TEMPERATURE AND SOLUTE-TRANSPORT SIMULATION IN STREAMFLOW

USING A LAGRANGIAN REFERENCE FRAME

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 81-2
A computer program for simulating one-dimensional, unsteady temperature and solute transport in a river has been developed and documented for general use. The solution approach to the convective-diffusion equation uses a moving reference frame (Lagrangian) which greatly simplifies the mathematics of the solution procedure and dramatically reduces errors caused by numerical dispersion.

The model documentation is presented as a series of four programs of increasing complexity. The conservative transport model can be used to route a single conservative substance, such as dye, through a reach of a river. The simplified temperature model predicts water temperature in rivers using only equilibrium temperature and windspeed as meteorological input. The complete temperature model is highly accurate but requires rather complete meteorological data. Finally, the 10-parameter model can be used to route as many as 10 interacting constituents through a river reach. An example problem is solved for a three-parameter system involving temperature, dissolved oxygen, and biochemical oxygen demand.
TEMPERATURE AND SOLUTE-TRANSPORT SIMULATION IN STREAMFLOW
USING A LAGRANGIAN REFERENCE FRAME

By Harvey E. Jobson

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations 81-2
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CONVERSION FACTORS

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<th>Multiply SI units</th>
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<th>To obtain inch-pound units</th>
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<td>3.281</td>
<td>foot (ft)</td>
</tr>
<tr>
<td>gram (g)</td>
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<td>pound (lb)</td>
</tr>
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<td>calorie (cal)</td>
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<td>foot per day (ft/d)</td>
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<td>square centimeter per hour (cm²/h)</td>
<td>0.001076</td>
<td>square foot per hour (ft²/h)</td>
</tr>
<tr>
<td>cubic meter per second (m³/s)</td>
<td>35.31</td>
<td>cubic foot per second (ft³/s)</td>
</tr>
<tr>
<td>gram per cubic centimeter (g/cm³)</td>
<td>1.942</td>
<td>slug per cubic foot (s/ft³)</td>
</tr>
<tr>
<td>kilopascal per degree Celsius (kPa/°C)</td>
<td>0.00806</td>
<td>pound per square inch per degree Fahrenheit [lb/(in²°F)]</td>
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<tr>
<td>centimeter per day per kilopascal [cm/(d kPa)]</td>
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<td>foot per day per pound per square inch [ft/(d lb/in²)]</td>
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<td>3.69</td>
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<td>1.00</td>
<td>British thermal unit per pound per degree Fahrenheit [BTU/(lb°F)]</td>
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<td>62.4</td>
<td>British thermal unit per cubic foot per degree Fahrenheit [BTU/(ft³°F)]</td>
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### LIST OF SYMBOLS

