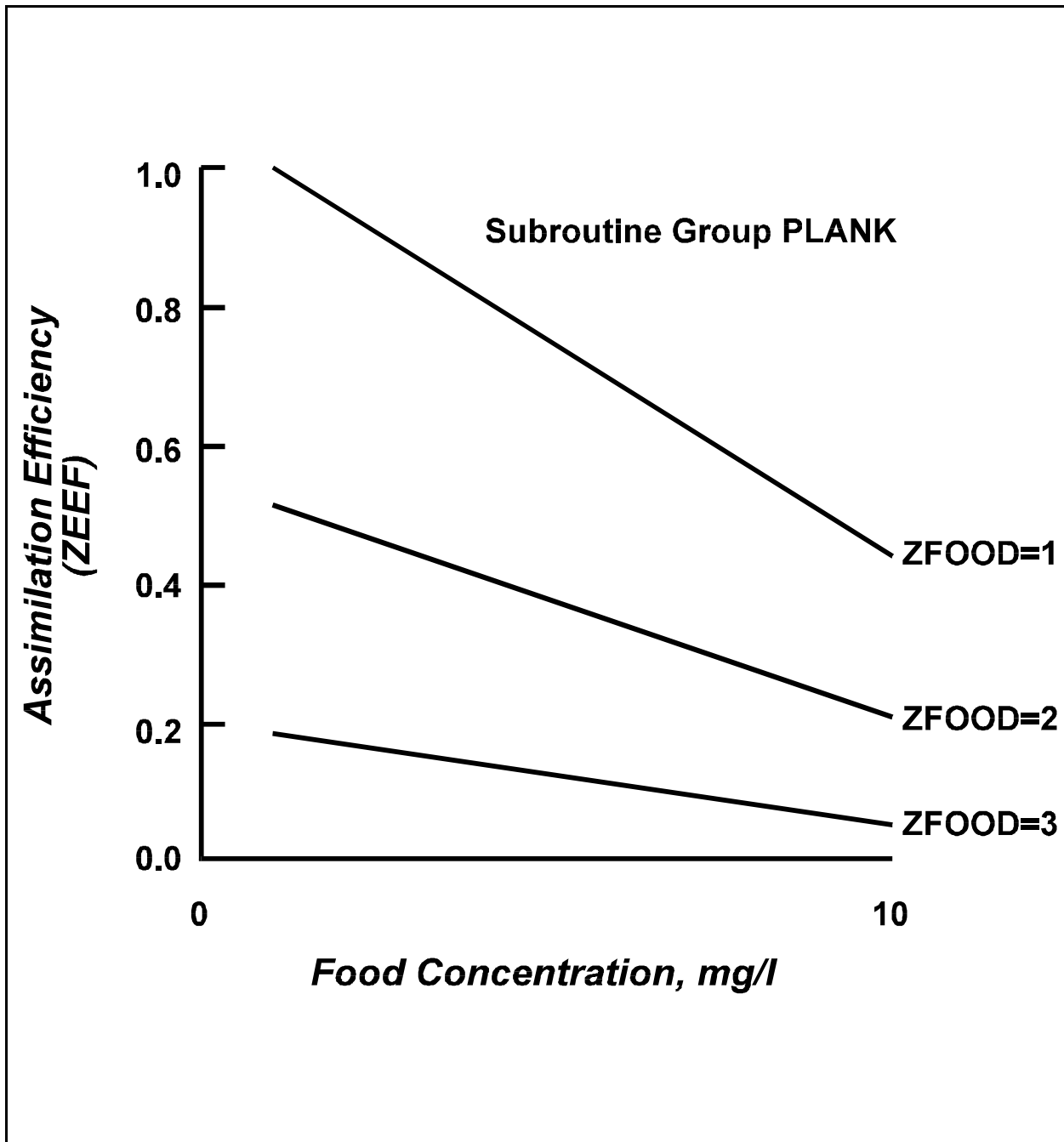


Figure 4.2(3).7.3-6 Zooplankton assimilation efficiency

```

IF ZFOOD = 1 THEN ZEFF = -0.06*PHYTO + 1.03
IF ZEFF > 0.99 THEN ZEFF = 0.99

```

(22)

```

IF ZFOOD = 2 THEN ZEFF = -0.03*PHYTO + 0.47
IF ZEFF < 0.20 THEN ZEFF = 0.20

```

```

IF ZFOOD = 3 THEN ZEFF = -0.013*PHYTO + 0.17
IF ZEFF < 0.03 THEN ZEFF = 0.03

```

These equations are extrapolations from research on *Daphnia* (Schindler, 1968). The corrections to ZEFF set reasonable upper or lower limits on efficiency for assimilating each type of food. The mass of ingested phytoplankton assimilated by zooplankton is calculated as:

```

ZOGR = ZEFF*ZEAT

```

(23)

where:

```

ZOGR = zooplankton growth (mg biomass/l per interval)
ZEFF = assimilation efficiency (dimensionless)
ZEAT = ingested phytoplankton (mg biomass/l per interval)

```

Respiration

Respiration is the biochemical process by which organic molecules are broken down, resulting in a release of energy which is essential for cellular and organismal activities. The oxidized molecules may either be carbohydrates and fats stored within the organism or food passing through the organism's digestive system. In either case, the end result of respiration is a decrease in zooplankton mass and a subsequent release of inorganic nutrients. The equation governing zooplankton respiration is:

```

ZRES = ZRES20*(TCZRES**(TW - 20.))*ZOO

```

(24)

where:

```

ZRES   = zooplankton biomass respired (mg zoo/l per interval)
ZRES20 = respiration rate at 20 degrees C (default= 0.0015/hr)
TCZRES = temperature correction factor for respiration (default = 1.07)
ZOO     = zooplankton (mg biomass/l)

```

Excretion Products

Excretion is the ingested food which is not assimilated by the zooplankton. These waste products contain both refractory and nonrefractory materials. The amount of refractory organic excretion is calculated as:

```

ZREFEX = REFR*ZEXMAS

```

(25)

where:

ZREFEX = refractory organic material excreted by zooplankton
(mg refractory biomass/l per interval)
ZEXMAS = total mass of zooplankton excretion
(ZEXMAS is the difference between ZEAT and ZOGR)
REFR = fraction of biomass which is refractory
(REFR is the complement of parameter NONREF)

The nonrefractory portion of the excretion is released to the water in the form of inorganic nutrients and undegraded BOD materials. The relative abundance of the materials is dependent upon the unit ingestion rate of the zooplankton (ZOEAT). At higher ingestion rates, a larger fraction of the nonrefractory excretion is not decomposed and is released as BOD materials. In the model, the parameter ZEXDEL is the fraction of nonrefractory excretion which is immediately decomposed and released to the water as inorganic nutrients when the unit ingestion rate of the zooplankton is maximal. If the unit ingestion rate is less than maximal, the model assumes that all the nonrefractory excretion is released to the water as inorganic nutrients. Thus, the amount of excretion released as inorganic materials is:

$$ZINGEX = ZEXDEC * (ZEXMAS - ZREFEX) \quad (26)$$

where:

ZINGEX = amount of biomass decomposed to inorganic excretion
(mg biomass/l per interval)
ZEXDEC = fraction of nonrefractory inorganic excretion
(ZEXDEC = 1 for ZOEAT ≤ MZOEAT and ZEXDEC = ZEXDEL for
ZOEAT > MZOEAT. Value of ZOEAT is that given by equation
20, i.e., prior to adjustment.)

The remaining portion of the excretion is considered to be BOD materials, and is calculated as:

$$ZNRFEX = ZEXMAS - ZREFEX - ZINGEX \quad (27)$$

where:

ZNRFEX = amount of biomass released as nonrefractory organic excretion
(mg biomass/l per interval)

Death

Zooplankton death is the termination of all ingestion, assimilation, respiration, and excretion activities. After death, zooplankton contribute both refractory and nonrefractory materials to the system. Under aerobic conditions, the mass rate of zooplankton death is determined by multiplying the natural zooplankton death rate, ZD, by the zooplankton concentration. If anaerobic conditions exist, an increase in zooplankton death rate is modeled by adding the value of the anaerobic death rate parameter, OXZD, to ZD. The default value of ZD is 0.0001/hr and that of OXZD is 0.03/hr.

Materials Balance for Related Constituents

Research has shown that 1.10 mg of oxygen are consumed for every gram of zooplankton mass which is respired (Richman, 1958). The DOX state variable is reduced accordingly in ZORX. If there is not sufficient oxygen available to satisfy respiration requirements, the deficit is added to the BOD state variable, and DOX is set equal to zero.

ZORX makes use of subroutine DECBAL to update the state variables TAM, NO3, and PO4 to account for additions from zooplankton respiration and inorganic excretion. The amount of inorganic constituents produced by these two processes is calculated by the following equations:

$$\begin{aligned} \text{ZNIT} &= (\text{ZINGEX} + \text{ZRES}) * \text{CVBN} \\ \text{ZPO4} &= (\text{ZINGEX} + \text{ZRES}) * \text{CVBP} \\ \text{ZCO2} &= (\text{ZINGEX} + \text{ZRES}) * \text{CVBC} \end{aligned} \quad (28)$$

where:

ZNIT = increment to TAM or NO3 state variable (mg N/l per interval)
 ZPO4 = increment to PO4 state variable (mg P/l per interval)
 ZCO2 = increment to CO2 state variable (mg C/l per interval)
 ZINGEX = biomass decomposed to inorganic excretion (mg biomass/l per interval)
 ZRES = biomass respired by zooplankton (mg biomass/l per interval)
 CVBN = conversion factor from biomass to equivalent nitrogen
 CVBP = conversion factor from biomass to equivalent phosphorus
 CVBC = conversion factor from biomass to equivalent carbon