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tbody>
<tr>
<td>A</td>
<td>cross-sectional area of the river</td>
</tr>
<tr>
<td>ALON</td>
<td>longitude</td>
</tr>
<tr>
<td>BED(I)</td>
<td>heat flux to the water from the bed at grid I</td>
</tr>
<tr>
<td>BOD</td>
<td>concentration of BOD</td>
</tr>
<tr>
<td>BW(I)</td>
<td>bank width at grid I</td>
</tr>
<tr>
<td>C</td>
<td>cross-sectional average concentration or concentration of a fluid parcel</td>
</tr>
<tr>
<td>c</td>
<td>concentration at a point in the cross section</td>
</tr>
<tr>
<td>C°</td>
<td>concentration of a parcel at time zero</td>
</tr>
<tr>
<td>cp</td>
<td>specific heat of water</td>
</tr>
<tr>
<td>CR(L,M)</td>
<td>reference concentration of constituent L in mass balance equation for constituent M</td>
</tr>
<tr>
<td>CV</td>
<td>heat storage capacity of the bed material</td>
</tr>
<tr>
<td>DBT(K,I)</td>
<td>change in water temperature which occurred at time kΔt and grid I</td>
</tr>
<tr>
<td>DP(K)</td>
<td>change in concentration (or temperature) of parcel K due to dispersion in a single time step</td>
</tr>
<tr>
<td>D_f</td>
<td>dispersion factor; ( D_f = \frac{D_x}{U \Delta t} )</td>
</tr>
<tr>
<td>DIF</td>
<td>thermal diffusivity of the bed material</td>
</tr>
<tr>
<td>DO</td>
<td>dissolved oxygen concentration</td>
</tr>
<tr>
<td>DQ(K)</td>
<td>apparent flow rate from parcel K to parcel K+1 due to velocity gradients in the cross section</td>
</tr>
<tr>
<td>DQQ</td>
<td>dispersion factor</td>
</tr>
<tr>
<td>DT,Δt</td>
<td>time step size in hours</td>
</tr>
<tr>
<td>DTM</td>
<td>part of time step for which total decay reaction is small</td>
</tr>
<tr>
<td>D_x</td>
<td>longitudinal dispersion coefficient</td>
</tr>
<tr>
<td>DX(I)</td>
<td>distance between grid I and I+1</td>
</tr>
<tr>
<td>E</td>
<td>evaporation in depth per unit time</td>
</tr>
<tr>
<td>EA, ( e_a )</td>
<td>vapor pressure of the air</td>
</tr>
<tr>
<td>e°</td>
<td>saturation vapor pressure of air at a temperature equal to that of the water surface</td>
</tr>
<tr>
<td>EBH(I)</td>
<td>effective barrier height at grid I</td>
</tr>
</tbody>
</table>
FL\text{LOW}(1,I) = \text{velocity at grid } I

FL\text{LOW}(2,I) = \text{cross-sectional area at grid } I

FL\text{LOW}(3,I) = \text{river top width at grid } I

FL\text{LOW}(4,I) = \text{tributary inflow at grid } I

H = \text{net addition of thermal energy to the water per unit time and surface area}

H_B = \text{heat flux caused by longwave radiation emitted by the water}

H_C = \text{heat flux conducted from the water to the air as sensible heat}

H_e = \text{heat utilized by evaporation}

H_L = \text{incoming atmospheric radiation}

H_N = \text{net heat flux caused by incoming radiation from the sun and the sky}

H_S = \text{incoming solar radiation}

I\text{GO} = \text{interior Eulerian grid number for which output is computed}

J = \text{index for time step number}

J\text{DAT} = \text{Julian date}

J\text{TS} = \text{number of time steps from midnight to time zero in the model}

K = \text{index for fluid parcel number, or surface exchange coefficient}

K\text{\O} = \text{parcel number at the beginning of the time step, before renumbering}

K\text{PG}(N,M) = \text{ parcel number of the } N\text{th fluid parcel which passed tributary } M \text{ during the current time step}

L = \text{latent heat of vaporization, or index for constituent number}

M\text{X} = \text{subreach in which the centroid of a fluid parcel is located}

N = \text{mass-transfer coefficient}

N\text{PT}(I) = \text{number of fluid parcels to pass grid point } I \text{ during the time step}