If ammonia is simulated, the inorganic nitrogen released is added to the TAM variable; otherwise, it is added to the NO3 variable. The value of ZCO2 is computed for use in subroutine group PHCARB if pH simulation is performed. Finally, ZORX calls subroutine ORGBAL to update the state variables for ORN, ORP, ORC, and BOD to account for additions from zooplankton death and organic excretion. The amounts of organic constituents produced by these processes are calculated as:

$$\begin{aligned} \text{ZORN} &= ((\text{REFR} * \text{ZDTH}) + \text{ZREFEX}) * \text{CVBN} \\ \text{ZORP} &= ((\text{REFR} * \text{ZDTH}) + \text{ZREFEX}) * \text{CVBP} \\ \text{ZORC} &= ((\text{REFR} * \text{ZDTH}) + \text{ZREFEX}) * \text{CVBC} \\ \text{ZBOD} &= (\text{ZDTH} * \text{CVNRBO}) + (\text{ZNRFXEX} * \text{CVBO}) \end{aligned} \quad (29)$$

where:

ZORN = increment to ORN state variable (mg N/l per interval)
 ZORP = increment to ORP state variable (mg P/l per interval)
 ZORC = increment to ORC state variable (mg C/l per interval)
 ZBOD = increment to BOD state variable (mg O/l per interval)
 REFR = refractory fraction of biomass
 ZDTH = zooplankton death (mg biomass/l per interval)
 ZREFEX = refractory organic excretion (mg biomass/l per interval)
 ZNRFXEX = nonrefractory organic excretion (mg biomass/l per interval)
 CVBO = conversion from biomass to equivalent oxygen
 CVNRBO = conversion from nonrefractory biomass to equivalent oxygen,
 times NONREF

4.2(3).7.3.5 Simulate Benthic Algae (subroutine BALRX)

Purpose

BALRX simulates those algae in the RCHRES which are attached to rocks or other stable structures. In free flowing streams, large diurnal fluctuations of oxygen can be attributed to benthic algae. During the sunlight hours, if sufficient nutrients exist to support photosynthesis, oxygen is produced in such large quantities that supersaturation often occurs. However, at night, when photosynthesis cannot occur, the benthic algae can exert a significant demand on the oxygen supply of the RCHRES due to respiratory requirements. Benthic algae influence the nutrient balance of the RCHRES by their extraction of nutrients for growth.

Approach

The growth and death of benthic algae are modeled in much the same manner as their free floating relatives, the phytoplankton. In fact, four of the five subroutines that are used for phytoplankton simulation are also used in the benthic algae simulation. These routines are ALGRO, GROCHK, ORGBAL, and NUTRUP. There are two major differences in modeling the two types of algae. First, since the benthic algae are attached to materials in the RCHRES, they are not subject to longitudinal advection. Second, the manner in which death of benthic algae is modeled is sufficiently different from the method used for phytoplankton that a special routine, BALDTH, is used. Within BALRX benthic algae are in units of micromoles phosphorus per liter so that the benthic algae simulation can take advantage of the same subroutines used by PHYRX. In order to obtain these units, the following conversion is performed:

$$BAL = BENAL * DEPCOR / CVPB \quad (30)$$

where:

BAL = benthic algae (micromoles phosphorus/l)
 BENAL = benthic algae (mg biomass/m²)
 CVPB = conversion factor from micromoles phosphorus to mg biomass
 DEPCOR = conversion from square meters to liters based on average depth of water in RCHRES during the interval (DEPCOR is computed in RQUAL)

Net Growth

Unit growth and respiration rates for benthic algae are calculated by subroutine ALGRO. The user has the option of multiplying either of these rates by a constant factor if there is evidence that the benthic algae population does not exhibit the same growth and respiration rates as the phytoplankton population. Thus, net growth rate is calculated as:

$$GROBAL = (GRO * CFBALG - RES * CFBALR) * BAL \quad (31)$$

where:

GROBAL = net growth rate of benthic algae (micromoles P/l per interval)
 GRO = unit growth rate as calculated in subroutine ALGRO
 CFBALG = ratio of benthic algae to phytoplankton growth rates
 under identical growth conditions (default = 1.0)
 RES = unit respiration rate as calculated in subroutine ALGRO
 CFBALR = ratio of benthic algae to phytoplankton respiration rates
 (default = 1.0)
 BAL = benthic algae concentration (micromoles P/l)

After GROBAL has been calculated, subroutine GROCHK is called to assure that the calculated growth does not reduce any nutrient to a concentration less than 0.001 mg/l. If it does, GROBAL is adjusted to satisfy this requirement.

Death of Benthic Algae

Subroutine BALDTH calculates the amount of benthic algae death and passes this information back to BALRX (variable DTHBAL). BALRX updates the state variable BAL to account for net growth and death. The value of BAL is not allowed to fall below 0.0001 micromoles of phosphorus per square meter.

Materials Balance for Related Constituents

The DOX state variable is updated to account for the net effect of benthic algae photosynthesis and respiration according to the following equation:

$$\text{DOX} = \text{DOX} + (\text{CVPB} * \text{CVBO} * \text{GROBAL}) \quad (32)$$

where:

DOX = concentration of dissolved oxygen (mg/l)
 CVPB = conversion factor from micromoles phosphorus to mg biomass
 CVBO = conversion factor from mg biomass to mg oxygen
 GROBAL = net growth of benthic algae (micromoles phosphorus/l per interval)

The additions to ORN, ORP, ORC, and BOD resulting from benthic algae death are calculated as:

$$\begin{aligned} \text{BALORN} &= \text{REFR} * \text{DTHBAL} * \text{CVBPN} * .014 \\ \text{BALORP} &= \text{REFR} * \text{DTHBAL} * .031 \\ \text{BALORC} &= \text{REFR} * \text{DTHBAL} * \text{CVBPC} * .012 \\ \text{BALBOD} &= \text{CVNRBO} * \text{CVPB} * \text{DTHBAL} \end{aligned} \quad (33)$$

where:

BALORN = increment to ORN state variable (mg N/l per interval)
 BALORP = increment to ORP state variable (mg P/l per interval)
 BALORC = increment to ORC state variable (mg C/l per interval)
 BALBOD = increment to BOD state variable (mg O/l per interval)
 REFR = refractory fraction of biomass
 DTHBAL = benthic algae death (micromoles P/l per interval)
 CVNRBO = conversion from mg biomass to equivalent mg
 oxygen demand (allowing for refractory fraction)
 CVPB = conversion from micromoles phosphorus to mg biomass
 CVBPN = conversion from micromoles phosphorus to micromoles nitrogen
 CVBPC = conversion from micromoles phosphorus to micromoles carbon

When BALORN, BALORP, BALORC, and BALBOD have been evaluated, subroutine ORGBAL is called to perform the actual increments to the appropriate state variables. Finally, subroutine NUTRUP is called to update the inorganic state variables to account for net growth.

External Units

The output values for benthic algae are in units of milligrams biomass per square meter and micrograms chlorophyll a per square meter.

4.2(3).7.3.5.1 Calculate Benthic Algae Death (subroutine BALDTH)

Purpose

BALDTH calculates algal death each interval by using one of two unit death rates specified in the User's Control Input. ALDL, the low unit death rate, is used when environmental conditions encourage sustained life; in situations where nutrients are scarce or the benthic algae population becomes excessive, ALDH, the high algal death rate, is used.

Method

The high algal death rate, which has a default value of 0.01/hr, is used if any one of three conditions exists:

1. the concentration of PO₄ is less than the value of parameter PALDH
2. the concentration of inorganic nitrogen is less than the value of parameter NALDH
3. the areal density of benthic algae is greater than the value of parameter MBAL

Subroutine Group PLANK

Regardless of whether these tests indicate that ALDH or ALDL (default equals 0.001/hr) should be used, an additional increment to death occurs if anaerobic conditions are prevalent during the interval. The increment to death rate due to anaerobic conditions is determined by the value of parameter OXALD. When the benthic algae population grows to a size greater than that which may be supported on the bottom surface, algae begin to break away from the bottom, a phenomenon known as sloughing. Whenever the population calculated exceeds the maximum allowable bottom density (MBAL), the sloughing process removes the excess algae. The amount of benthic algae death which occurs during the interval is calculated as:

$$DTHBAL = (ALD * BAL) + SLOF \quad (34)$$

where:

DTHBAL = amount of benthic algae death (micromoles P/l per interval)
ALD = unit algal death rate determined by environmental conditions
(/interval)
BAL = concentration of benthic algae (micromoles P/l)
SLOF = amount of benthic algae sloughed (micromoles P/l per interval)

4.2(3).7.4 Simulate pH, Carbon Dioxide, Total Inorganic Carbon,
and Alkalinity (Subroutine Group PHCARB of Module RCHRES)

Purpose

PHCARB calculates the pH of the water within a RCHRES. The primary value of pH is as an indicator of the chemical environment of the system. Under normal circumstances, pH is near neutral, that is, near seven. Most life sustaining processes are impaired at extremes of pH.

Method

Figure 4.2(3).7.4-1 illustrates the fluxes and storages of constituents introduced in this section. Determination of pH requires simulation of alkalinity, carbon dioxide, and total inorganic carbon. Within PHCARB, state variables for alkalinity (ALK), carbon dioxide (CO₂), and total inorganic carbon (TIC) are expressed as molar concentrations to correspond to the equilibrium expressions necessary to determine pH. The conversion from mg/l to moles/l takes place after longitudinal advection has been considered. Externally, ALK, CO₂, and TIC are expressed in mg/l.

Alkalinity

Alkalinity is defined as the amount of acid required to attain a pH value equal to that of a total inorganic carbon molar solution of H₂CO₃. This pH value is near 4.5, which is approximately the lowest pH value tolerated by most forms of aquatic life. Alkalinity is interpreted as the acid neutralizing capacity of natural waters.

Alkalinity is simulated as a conservative constituent, in module section CONS. Parameter ALKCON, in the User's Control Input for PHCARB, specifies which conservative substance is alkalinity. For example, if ALKCON = 3 then subroutine PHCARB will assume that alkalinity is the 3rd conservative constituent.