N\text{S} = \text{total number of parcels in the system}

N\text{XSEC} = \text{total number of Eulerian grids}
PDC(K) = total change in concentration (temperature) of fluid parcel due to a specified decay process
PDFU, PDF(K) = total change in concentration of first parcel or parcel K due to dispersion
PDT = time required for a parcel to traverse the distance to the next Eulerian grid
PDX = part of subreach remaining to be traversed
PHI = latitude
PHU, PH(K) = time first parcel or parcel K entered the system
PTU, PT(K) = concentration (or temperature) of first parcel or parcel K
PTIU, PTI(K) = initial concentration (temperature) of first parcel or parcel K
PTRU, PTR(K) = change in concentration (temperature) of first parcel or parcel K due to tributary inflow
PVU, PV(K) = volume of first parcel or parcel K
PXU, PX(K) = location of first parcel, or parcel K, in grid units
Q = discharge
RDT = part of time step Δt remaining
RFØ = response of the bed to a unit change in water temperature
RS = portion of the incoming solar radiation absorbed by the water
SA = altitude of the sun in degrees
SL = source term for constituent L
T = temperature of the water
t = time
Ta, TA = air temperature
TRIB(N) = concentration (temperature) of tributary N
TUP = new concentration at upstream boundary
TZM = meridian of the time zone
U = mean flow velocity
u = local flow velocity
U(I) = velocity in subreach between grids I and I+1
U* = shear velocity
\( u' \) = deviation from the mean velocity
\( \overline{u'c'} \) = average value of the product of the velocity and concentration deficit
\( V \) = windspeed
\( \psi \) = volume of a fluid parcel
\( W \) = width of the river
\( x \) = longitudinal coordinate
\( XK \) = kinematic surface exchange coefficient
\( XK(L,M) \) = reaction rate coefficient for the rate of change of concentration of constituent L, due to the presence of constituent M
\( X\text{\textsc{old}} \) = present location of fluid parcel
\( x_0 \) = location of a parcel at time \( t_0 \)
\( X_P \) = location of a parcel in Eulerian grids
\( Y \) = depth
\( \alpha \) = constant in wind function
\( \gamma \) = psychrometric constant
\( \Delta a \) = area of typical element of a fluid parcel
\( \Delta t, DT \) = time step size in the model, in hours
\( \Delta x \) = length of a fluid parcel
\( \varepsilon \) = emissivity of water
\( \xi \) = Lagrangian distance coordinate
\( \rho \) = density of water
\( \sigma \) = Stefan-Boltzman constant
\( \phi \) = cross-sectional average value of the source term
\( \phi \) = source term evaluated at a point
\( \psi \) = empirical function of windspeed
TEMPERATURE AND SOLUTE-TRANSPORT SIMULATION IN STREAMFLOW USING A LAGRANGIAN REFERENCE FRAME

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ABSTRACT

A computer program for simulating one-dimensional, unsteady temperature and solute transport in a river has been developed and documented for general use. The solution approach to the convective-diffusion equation uses a moving reference frame (Lagrangian) which greatly simplifies the mathematics of the solution procedure and dramatically reduces errors caused by numerical dispersion. The solution procedure has the further advantages, relative to conventional Eulerian solution schemes, of being easy to understand in the physical sense, of being extremely stable numerically, and of providing an accounting system which is very useful for model calibration.

The model documentation is presented as a series of four programs of increasing complexity. The conservative transport model can be used to route a single conservative substance, such as dye, through a reach of a river. The simplified temperature model is used to predict water temperature in rivers, either with or without thermal loading, when few meteorological data are available. Only equilibrium temperature and windspeed are required. It is suggested that air temperature can be used to approximate equilibrium temperature. The complete temperature model is highly accurate but requires rather complete meteorological data. Finally, the 10-parameter model can be used to route as many as 10 interacting constituents through a river reach. The mathematical description of the interaction between the constituents, which does not need to be linear, is generally up to the user to supply. An example problem is solved for a three-parameter system involving temperature, dissolved oxygen, and biochemical oxygen demand.

For simplicity, all models are developed and presented assuming steady non-uniform flow. Generalization of the models to allow unsteady flow is extremely simple, involving the addition of no more than 18 cards to the program deck. The report is concluded by describing this generalization for any of the models. Before using the models with unsteady flow, a flow model must be used to calculate and store the necessary flow data at each cross section and time step. Such a flow model is available and documented.
INTRODUCTION

The simulation of the transport of heat and pollutants in rivers and estuaries has received wide attention. Historically, the problem has been approached by applying the conservation principle in the Eulerian sense. Although an enormous amount of literature exists that describes various numerical techniques for solving the resulting so called convective-diffusion equation, all practical solution schemes are mathematically very complex and contain an undesirably large amount of numerical dispersion. In general, both the mathematical complexity and numerical dispersion are the result of attempts to accurately simulate the advective term of the equation.

If the conservation principle is applied in the Lagrangian sense, the troublesome advection term does not appear so the mathematical difficulties of numerically solving the equation are much reduced. Although straightforward, transforming the Lagrangian solution back to a fixed coordinate grid is somewhat involved. The purpose of this report is to document a rather simple one-dimensional Lagrangian transport model for general use.