Carbon Dioxide and Total Inorganic Carbon

HSPF assumes that changes in the TIC concentration occur only as changes in CO₂ concentration. Thus, the sources of TIC are:

1. carbon dioxide invasion (input) from the atmosphere
2. zooplankton respiration
3. carbon dioxide released by BOD decay
4. net growth of algae (if negative)
5. benthic release of carbon dioxide (if BENRFG = 1)

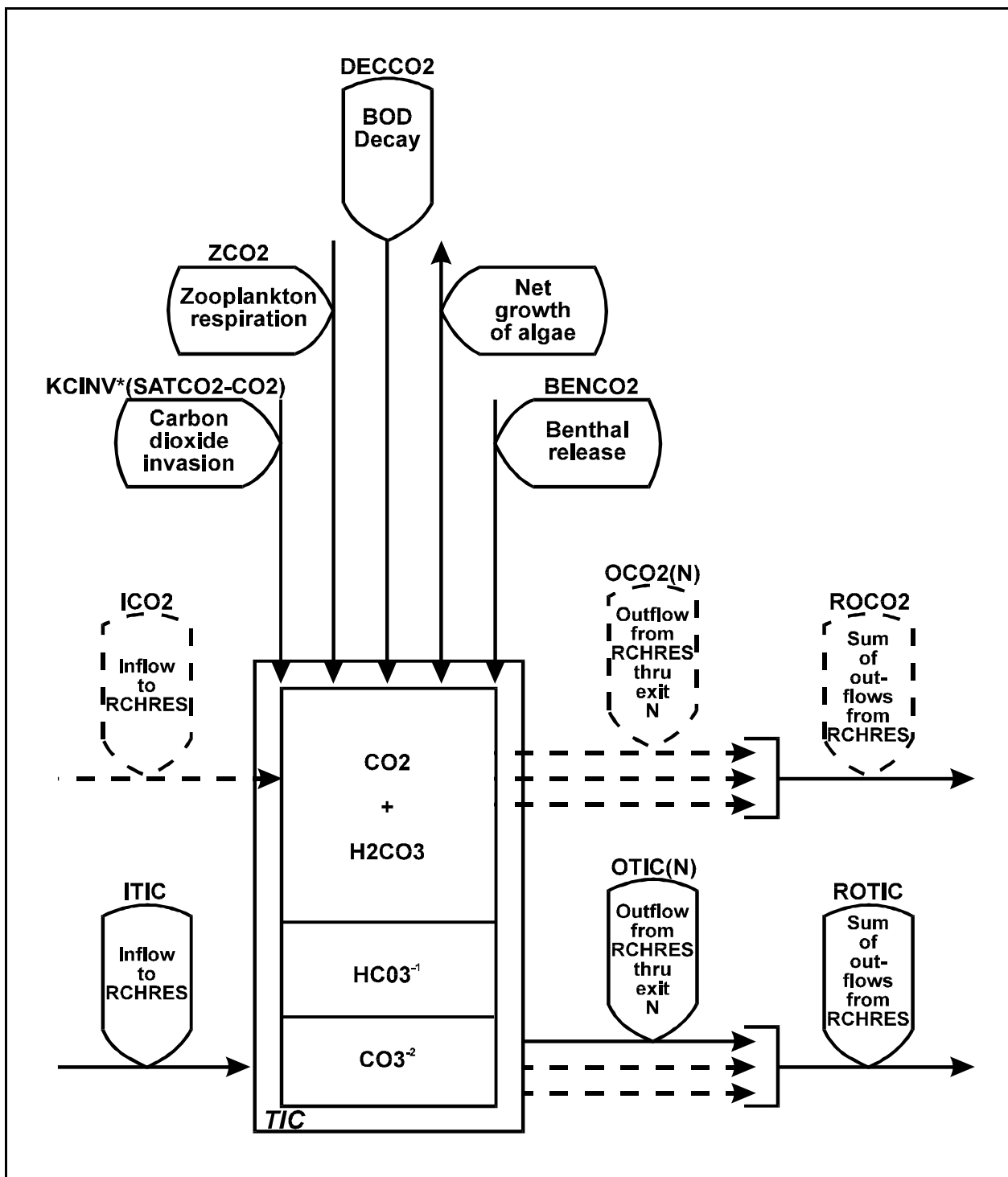


Figure 4.2(3).7.4-1 Flow diagram of inorganic carbon in the PHCARB group of the RCHRES Application Module

The sinks of TIC are:

1. carbon dioxide release to the atmosphere
2. net growth of algae (if positive)

All of these quantities except carbon dioxide invasion are calculated in other subroutines and passed into PHCARB.

Carbon Dioxide Invasion

In order to calculate carbon dioxide invasion, the saturation concentration of CO₂ must be determined. First, Henry's constant for CO₂, defined as the molar concentration of atmospheric CO₂ divided by the partial pressure of CO₂, is calculated by the equation:

$$S = 10.**(2385.73/TWKELV - 14.0184 + 0.0152642*TWKELV) \quad (1)$$

where:

S = Henry's constant for CO₂
 TWKELV = temperature of water (deg K)

Using Henry's constant, the saturation concentration of CO₂ is calculated as:

$$SATCO2 = 3.16E-04*CFPRES*S \quad (2)$$

where:

SATCO2 = saturation concentration of CO₂ (moles CO₂-C/l)
 CFPRES = correction to atmospheric pressure resulting from elevation difference (calculated in the Run Interpreter)
 S = Henry's constant for CO₂

The carbon dioxide invasion is then calculated by the following equation:

$$ATCO2 = KCINV*(SATCO2 - CO2) \quad (3)$$

where:

ATCO2 = carbon dioxide invasion expressed as moles CO₂-C/l per interval
 KCINV = carbon dioxide invasion coefficient (/interval)
 SATCO2 = saturation concentration of CO₂ (moles CO₂-C/l)
 CO2 = concentration of CO₂ after longitudinal advection (moles CO₂-C/l)

A positive value for ATCO2 indicates addition of CO₂ to the water; a negative value indicates a release of CO₂ from water to the atmosphere. The value of KCINV is dependent upon the value calculated for KOREA, the oxygen reaeration coefficient, in subroutine group OXRX:

$$KCINV = CFCINV * KOREA \quad (4)$$

where:

KCINV = carbon dioxide invasion coefficient (/interval)
 CFCINV = parameter specifying ratio of CO₂ invasion rate to O₂ reaeration rate
 KOREA = oxygen reaeration coefficient (/interval)

Net Carbon Dioxide Flux

The net carbon dioxide flux is determined by the following equation:

$$DELTC D = ATCO_2 + (ZCO_2 - ALGCO_2 + DECCO_2 + BENCO_2) / 12000. \quad (5)$$

where:

DELTC D = net CO₂ flux (moles CO₂-C/l per interval)
 ATCO₂ = CO₂ invasion (moles CO₂-C/l per interval)
 ZCO₂ = CO₂ released by zooplankton excretion and respiration (mg CO₂-C/l per interval)
 ALGCO₂ = CO₂ flux due to net growth of algae (mg CO₂-C/l per interval)
 DECCO₂ = CO₂ released by BOD decay (mg CO₂-C/l per interval)
 BENCO₂ = benthal release of CO₂ (mg CO₂-C/l per interval)
 12000. = conversion from mg CO₂-C/l to moles CO₂-C/l

If DECFG, the flag which decouples CO₂ from the algal simulation, has a value of one, ALGCO₂ has a value of zero in this equation. Benthal release rates for both aerobic and anaerobic conditions must be included in the User's Control Input if benthal release of CO₂ is simulated. Since HSPF assumes that changes in total inorganic carbon concentration only occur as changes in carbon dioxide, the update to the TIC state variable for each simulation interval is:

$$TIC = TIC + DELTC D \quad (6)$$

where:

TIC = total inorganic carbon (moles C/l)

The Carbonate System

The value of pH is controlled by the carbonate system. There are three species of importance to the system: [H₂CO₃*], [HCO₃], and [CO₃]. [H₂CO₃*] is defined as the sum of [H₂CO₃] and [CO₂]; for modeling purposes [H₂CO₃] is negligible relative to [CO₂]. The carbonate system can be described by the following equations:

$$\begin{aligned} [H] * [HCO_3] / [H_2CO_3^*] &= K1EQU \\ [H] * [CO_3] / [HCO_3] &= K2EQU \\ [H] * [OH] &= KWEQU \\ [H_2CO_3^*] + [HCO_3] + [CO_3] &= TIC \\ [HCO_3] + 2 * [CO_3] + [OH] - [H] &= ALK \end{aligned} \quad (7)$$

where:

[H] = hydrogen ion concentration (moles/l)
 [OH] = hydroxide ion concentration (moles/l)
 [CO3] = carbonate ion concentration (moles/l)
 [HCO3] = bicarbonate ion concentration (moles/l)
 [H2CO3*] = carbonic acid/carbon dioxide concentration (moles/l)
 K1EQU = first dissociation constant for carbonic acid
 K2EQU = second dissociation constant for carbonic acid
 KWEQU = ionization product of water

The five unknown values ([H2CO3*], [HCO3], [CO3], [H], [OH]) can be determined when K1EQU, K2EQU, KWEQU, TIC, and ALK are known. K1EQU, K2EQU, and KWEQU are all functions of water temperature and are evaluated by the following equations:

$$\begin{aligned} K1EQU &= 10.**(-3404.71/TWKELV + 14.8435 - 0.032786*TWKELV) \\ K2EQU &= 10.**(-2902.39/TWKELV + 6.4980 - 0.02379*TWKELV) \\ KWEQU &= 10.**(-4470.99/TWKELV + 6.0875 - 0.01706*TWKELV) \end{aligned} \quad (8)$$

where:

TWKELV = absolute temperature of water (deg K)

Calculation of pH and CO2

Once values have been determined for K1EQU, K2EQU, KWEQU, TIC, and ALK, an equilibrium equation can be developed for hydrogen ion concentration ([H]). The five equations representing the carbon system (Equation 7) can be reduced to a fourth order polynomial expression:

$$[H]**4 + COEFF1*([H]**3) + COEFF2*([H]**2) + COEFF3*[H] + COEFF4 = 0 \quad (9)$$

where:

COEFF1 = ALK + K1EQU
 COEFF2 = -KWEQU + ALK*K1EQU + K1EQU*K2EQU - TIC*K1EQU
 COEFF3 = -2.*K1EQU*K2EQU*TIC - K1EQU*KWEQU + ALK*K1EQU*K2EQU
 COEFF4 = -K1EQU*K2EQU*KWEQU
 [H] = hydrogen ion concentration (moles/l)

The solution of this equation is performed by subroutine PHCALC. Based on the hydrogen ion concentration calculated in PHCALC, the concentration of CO2 is recalculated as:

$$CO2 = TIC/(1. + K1EQU/HPLUS + K1EQU*K2EQU/(HPLUS**2)) \quad (10)$$

where:

CO2 = carbon dioxide concentration (moles C/l)
 TIC = total inorganic carbon concentration (moles C/l)

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K1EQU = first dissociation constant of carbonic acid
K2EQU = second dissociation constant of carbonic acid
HPLUS = hydrogen ion concentration (moles H/l)

Finally, the units of TIC, CO₂, and ALK are converted back to mg/l for use outside of PHCARB.

4.2(3).7.4.1 Calculate pH (subroutine PHCALC)

PHCALC uses the Newton-Raphson method to solve the fourth order polynomial expression for the hydrogen ion concentration (Equation 9). The user specifies the maximum number of iterations performed by assigning a value to parameter PHCNT. PHCALC continues the iteration process until the solutions for pH concentration of two consecutive iterations differ by no more than one tenth of a pH unit. If the solution technique does not converge within the maximum allowable number of iterations, PHCALC passes this information back to PHCARB by assigning a value of zero to CONVFG. An error message is printed and then PHCALC is called again, to repeat the unsuccessful iteration process. This time, the "debug flag" (PHDBG) is set ON so that, for each iteration, PHCALC will print information which will help the user track down the source of the problem.

4.2(11) Copy Time Series (Utility Module COPY)

This utility module is used to copy one or more time series from a source specified in the EXT SOURCES or NETWORK Block of the User's Control Input (UCI), to a target specified in the NETWORK or EXT TARGETS Block (Part F, Section 4.6).

To operate the COPY module, the user must specify the time interval used in the internal scratch pad (INDELT) and the number of point-valued and mean-valued time series to be copied (NPT and NMN in Part F, Section 4.4(11).1). Up to 20 point-valued and/or 20 mean-valued time series may be copied in a single operation.

Module TSGET transfers the time series from the source(s), which may be either external (e.g. WDM or DSS data set or sequential file) or the output(s) from one or more preceding operations, to the INPAD. DSS Data sets with time steps other than the internal scratch pad time interval (INDELT) will be automatically aggregated or disaggregated. Data from sequential files must be at the INDELT interval. It also automatically alters the "kind" of time series, if appropriate, and can multiply each value by a user-specified factor.

Module TSPUT then transfers the time series from the INPAD to the target which, again, can be either external or internal. The work performed is a mirror image of that done by TSGET; time series can be aggregated/disaggregated and/or transformed in the same way.

Module COPY is typically used to transfer time series, such as precipitation and potential evapotranspiration data, from a sequential file (e.g., ASCII data) to a data set in the WDM file or DSS. Thereafter, when these data are used as inputs to simulation operations, they are read directly from the WDM or DSS.

COPY can also be used to change the "kind" and/or interval of one or more time series. For example, a WDM data set containing hourly precipitation data could be input to COPY and the output stored in another WDM data set with a daily time step. The data would automatically be aggregated.

4.2(12) Prepare Time Series for Display on a Plotter (Utility Module PLTGEN)

This utility module prepares one or more time series for simultaneous display on a plotter. As with the COPY module (Section 4.2(11)), the user must specify the input(s) (sources), using entries in the EXT SOURCES or NETWORK Blocks in his control input (UCI). The internal time-step and the number of point- and/or mean-valued time series to be displayed must also be specified.

TSGET transfers the time series from the source(s) to the INPAD (as in COPY). PLTGEN then outputs these data to a plot file (PLOTFL). This is a sequential file; the first 25 records contain general information, such as the plot heading, number of curves to be plotted, scaling information, etc. Each subsequent record contains:

<u>Cols</u>	<u>Contents</u>
1 - 4	Identifier (first 4 characters of title)
6 - 10	Year
11 - 13	Month
14 - 16	Day
17 - 19	Hour
20 - 22	Minute
25 - 36	Value for curve 1, for this date/time
39 - 50	Value for curve 2, for this date/time
etc	(repeats until data for all curves are supplied)

Format: A4,1X,I5,4I3,10(2X,G12.5)

The time resolution of the PLOTFL is the INDELT of the run, an integer multiple of the INDELT which is also evenly divisible into one day, one month, or one year.

A PLOTFL may contain only records greater than a certain threshold value, THRESH, or during a certain span of time specified in the Special Actions Block.

The contents of a sample PLOTFL are listed in Figure 4.2(12)-1. To keep the listing short, only the first four values have been included

A plot file is intended to be read by a stand-alone plot program, which translates its contents into information used to drive a plotting device. Alternative uses of a PLOTFL are:

1. To display one or more time series in printed form. For example: To examine the contents of a data set in the WDM file, input it to PLTGEN and list the contents of the PLOTFL on a line printer or terminal.
2. To transfer time series to some other stand-alone program, such as a spreadsheet or graphical display program. For example, one could specify the contents of a PLOTFL as input to a program which performs statistical analysis or computes cross correlations between time series.

```

Plot HSPF FILE FOR DRIVING SEPARATE PLOT PROGRAM
Plot Time interval: 30 mins          Last month in printout year: 9
Plot No. of curves plotted: Point-valued: 2   Mean-valued: 0   Total: 2
Plot Label flag: 0          PIVL: 1          IDELT: 30
Plot Plot title: Plot of reservoir flowrates
Plot Y-axis label: Flow (ft3/sec)
Plot Scale info: Ymin: .00000E+00
Plot Ymax: 1000.0
Plot Time: 48.000 intervals/inch
Plot Data for each curve (Point-valued first, then mean-valued):
Plot Label          LINTYP      INTEQ      COLCOD      TRAN      TRANCOD
Plot Inflow          0          0          1          SUM          1
Plot Outflow          0          0          1          SUM          1
Plot
Plot
Plot
Plot
Plot
Plot
Plot
Plot
Plot
Plot Time series (pt-valued, then mean-valued):
Plot
Plot Date/time          Values
Plot
Plot 1974  5 31 24  0      .00000E+00      1.0000
Plot 1974  6  1  0 30      .82838          1.0000
Plot 1974  6  1  1  0      1.5071          1.0000
Plot 1974  6  1  1 30      2.0631          1.0000

```

Figure 4.2(12)-1 Sample PLOTFL (showing four time points)

4.2(13) Display Time Series in a Convenient Tabular Format (Utility Module DISPLY)

The purpose of this module is to permit any time series to be displayed (at a variety of time intervals) in a tabular format. Sample outputs are shown in Figures 4.2(13)-1 through -3. Salient features of this module are:

1. Any time series (input or computed) can be displayed. The user specifies the time series in the EXT SOURCES or NETWORK Block, as with any other module.
2. As with any other module, the data are first placed in the INPAD, by module TSGET. At this point they are at the time interval specified for this operation in the OPN SEQUENCE Block (INDELT). This might have involved aggregation or disaggregation if the data were brought in from the WDM file. In general, INDELT can be any of the 19 HSPF supported time steps, ranging from 1 minute to 1 day.
3. The user can elect to display the data in a "long-span table" or a "short-span table". The term "span" refers to the period covered by each table. A short-span table (Figures 4.2(13)-1 and -2) covers a day or a month at a time and a long-span table (Figure 4.2(13)-3) covers a year.
4. The user selects the time-step for the individual items in a short-span display (the display interval) by specifying it as a multiple (PIVL) of INDELT. For example, the data in Figure 4.2(13)-1 are displayed at an interval of 5 minutes. This could have been achieved with the following scenarios:

INDELT	PIVL
5 min	1
1 min	5

If the display interval is less than one hour, one hours worth of data are displayed on one printed "row" (Figure 4.2(13)-1). The number of items in a row depends on their interval (e.g., 60 for one minute, 12 for 5 minutes, 2 for 30 mins.). A "row" may actually occupy up to 5 physical lines of printout because a maximum of 12 items is placed on a line. The entire table spans one day.

If the display interval is greater than or equal to one hour, a day's worth of data are displayed on one "row" (Figure 4.2(13)-2). Again, the number of items in a row depends on the display interval. In this case the entire table spans a month.

5. A long-span table always covers one year; the display interval for the individual items in the table is one day (Figure 4.2(13)-3). The user can select the month which terminates the display (December in the example) so that the data can be presented on a calendar year, water year or some other basis.
6. For the purpose of aggregating the data from the interval time step (INDELT) to the display interval, day-value, month-value, or year-value, one of five "transformation codes" can be specified:

Code	Meaning
SUM	Sum of the data
AVER	Average of the data
MAX	Take the max of the values at the smaller time step
MIN	Take the minimum
LAST	Take the last of the values belonging to the shorter time step

SUM is appropriate for displaying data like precipitation; AVER is useful for displaying data such as temperatures.

7. The module incorporates a feature designed to permit reduction of the quantity of printout produced when doing short-span displays. If the "row-value" ("hour-sum" in Figure 4.2(13)-1; "day-average" in Figure 4.3(13)-2) is less than or equal to a threshold value, printout of the entire row is suppressed. The default threshold is 0.0. Thus, in Figure 4.2(13)-1; data for dry hours are not printed.
8. The user can also specify the following:
 - a. The number of decimal digits to use in a display.
 - b. A title for the display.
 - c. A linear transformation, to be performed on the data when they are at the INDELT time interval (i.e. before module DISPLY performs any aggregation). By default, no transformation is performed.