The model documentation is presented as a series of programs of increasing complexity. The simpler versions are, in general, a subset of the more complex program. The simplest problem therefore could be solved by the most complex program, but it is desired that the model user have the deepest understanding of the program which he is using. In order to encourage this understanding, the modeler is not troubled by options which are not necessary to his problem. By selecting the simplest possible program capable of meeting his situation, the modeler is encouraged to modify the program to more nearly fit his particular needs. Even if one is considering the most complex problem, it would be wise to work through each of the programs in the series as a learning device.

All of these models solve the convective diffusion equation in the Lagrangian reference frame. The simplest model involves the transport of a single conservative substance, such as dye. The next step is to generalize the model to predict temperatures using only equilibrium temperature and windspeed as meteorologic inputs. The third step is to develop a complete and sophisticated temperature model, and finally, a model is presented which is capable of simulating as many as 10 interacting constituents.

Many problems can be solved by use of the steady flow assumption. For example, one is often interested in predicting concentration under the assumed 10-year low flow condition. Although it is easy to generalize the transport model to handle unsteady flow, the simulation of the unsteady velocities and areas needed as input for the unsteady model is
a major modeling effort in itself. It is believed, therefore, that
these models will often be used under the conditions of steady flow.
For this reason, all transport models are presented in the steady flow
form first. After the most sophisticated transport model has been
developed for steady flow conditions, the slight generalization necessary
to handle unsteady flow in upland (unidirectional) rivers is presented.

The transport model discretizes a river reach into a number of
subreaches separated by grid points. A maximum of 50 grid points is
allowed in the code. For steady flow applications, the only hydraulic
inputs needed are the discharge at the upstream end of the reach and the
cross-sectional properties (area, width, and tributary inflow) at the
grid points. For unsteady-flow applications a streamflow model must be
used to calculate the hydraulic properties at each grid point and time
step. Land (1978) has recently documented a streamflow model that is
designed to supply the needed data for unsteady flow. A flow model
presented by Dawdy and others (1978) is used for the example simulation
of this report.

In addition to hydraulic data the transport model requires the
concentration of the modeled substance at the upstream end of the reach
and at each tributary for discrete time steps. Although the code is set
up for equal time steps, it can be easily modified to allow unequal time
steps (Barry A. Benedict, oral commun., 1980). Of course certain rate
coefficients and meteorologic data are required to model specific
substances.

BASIS FOR MODEL DEVELOPMENT

In the Lagrangian framework, one conceptually follows an individual
fluid parcel while keeping track of all factors which act to change its
concentration. A typical fluid parcel for a river is illustrated in
figure 1. The parcel moves downstream with a velocity U. Because the
flow velocity in the river, \( u \), is not uniform in the cross section, one
must consider an individual element of the fluid parcel in order to
apply the conservation principle. Applying this principle to a typical
element of the parcel, shown in figure 1, with cross-sectional area \( A_a \)
and length \( \Delta x \) which moves downstream at a velocity \( U \) gives

\[
\frac{\partial (c A_a \Delta x)}{\partial t} = A_a \Delta x \frac{\partial u' c}{\partial \xi} + \phi A_a \Delta x
\]

in which \( c \) = concentration of the transported substance, \( t = \) time,
\( u' = (U - u) \) which is the local instantaneous velocity relative to the
coordinate system which moves downstream with velocity \( U \), \( \xi = \) Lagrangian
distance coordinate, and \( \phi = \) the production of the transportable substance
per unit volume and time. The Lagrangian distance coordinate, \( \xi \),
is given by
Figure 1.--Typical flow element in a typical fluid parcel of a river.
\[ \xi = x - x_0 - \int_{t_0}^{t} U \, dt \]  \hspace{1cm} (1)

in which \( x_0 \) is the location of the parcel at time \( t_0 \), and \( U \) is the cross-sectional average flow velocity evaluated at the location of the parcel. Note that \( \xi = 0 \) for the particular parcel at any time.