WDM 39 Precip. (in/100)
Summary for DAY 1976/10/4
Date interval: 5 mins

HOUR	SUM	Interval Number											
		1	2	3	4	5	6	7	8	9	10	11	12
3:	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0
4:	3.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	1.0	0.0	0.0
5:	5.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	2.0	2.0
6:	6.0	1.0	1.0	2.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7:	3.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0
8:	3.0	0.0	0.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0
9:	3.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	1.0	0.0
10:	3.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	1.0
11:	3.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	1.0	0.0
12:	4.0	1.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0
13:	3.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0
14:	2.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
15:	4.0	0.0	0.0	1.0	0.0	1.0	0.0	0.0	1.0	0.0	0.0	1.0	0.0
16:	7.0	0.0	0.0	1.0	0.0	1.0	1.0	1.0	1.0	1.0	0.0	1.0	0.0
17:	3.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0
18:	6.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0	1.0	0.0	1.0	1.0
19:	5.0	1.0	1.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0

WDM 121 Temperature (Deg. F)
 Summary for MONTH 1976/8/
 Data interval: 120 mins

DAY	AVER	Interval Number											
		1	2	3	4	5	6	7	8	9	10	11	12
1	67.7	58.0	61.3	55.1	61.3	69.0	75.6	79.8	81.8	77.4	71.4	65.9	61.2
2	67.2	57.5	55.2	54.2	60.8	69.1	76.1	80.7	82.8	77.6	70.4	64.0	58.4
3	66.7	54.1	51.5	50.2	57.8	67.2	75.1	80.4	82.8	78.6	72.8	67.5	62.8
4	72.8	59.3	57.2	56.2	63.5	72.7	80.3	85.4	87.8	84.4	79.6	75.4	71.6
5	73.0	68.8	67.0	66.1	69.8	74.3	78.2	80.7	81.9	78.6	74.1	69.9	66.3
6	68.3	63.6	61.9	61.1	65.4	70.8	75.4	78.4	79.9	74.9	68.2	62.2	56.9
7	65.2	52.8	50.4	49.2	57.0	66.7	74.8	80.3	82.8	77.4	70.1	63.5	57.7
8	66.0	53.2	50.5	49.2	57.2	67.1	75.6	81.1	83.8	78.6	71.4	65.0	59.4
9	71.4	55.1	52.5	51.2	59.9	70.8	79.9	85.9	88.8	85.2	80.2	75.8	71.9
10	76.5	68.9	67.1	66.1	71.2	77.4	82.7	86.2	87.9	84.4	79.6	75.4	71.6
11	75.9	68.8	67.0	66.1	70.9	76.9	81.9	85.3	86.9	83.4	78.6	74.4	70.6
12	75.5	67.8	66.0	65.1	70.4	76.9	82.4	86.2	87.9	83.7	78.1	73.1	68.6
13	70.7	65.2	63.2	62.2	66.2	71.3	75.7	78.6	79.9	77.0	73.2	69.7	66.6
14	68.6	64.2	62.8	62.1	66.0	70.8	74.9	77.6	78.9	74.6	68.8	63.5	58.8
15	63.4	55.3	53.2	52.2	57.9	64.9	71.0	74.9	76.9	72.2	65.9	60.3	55.4
16	63.3	51.6	49.3	48.2	54.8	63.0	70.1	74.7	76.8	73.7	69.4	65.5	62.1
17	71.5	59.5	57.9	57.1	63.8	72.1	79.1	83.7	85.8	82.	76.9	72.2	68.2
18	73.0	65.0	63.1	62.1	67.4	73.9	79.4	83.2	84.9	81.2	76.2	71.8	67.9
19	72.8	64.9	63.1	62.1	67.6	74.5	80.2	84.1	85.9	81.4	75.4	69.9	65.1
20	72.6	61.5	59.2	58.2	65.1	73.6	80.8	85.6	87.8	83.4	77.4	71.9	67.1
21	75.9	63.5	61.2	60.2	67.5	76.7	84.3	89.4	91.8	87.4	81.4	75.9	71.1
22	76.2	67.5	65.2	64.2	69.9	76.9	83.0	86.9	88.9	85.1	79.9	75.2	71.2
23	74.9	68.0	66.1	65.1	70.2	76.4	81.7	85.2	86.9	82.7	77.1	72.1	67.6
24	73.0	64.2	62.2	61.2	66.6	73.5	79.2	83.1	84.9	81.6	77.1	72.9	69.3
25	75.6	66.6	64.9	64.1	69.9	76.9	83.0	86.9	88.9	84.6	78.8	73.5	68.9
26	78.5	65.3	63.2	62.2	69.5	78.7	86.3	91.4	93.8	90.1	84.9	80.2	76.2
27	73.4	73.0	71.1	70.1	72.8	76.2	79.1	81.1	81.9	77.4	71.4	65.9	61.2

WDM 121 Temperature (Deg. F)
Annual data display: Summary for period ending 1976/12

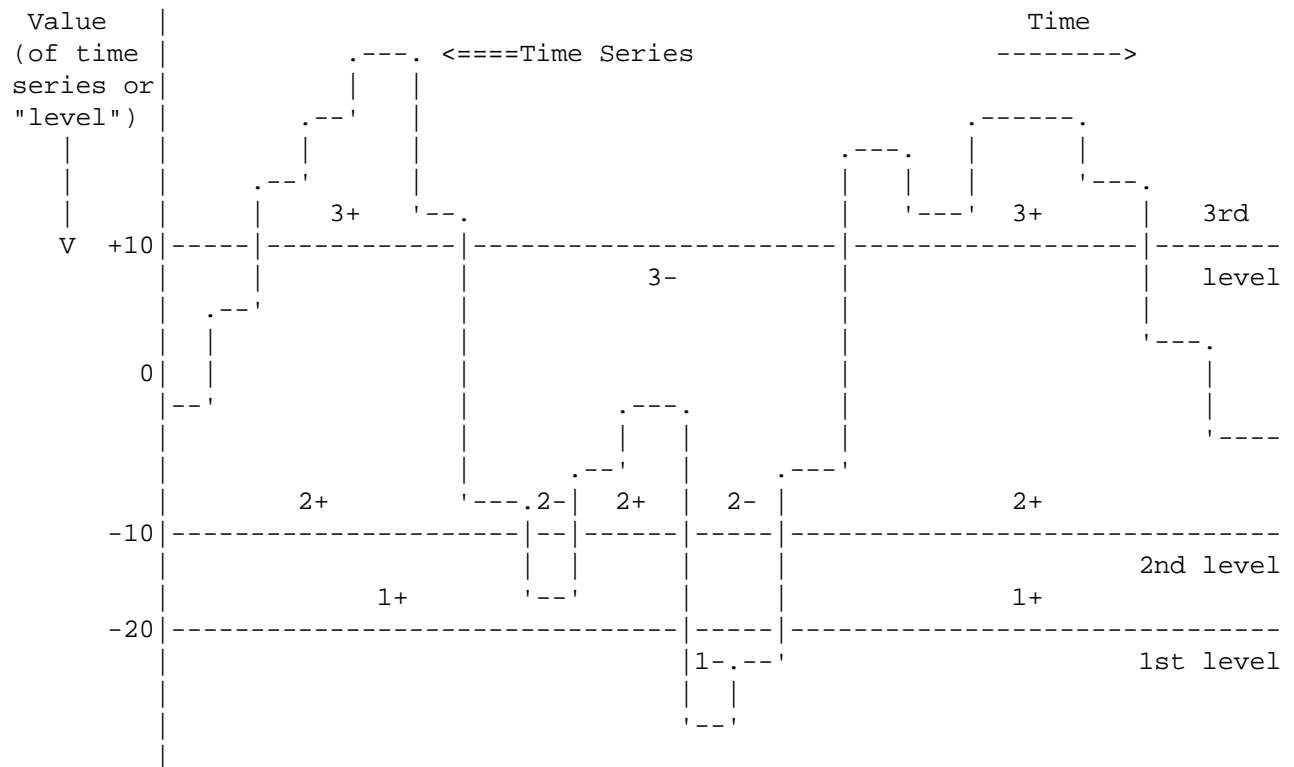
DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	27.6	9.4	33.1	49.2	49.4	67.5	67.0	67.7	68.3	68.2	45.7	11.8
2	18.4	17.7	33.3	48.5	45.3	66.3	67.3	67.2	68.9	66.8	42.7	9.1
3	7.0	21.9	29.8	49.3	49.7	65.1	70.5	66.7	72.7	65.9	35.3	13.4
4	13.8	12.6	28.6	48.9	59.7	68.7	73.0	72.8	67.8	58.5	33.0	16.5
5	20.3	15.9	25.0	52.0	57.3	71.0	72.7	73.0	66.1	46.5	36.7	18.0
6	18.0	24.8	25.7	50.8	49.0	71.4	72.8	68.2	71.8	42.4	32.9	4.2
7	0.5	32.5	31.1	47.8	50.6	73.1	76.1	65.2	71.8	43.4	29.1	2.5
8	5.5	36.7	32.7	46.1	55.2	74.0	77.4	66.0	65.4	45.5	34.1	17.7
9	9.9	39.0	35.1	53.6	64.2	72.6	82.0	71.4	63.2	51.5	35.5	23.1
10	16.6	36.5	38.8	54.1	60.9	75.2	84.9	76.5	62.3	56.0	25.2	9.3
11	30.4	44.2	36.4	43.6	58.8	77.2	81.9	75.9	66.3	62.6	20.3	11.3
12	26.7	46.0	32.2	48.7	57.0	78.8	77.7	75.5	68.6	59.9	20.7	11.7
13	27.5	37.1	34.0	54.8	58.5	72.2	80.9	70.7	69.0	59.5	23.9	20.4
14	30.1	41.2	33.2	64.7	63.0	72.2	81.3	68.6	68.0	57.2	27.5	29.7
15	28.5	44.0	27.5	67.6	60.1	69.6	73.8	63.4	59.1	43.5	32.8	28.4
16	13.5	34.6	30.7	71.1	58.2	68.2	68.1	63.3	60.4	39.4	36.7	35.2
17	11.6	33.6	44.1	65.7	56.2	69.8	69.9	71.5	66.9	34.8	46.0	38.9
18	21.5	39.6	55.7	59.2	58.3	65.5	72.7	73.0	62.2	32.9	40.8	36.5
19	20.7	39.6	55.8	48.4	68.3	65.8	78.9	72.8	62.5	40.1	35.5	27.7
20	18.8	34.2	48.1	48.0	71.5	66.7	76.0	72.6	58.9	37.4	29.7	9.7
21	25.5	27.7	35.7	54.9	65.3	67.1	71.8	75.9	61.9	37.8	27.6	17.1
22	25.7	29.0	43.8	50.8	58.8	69.6	78.9	76.2	58.2	35.5	23.1	17.1
23	28.6	36.3	55.2	50.6	59.2	66.5	79.8	74.9	54.4	38.8	28.8	22.3
24	27.2	40.8	55.8	47.0	58.1	71.1	74.3	73.0	51.0	42.1	41.0	23.8
25	22.6	47.5	49.3	43.4	60.1	72.5	71.9	75.6	54.3	36.9	41.7	25.1
26	10.1	44.8	45.5	43.8	62.0	73.9	75.4	78.5	56.1	37.1	28.7	30.5
27	18.1	41.2	47.3	46.3	65.9	74.1	73.8	73.4	53.7	37.3	10.3	22.3
28	22.2	39.2	45.3	48.5	62.5	72.2	73.9	65.8	57.6	40.2	6.3	3.8

4.2(14) Perform Duration Analysis on a Time Series (Utility Module DURANL)

This module examines the behavior of a time series, computing a variety of statistics relating to its excursions above and below certain specified levels (Figure 4.2(14)-1). Sample printout is shown in Figure 4.2(14)-2. The quantity of printout produced can be regulated by the user with a print-level-flag (PRFG), which has a valid range of values from 1 through 6.

The basic principles are:

1. The module works on the time series after it has been placed in the INPAD. The data are, thus, at the internal time step of the operation (INDELT). This module operates on a mean-valued input time series. Therefore, if a point-valued time series is routed to it, TSGET will, by default, generate mean values for each time step, and these will be analyzed.
2. When the value of the time series rises above the user-specified level, a positive excursion commences. When it next falls below the level, this excursion ends. A negative excursion is defined in the reverse way. (Figure 4.2(14)-1).
3. If the time series has a value less than -10.0×10 this is considered to be an undefined event (e.g., the concentration of a constituent when there is no water). In this case the value is in a special category - it is in neither a positive nor a negative excursion.
4. The above is true if the specified duration is one time step. In this case, the results produced include a conventional frequency analysis (e.g., flow duration) of the data. However, the user may specify up to 10 durations; each is given as a multiple (N) of the basic time step (INDELT). Then, for an excursion or undefined event to be considered, it has to endure for at least N consecutive intervals; else it is ignored.
5. The user may specify an analysis season. This is a period (the same in each year) for which the data will be analyzed (e.g., Oct 1 through May 10). Data falling outside the analysis season will not be considered.



Legend: 2+ excursion above second level (duration ≥ 1)
 2- excursion below second level (duration ≥ 1)
 etc.

Figure 4.2(14)-1 Definition of terms used in duration analysis module

The analyses performed, and printout produced (Figure 4.2(14)-2), are:

1. Introductory information - Title, start and end date/time, analysis season.
2. The next seven sets of tables are all similar in format; each contains data on positive and negative excursions, for each level and duration, and information on undefined event conditions which persisted for each of the specified durations. The value of PRFG required to generate each of these, and the table heading and the data displayed in it are:
 - a) PRFG > 0. "Fraction of time spent in excursions at each level with duration greater than or equal the specified durations. The fraction is relative to the total time span." These are the fractions of total considered time that each of the above-defined conditions existed.
 - b) PRFG > 1. "Fraction of time spent in excursions at each level with duration greater than or equal the specified durations. The fraction is relative to the time spent in excursions at each level." In the "Positive Excursions" table, this gives, for each specified level, the total time that an excursion of duration N existed, divided by the total time that an excursion of duration 1 existed. A similar definition holds for the numbers in the "Negative Excursions" table.
 - c) PRFG > 2. "Time spent in excursions at each level with duration greater than or equal the specified durations." The tables give the total number of time steps for which the various conditions occurred.
 - d) PRFG > 3. "Number of excursions at each level with duration greater than or equal the specified durations". These give the total number of events that were found (number of positive and negative excursions for each level and duration, and number of "undefined occurrences" of each duration).
 - e) PRFG > 4. "Average duration of excursions at each level given that the duration is greater than or equal the specified durations". These values answer the question: "given that a specified excursion or undefined condition occurred, what was the mean number of time steps that it persisted?"
 - f) PRFG > 5. "Standard deviation of duration of excursions at each level given that the duration is greater than or equal the specified durations." These tables are similar to those discussed in (e) above, except that the standard deviation, instead of the mean, is considered.
 - g) PRFG > 6. "Fraction of excursions with duration N with respect to the total number of excursions (duration 1) for each level". These tables give the number of excursions at each duration divided by the number of excursions at duration 1 for each level.
3. Summary information: Total number of time intervals analyzed, total number of time intervals for which values were "undefined", total number of days analyzed, sample size, max, min, mean, standard deviation.

Duration analysis operation no. 1
 Analysis of Subb. 4 Outflow (cfs)
 Start date: 1972/12/31 24: 0 End date: 1974/12/31 24: 0
 Analysis season starts: 2/28 24: 0 Ends: 11/30 24: 0

PERCENT OF TIME TABLES (WITH RESPECT TO THE TOTAL SPAN OF TIME)

POSITIVE EXCURSIONS

		DURATIONS		
		1	12	24
LEVELS				
.0000E+00	1.000	1.000	1.000	1.000
10.00	.7308	.7259	.7235	
20.00	.5128	.5062	.5034	
50.00	.1790	.1674	.1633	
500.0	.2273E-02	.0000E+00	.0000E+00	

NEGATIVE EXCURSIONS

		DURATIONS		
		1	12	24
LEVELS				
.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
10.00	.2692	.2655	.2645	
20.00	.4872	.4813	.4762	
50.00	.8210	.8121	.8030	
500.0	.9977	.9977	.9977	

UNDEFINED EVENTS (NO WATER)

	DURATIONS		
	1	12	24
	.0000E+00	.0000E+00	.0000E+00

Figure 4.2(14)-2 Sample Duration Analysis Printout
 [Continued on next 2 pages]

PERCENT OF TIME TABLES (WITH RESPECT TO THE TIME SPENT IN EXCURSIONS)

POSITIVE EXCURSIONS

		DURATIONS		
		1	12	24
LEVELS				
.0000E+00	1.000	1.000	1.000	1.000
10.00	1.000	.9933	.9899	
20.00	1.000	.9871	.9817	
50.00	1.000	.9353	.9124	
500.0	1.000	.0000E+00	.0000E+00	

NEGATIVE EXCURSIONS

		DURATIONS		
		1	12	24
LEVELS				
.0000E+00	.0000E+00	.0000E+00	.0000E+00	
10.00	1.000	.9862	.9828	
20.00	1.000	.9879	.9775	
50.00	1.000	.9892	.9780	
500.0	1.000	1.000	1.000	

UNDEFINED EVENTS (NO WATER)

		DURATIONS		
		1	12	24
		.0000E+00	.0000E+00	.0000E+00

TIME SPENT IN EXCURSIONS

POSITIVE EXCURSIONS

		DURATIONS		
		1	12	24
LEVELS				
.0000E+00	.1320E+05	.1320E+05	.1320E+05	
10.00	9647.	9582.	9550.	
20.00	6769.	6682.	6645.	
50.00	2363.	2210.	2156.	
500.0	30.00	.0000E+00	.0000E+00	

NEGATIVE EXCURSIONS

		DURATIONS		
		1	12	24
LEVELS				
.0000E+00	.0000E+00	.0000E+00	.0000E+00	
10.00	3553.	3504.	3492.	
20.00	6431.	6353.	6286.	
50.00	.1084E+05	.1072E+05	.1060E+05	
500.0	.1317E+05	.1317E+05	.1317E+05	

UNDEFINED EVENTS (NO WATER)

		DURATIONS		
		1	12	24
		.0000E+00	.0000E+00	.0000E+00

STANDARD DEVIATION OF TIME SPENT IN EXCURSIONS

POSITIVE EXCURSIONS

LEVELS	DURATIONS			
	1	12	24	
.0000E+00	.0000E+00	.0000E+00	.0000E+00	
10.00	922.9	2032.	2181.	
20.00	321.6	581.1	602.0	
50.00	71.65	132.1	128.7	
500.0	.7423	.0000E+00	.0000E+00	

NEGATIVE EXCURSIONS

LEVELS	DURATIONS			
	1	12	24	
.0000E+00	.0000E+00	.0000E+00	.0000E+00	
10.00	107.2	113.8	113.3	
20.00	127.0	140.0	141.4	
50.00	167.6	188.1	191.6	
500.0	1202.	1202.	1202.	

UNDEFINED EVENTS (NO WATER)

DURATIONS			
1	12	24	
.0000E+00	.0000E+00	.0000E+00	

SUMMARY

TOTAL LENGTH OF DEFINED EVENTS: 13200. INTERVALS
 TOTAL LENGTH OF UNDEFINED EVENTS: 0. INTERVALS
 TOTAL LENGTH OF ANALYSIS: 550. DAYS
 SAMPLE SIZE: 13200
 SAMPLE MAXIMUM: .1307E+05
 SAMPLE MINIMUM: 2.290
 SAMPLE MEAN: 37.80
 SAMPLE STANDARD DEVIATION: 164.0

4. Lethality analysis:

The function of this section of the DURANL module is to assess the risk associated with any contaminant concentration time series generated by the HSPF application modules. The methodology links frequency data on instream contaminant levels to toxicity information resulting from both acute and chronic laboratory bioassays. The methodology is based on the Frequency Analysis of Concentration (FRANCO) program developed by Battelle, Pacific Northwest Laboratories as part of their Chemical Migration and Risk Assessment (CRMA) Methodology.