Dividing by \( \Delta a \Delta x \) since they are constant for a given element of the parcel gives

\[ \frac{\partial c}{\partial t} - \frac{\partial u'c}{\partial \xi} = \phi \]

Integrating the equation over the cross section, one obtains

\[ \frac{\partial c}{\partial t} - \frac{\partial u'c'}{\partial \xi} = \phi \]  \hspace{1cm} (2)

in which \( C \) and \( \phi \) are the cross-sectional average value of concentration and production, respectively, and \( u'c' \) is the cross-sectional average value of the product of the velocity and concentration deficit \( (C - c) \). The term \( \phi \) can represent several processes. For example, it can represent point sources of the substance such as those that occur at tributaries, as well as a distributed source of substance such as the heat absorbed at the air-water interface. Equation 2 is applied to a series of fluid parcels along the length of the stream in order to obtain a solution for the system.

The second term in equation 2 is the so-called dispersion term. Actually, it is mainly a correction factor to account for treating a three-dimensional problem by use of a time and space averaged one-dimensional equation. For lack of a better approach, the dispersion term has invariably been represented by analogy with molecular and turbulent mixing due to diffusion. In other words, it has been assumed that

\[ u'c' = - D \frac{\partial c}{\partial \xi} \]  \hspace{1cm} (3)

in which \( D \) is called the longitudinal dispersion coefficient. It can be shown theoretically that \( D = 5.9U^*Y \) for flow in a wide open channel with a logarithmic velocity profile (Elder, 1959). Here \( U^* \) and \( Y \) are the shear velocity and depth, respectively. Fischer (1973) summarizes measurements in both the laboratory and natural channels. The reported values range from \( D = 5.9U^*Y \) to \( D = 7500 U^*Y \).
Combining equations 2 and 3, the governing equation for Lagrangian transport is obtained as

\[ \frac{\partial C}{\partial t} + (D \frac{\partial C}{\partial \xi}) = 0 \]  

Integrating equation 4 gives

\[ C = C_0 - \int_0^t (D \frac{\partial C}{\partial \xi}) dt' + \int_0^t \Phi dt' \]  

in which \( C_0 \) is the concentration of the parcel at time zero and \( C \) is the concentration after a time lapse of \( t \). The time lapse (or traveltime), \( t \), can be considered either as a single time step in the model or as the total time for a parcel to pass through the system. Equation 5 is very amenable to numerical analysis because of its integral rather than differential form.

A solution is constructed by solving equation 5 for a series of parcels. The location of each parcel is continually tracked by use of equation 1 with \( \xi = 0 \). Since a new parcel is added at the upstream boundary for each time step, the distance between parcels is \( U \Delta t \). Knowing the distance between parcels the dispersion term can be approximated by a very simple explicit finite difference method for each time step

\[ \int_0^{\Delta t} (D \frac{\partial C}{\partial \xi}) dt' = \frac{D_x}{U^2 \Delta t} (C_{i+1}^0 - C_i^0) - \frac{D_x}{U^2 \Delta t} (C_i^0 - C_{i-1}^0) \]  

in which \( C_{i-1}^0, C_i^0, \) and \( C_{i+1}^0 \) are the old values of concentrations of parcel \( i-1, i, \) and \( i+1 \), respectively, and \( D_x \) is the dispersion coefficient evaluated at a point halfway between parcel \( i \) and \( i+1 \). The dimensionless ratio, called the dispersion factor, \( D_f \), is defined as

\[ D_f = \frac{D_x}{U^2 \Delta t} = \left( \frac{\sqrt{D_x}}{U \Delta t} \right)^2 \]  

It will be seen that the accuracy of the numerical approximation is totally controlled by the value of this ratio. The distance between parcels is \( U \Delta t \) and the characteristic distance scale for a diffusive process is \( \sqrt{D_x} \Delta t \) (Carslaw and Jaeger, 1959). The length scale \( \sqrt{D_x} \Delta t \) is a measure of the distance of travel of an advancing diffusion front. The value of the dispersion factor is seen to be the square of the ratio of the length scale of the diffusive process to the distance between parcels. It can be shown, empirically, that the accuracy of equation 6 is optimum for a value of \( D_f = 0.2 \) but that the accuracy remains very
good as long as $0.05 \leq D_f \leq 0.3$ (Jobson, 1980). The value of the dispersion factor, $D_f$, can be controlled by the modeler through the selection of $\Delta t$. Values outside the suggested range will generally result in the model underestimating the actual dispersion.