Laboratory toxicity experiments provide the main basis for developing a risk analysis for fish or other aquatic organisms. A common method of summarizing the results of these experiments is to use a lethal concentration where 50% of the fish die (LC50). Usually information for LC50 concentrations at 24, 48, and 96 hours can be derived from laboratory experiments in the form of pairs of lethal concentration and duration values. By connecting these pairs with straight line segments and extending the function in a reasonable manner at each end, a function is defined such that an event defined by a particular concentration level with a particular duration can be classified as exceeding or not exceeding the function, i.e., exceeding an LC50 value. (Figure 4.2(14)-3). An event exceeds the LC function when the concentration defining the event and the duration of the event results in the pair falling above and to the right of the combined LC50, or global exceedance, curve.

If LCNUM is greater than zero, a global exceedance summary table is printed which gives the fraction of time that a global exceedance curve is exceeded. Up to 5 LC curves can be analyzed at one time. It should be noted that the global exceedance summary eliminates double counting by reporting only those exceedance events with the lowest concentrations that occur in different contaminant peaks. (FRANCO documentation should be consulted for more detailed discussion).

If LCOUT=1 and LCNUM=0, a lethal event summary is printed to supplement the global exceedance information. The table gives a summary of all lethal events including ending time, lethal curve number, number of intervals in event, and concentration level. Printout is to unit PUNIT, which should be unique to the duration analysis; otherwise, the output from the lethal event summary will be mixed with the printout from application modules.

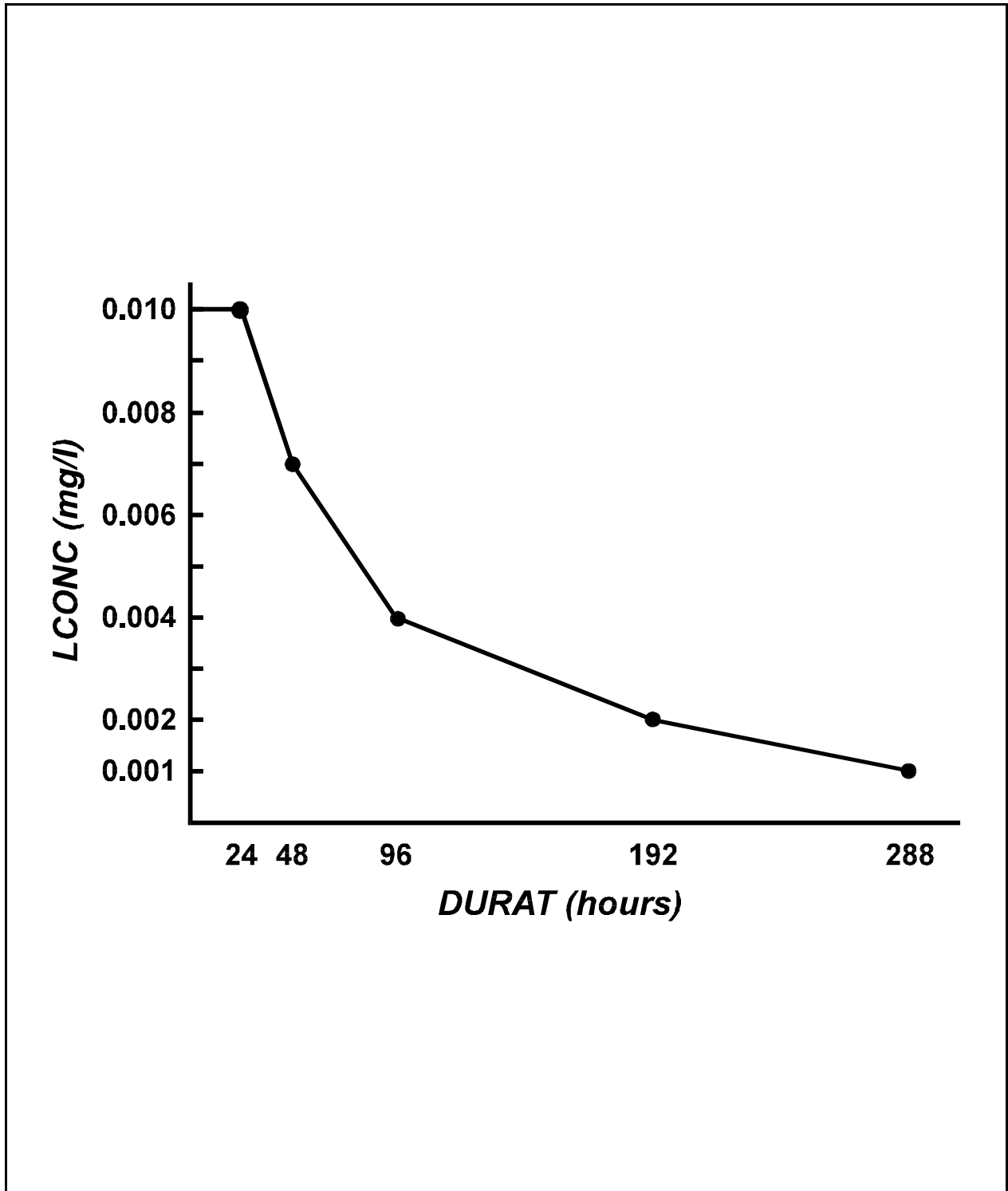


Figure 4.2(14)-3 Sample Lethal Concentration (LC) Function for Global Exceedance Calculation

4.2(15) Generate a Time Series from One or Two Other Time Series (Utility Module GENER)

This module is designed to perform any one of several possible transformations on input time series. The transformation is specified by supplying an "option code" (OPCODE). If A and B are the input time series and C is the computed time series, then the transformations performed for each possible value of OPCODE are:

OPCODE	Action
1	C= Abs value (A)
2	C= Square root (A)
3	C= Truncation (A) e.g. If A=4.2, C=4.0 A=-3.5, C=-3.0
4	C= Ceiling (A). The "ceiling" is the integer \geq given value. e.g. If A=3.5, C=4.0 A=-2.0, C=-2.0
5	C= Floor (A). The "floor" is the integer \leq given value. e.g. If A=3.0, C=3.0 A=-2.7, C=-3.0
6	C= loge (A)
7	C= log10 (A)
8	C= $K(1)+K(2)*A+K(3)*A^2$ (up to 7 terms) The user supplies the number of terms and the values of the coefficients (K).
9	C= $K**A$
10	C= $A**K$
11	C= A+K
12	C= Sin (A)
13	C= Cos (A)
14	C= Tan (A)
15	C= Sum (A)
16	C= A+B
17	C= A-B
18	C= A*B
19	C= A/B
20	C= MAX (A,B)
21	C= MIN (A,B)
22	C= A**B
23	C= cumulative departure of A below B
24	C= K
25	C= Max (A,K)
26	C= Min (A,K)

Note that if OPCODE is less than 15, or OPCODE equals 25 or 26, only one input time series is involved (unary operators); if OPCODE is 24, no inputs are required (constant); otherwise two inputs are required (binary operators). As with the other operating modules, the input time series are first placed in the INPAD by module TSGET (This may involve a change of time step and/or "kind"). Therefore, by the time module GENER works on them, they are mean valued time series with a time step equal to INDELT.

4.2(16) Multiple Sequential Input of Time Series from an HSPF Stand Alone Plotter File (Utility Module MUTSIN)

This utility module reads a sequential external file previously written on disk. This file has the same format as the PLOTFL produced with utility module PLTGEN (Section 4.2(12)). The user specifies the number of point and/or mean-valued time series to be read and the number of lines to skip at the beginning of the external file.

The missing data flag, MISSFG, is used to specify how MUTSIN reacts to missing data. A MISSFG value of 0 indicates that MUTSIN is to report an error and quit if any data are missing. Therefore, in this case, the internal time-step (DELT) must equal the time-step of the external file, the starting time of the run must correspond with the first entry read from the external file, and no entries may be missing. A MISSFG value of 1 indicates that MUTSIN is to fill missing sequential file entries with 0.0. A MISSFG value of 2 indicates that MUTSIN is to fill missing entries with -1.0E30. A MISSFG value of 3 indicates that MUTSIN is to fill missing values with the value of the next available entry.

Note that the date and time appearing in each record of the file must be in the same format as that used by the PLTGEN module to write a PLOTFL. (Section 4.2(12)). That is, the full year/month/day/hour/minute string must be present and a time, e.g., midnight is coded as 74 01 02 24 00, not 75 01 03 00 00.

The EXT TARGETS and/or NETWORK blocks are used to specify where TSPUT places the time series data read in from the external file.

MUTSIN has four potential uses:

1. It may be used to form a simple interface with other continuous models. The other model can output its results in the form of an HSPF PLOTFL (or a format conversion program can be used), and MUTSIN can be used to input this data to HSPF. Conversely, data can be output from HSPF, using the PLTGEN module, for input to the other model.
2. MUTSIN may be used to transfer data in a WDM file to another WDM file. This transfer requires the use of PLTGEN to output the data from the source file and MUTSIN to input to the target file.
3. MUTSIN can be used to transfer data between different types of computer hardware where WDM or DSS files are incompatible (e.g., Unix to personal computer and vice versa).
4. MUTSIN may also be used to input point valued data or data with a time interval not included in the standard HSPF sequential input formats (Part F, Section 4.9).

4.3 Module TSPUT

Module TSPUT is complementary to, and may be viewed as a mirror image of, module TSGET (Section 4.1). TSGET obtains time series from a WDM file, DSS, sequential file, or the INPAD and places its output in the INPAD. Conversely, TSPUT obtains a time series from the INPAD and places its output in the WDM file, DSS, or back in the INPAD. It has similar capabilities to TSGET, to alter the time step, "kind" or to perform a linear transformation on the time series with which it deals.

Compared to TSGET, module TSPUT contains one major complicating factor. When a time series is to be written to a WDM or DSS data set, the action taken depends on how any pre-existing data are to be treated. The possible access modes, ADD and REPL, are discussed in Part F, Section 4.6.

REFERENCES

- American Society for Testing and Materials. 1980. Annual Book of ASTM Standards: Part 31, Water, Philadelphia, PA.
- Anderson, E.A. 1968. Development and Testing of Snow Pack Energy Balance Equations, Water Resources Research, 4(1):19-37.
- Anderson, E.A., and N.H. Crawford. 1964. The Synthesis of Continuous Snowmelt Runoff Hydrographs on a Digital Computer, Department of Civil Engineering, Stanford University, Stanford, California, Technical Report No. 36, 103 p.
- Caupp, C.L., J.T. Brock, and H.M. Runke. 1994. Model formulation and program description of the Dynamic Stream Simulation and Assessment Model (DSSAMt): Application to the Truckee River, Nevada for Truckee River Operating Agreement (TROA) DEIS/DEIR. Technical Report No. RCR94-1. Submitted to the U.S. Bureau of Reclamation, Carson City, NV, Rapid Creek Research, Inc., Boise, Idaho.
- Chou, T.-W. 1980. Aquatic Biodegradation, Chapter 6 in Mill et al., 1980.
- Churchill, M.A., H.L. Elmore, and R.A. Buckingham. 1962. The Prediction of Stream Reaeration Rates. Amer. Soc. Civil Engineers Journ. 88(SA4), p. 1-46.
- Committee on Sanitary Engineering Research. 1960. Solubility of Atmospheric Oxygen in Water. Twenty-ninth Progress Report. ASCE, Journal of the Sanitation Engineering Div., 86(SA4):41.
- Covar, A.P. 1976. Selecting the Proper Reaeration Coefficient for Use in Water Quality Models, Proceedings of the Conference on Environmental Modeling and Simulation, Cincinnati, OH, EPA 600/9-76-016, 861p.
- Crawford, N.H., and A.S. Donigian, Jr. 1973. Pesticide Transport and Runoff Model for Agricultural Lands. Office of Research and Development, U.S. Environmental Protection Agency, Washington D.C. EPA 660/2-74-013. 211p.
- Crawford, H.H. and R.K. Linsley. 1966. Digital Simulation in Hydrology: Stanford Watershed Model IV, Technical Report No. 39, Dept. of Civil Engineering, Stanford University, Stanford, CA, 210p.
- Di Toro, D.M., D.T. O'Connor, and R.V. Thomann. 1970. A Dynamic Model of Phytoplankton Populations in Natural Waters, Environmental Engineering and Science Program, Manhattan College, New York.
- Donigian, A.S., Jr., and N.H. Crawford. 1976a. Modeling Pesticides and Nutrients on Agricultural Lands, Environmental Research Laboratory, Athens, GA, EPA 600/2-7-76-043, 317 p.
- Donigian, A.S., Jr., and N.H. Crawford. 1976b. Modeling Nonpoint Pollution From the Land Surface, Environmental Research Laboratory, Athens, GA, EPA 600/3-76-083, 280p.

REFERENCES

- Donigian, A.S, Jr., D.C. Beyerlein, H.H. Davis, Jr., and N.H. Crawford. 1977. Agricultural Runoff Management (ARM) Model Version II: Refinement and Testing, Environmental Research Laboratory, Athens, GA, EPA 600/3-77-098, 294p.
- Dugdale, R.C., and J.J. Macisaac. 1971. A Computational Model for the Uptake of Nitrate in the Peru Upwelling. Prepublication Copy.
- Falco, J.W., K.T. Sampson, and R.F. Carsel. 1976. Physical Modeling of Pesticide Degradation. Proceedings of Symposium on Model Ecosystem Approach to Biodegradation Studies, Society for Industrial Microbiology, pp. 193-202.
- Harnard, H.S. and R. Davis. 1943. The Ionization Constant of Carbonic Acid in Water and the Solubility of CO₂ in Water and Aqueous Salt Solution from 0 to 50 C, Journal of the American Chemical Society, 65:2030.
- Hydrocomp, Inc. 1977. Hydrocomp Water Quality Operations Manual, Palo Alto, CA.
- Hydrocomp, Inc. 1976. Hydrocomp Simulation Programming: Operations Manual, Palo Alto, CA, 2nd ed.
- Jobson, H.E. 1977. Bed Conduction Computation for Thermal Models, J. Hydraulics Div., ASCE, 103(HY10), 1213-1217.
- Jobson, H.E. and T.N. Keefer. 1979. Modeling Highly Transient Flow, Mass, and Heat Transport in the Chattahoochee River near Atlanta, Georgia. U.S. Geological Survey Professional Paper No. 1136.
- Johanson, R.C., J.C. Imhoff and H.H. Davis, Jr. 1979. Programmer's Supplement for the Hydrological Simulation Program - Fortran (HSPF).
- Krone, R.B. 1962. Flume Studies of the Transport of Sediment in Estuarial Shoaling Processes. Hydraulic Engineering Laboratory and Sanitary Engineering Research Laboratory, University of California, Berkeley, CA.
- Loehr, R.C., T.B.S. Prakasam, E.G. Srinath, and Y.D. Joo. 1973. Development and Demonstration of Nutrient Removal from Animal Wastes, U.S. Environmental Protection Agency, Washington, D.C. EPA R2-73-095.
- Mabey, W.R., T. Mill, and D.G. Hendry. 1980. Photolysis in Water, Chapter 3 in Mill et al., 1980.
- Meyer, L.D., and W.H. Wischmeier. 1969. Mathematical Simulation of the Process of Soil Erosion by Water. Trans. Am. Soc. Agric. Eng. 12(6):754-758,762.
- Mill, T., W.R. Mabey, D.C. Bomberger, T.-W. Chou, D.G. Hendry, and J.H. Smith. 1980. Laboratory Protocols for Evaluating the Fate of Organic Chemicals in Air and Water. SRI International, Menlo Park, CA, Environmental Research Laboratory, Athens, GA.
- Mill, T., W.R. Mabey, and D.G. Hendry. 1980. Hydrolysis in Water, Chapter 2 in Mill et al., 1980.

REFERENCES

- Mill, T., W.R. Mabey, and D.G. Hendry. 1980. Oxidation in Water, Chapter 4 in Mill et al., 1980.
- Negev, M. 1967. A Sediment Model on a Digital Computer, Department of Civil Engineering, Stanford University, Stanford, CA, Technical Report No. 76, 109p.
- O'Connor, D.J., and D.M. Di Toro. 1970. Photosynthesis and Oxygen Balance in Streams. ASCE, Journal of Sanitation Engineering Div., 96(SA2):7240.
- O'Connor, D.J., and W.E. Dobbins. 1958. Mechanism of Reaeration in Natural Streams. Trans. of the ASCE, Vol. 123, p. 641-684.
- Onishi, Y. and S.E. Wise. 1979. Mathematical Model, SERATRA, for Sediment-Contaminant Transport in Rivers and its Application to Pesticide Transport in Four Mile and Wolf Creeks in Iowa. Battelle, Pacific Northwest Laboratories, Richland, WA.
- Onstad, C.A., and G.R. Foster. 1975. Erosion Modeling on a Watershed, Trans. of ASAE, 18(2):288-292.
- Owens, M., R.W. Edwards, and J.W. Gibbs. 1964. Some Reaeration Studies in Streams, Intl. Journal of Air and Water Pollution, Vol. 8, p. 469-486.
- Partheniades, E. 1962. A Study of Erosion and Deposition of Cohesive Soils in Salt Water, Ph.D. Thesis, University of California, Berkeley, CA.
- Philips, J.R. 1957. The Theory of Infiltration: The Infiltration Equation and Its Solution, Soil Science, 83:345-375.
- Reddy, K.R., R. Khaleel, M.R. Overcash, and P.W. Westerman. 1979. A Nonpoint Source Model for Land Areas Receiving Animal Wastes: II. Ammonia Volatilization, Trans. of ASAE, 22(6):1398-1405.
- Richman, S. 1958. The Transformation of Energy by *Daphnia pulex*. Ecolog. Monogr. Vol. 28, p. 273-291.
- Schindler, D.W. 1968. Feeding, Assimilation and Respiration Rates of *Daphnia magna* Under Various Environmental Conditions and their Relation to Production Estimates, Journal of Animal Ecology, Vol. 37, p. 369-385.
- Shaffer, M.J., A.D. Halvorson, and F.J. Pierce. 1991. Nitrate Leaching and Economic Analysis Package (NLEAP): Model Description and Application. In: Managing Nitrogen for Groundwater Quality and Farm Profitability. R.F. Follett, D.R. Keeney, and R.M. Cruse (eds.). Soil Science Society of America, Inc.
- Smith, J.H., and D.C. Bomberger. 1980. Volatilization from Water, Chapter 7 in Mill et al., 1980.
- Smith, J.H., W.R. Mabey, N. Bohonos, B.R. Holt, S.S. Lee, T.-W. Chou, D.C. Bomberger, and T. Mill. 1977. Environmental Pathways of Selected Chemicals in Freshwater Systems, Part I: Background and Experimental Procedures. Environmental Research Laboratory, Athens, GA, EPA 600/7-77-113.

REFERENCES

- Thomann, R.V. 1972. Systems Analysis and Water Quality Management. McGraw-Hill, Inc., New York, 286p.
- Tsivoglou, E.C., and J.R. Wallace. 1972. Characterization of Stream Reaeration Capacity, U.S. Environmental Protection Agency, EPA R3-72-012.
- U.S. Army Corps of Engineers. 1956. Snow Hydrology, Summary Report of the Snow Investigations, North Pacific Division. Portland, OR, 437p.
- U.S. Environmental Protection Agency. 1975. Process Design Manual for Nitrogen Control, Office of Technology Transfer, Washington D.C.
- Vanomi, V.A., Editor. 1975. Sedimentation Engineering. Prepared by the ASCE Task Committee for the Preparation of the Manual on Sedimentation of the Sedimentation Committee of the Hydraulics Division, New York.
- Wezerak, C.G., and J.J. Gannon. 1968. Evaluation of Nitrification in Streams. ASCE, Journal of the Sanitation Engineering Div., 94(SA5):6159.
- Wischmeier, W.H., and D.D. Smith. 1965. Predicting Rainfall Erosion Losses from Cropland East of the Rocky Mountains. U.S. Department of Agriculture, Agricultural Handbook No. 282. 47p.
- Zepp, R.G. and D.M. Cline. 1977. Rates of Direct Photolysis in Aquatic Environments, Environmental Science and Technology, 11:359-366.