In order to insure that equation 6 conserves mass when applied to parcels of finite size it is well to rederive it from mass balance considerations paying special attention to the details concerning the mass balance of parcels.

Longitudinal dispersion is caused primarily by the difference in streamwise velocity between different points in the cross section (Fischer, 1972, p. B5). The boundaries between parcels are convected through the reach at the mean stream velocity while the water near the surface and center may move faster than the mean and the water near the bed and banks will move slower, as illustrated in figure 2. Because of these differential velocities, waters intermingle between Lagrangian parcels. This intermingling dominates the longitudinal dispersion process. Consider figure 2 which illustrates a wide river with parcels separated by moving planes, the dashed lines. Assuming that the concentration in each parcel is well mixed and that the flow rate from parcel $K$ to $K+1$ is $DQ(K)$, the flux of material across the boundary can easily be computed. From continuity considerations an equal apparent flow rate must exist from parcel $K+1$ to parcel $K$ so the total dispersive increase in concentration of parcel $K$ during $\Delta t$ can be determined from

$$
\int_{0}^{\Delta t} \frac{\partial u'c'}{\partial t} \, dt' = \frac{DQ(K-1)\Delta t(c^0_{K-1} - c^0_K) + DQ(K)\Delta t(c^0_{K+1} - c^0_K)}{\psi}
$$

in which $\psi$ is the volume of parcel $K$.

The rate of flow of water between parcels ($DQ$) is determined from the distribution of velocity in the cross section and the mean velocity. The value of $DQ$ will remain a constant percentage of the discharge, provided the velocity distribution in the cross section remains similar. For example, if there were no lateral variation in velocity and the vertical variation were logarithmic, the ratio of $DQ/Q$ (called $DQQ$) would be only a function of the ratio of the mean velocity to the shear velocity. This ratio would increase from 0.092 to 0.184 as the ratio of the mean to shear velocity decreased from 10.0 to 5.0. Since the ratio of $DQ/Q = DQQ$ is constant, equation 8 could be written as

$$
\int_{0}^{\Delta t} \frac{\partial u'c'}{\partial t} \, dt' = \frac{DQQ(K-1)AU\Delta t(c^0_{K-1} - c^0_K) + DQQ(K)AU\Delta t(c^0_{K+1} - c^0_K)}{\psi}
$$

in which $A$ is the cross-sectional area of the river. For steady uniform flow the volume of the parcel is $AU\Delta t$ and equation 9 is identical to
Figure 2.--Schematic of a longitudinal section of a river with fluid parcels delineated to illustrate the dispersive process.
equation 6 wherein $DQQ$ is equivalent to $D_c$; however, use of equation 9 conserves mass even for nonuniform unsteady flow conditions with finite parcel sizes. For this reason equation 9 is used in the model computations.

Equation 9 can become unstable for highly unsteady flow or if adjacent parcel volumes of very unequal size exist in the river. If $DQ \Delta t > V$ more fluid is removed from a parcel during the time step than was there to begin with. This potential instability is overcome by forcing the value of $DQ \Delta t$ to be less than 0.35 $V$. This reduction in $DQ$ is seldom executed except for extremely unsteady flow but when executed, reduces the computed dispersion below actual values.

**SOLUTION ALGORITHM**

The traditional Eulerian solution scheme for transport problems involves discretizing the river reach into a number of subreaches separated by grid points. The initial conditions for the solution are known concentrations of water parcels at each grid point. New concentrations of different water parcels at the same grid points are then computed for some later time, $\Delta t$. One boundary condition and a finite-difference approximation of the convective diffusion equation are used to compute the new concentrations. The new concentrations are then considered as initial or old values and the process is repeated as many times as desired.

In the Lagrangian approach, the Eulerian grid must be retained because it is the reference upon which the depth, area, and velocity of flow are defined. The solution scheme starts at time zero with a known concentration of a water parcel centered at each grid point just as in the Eulerian scheme. In the Lagrangian approach, however, new concentrations are computed by use of equation 5 for the same water parcels, which, of course, are no longer at the same location after a time lapse of $\Delta t$. The new location of each water parcel is determined by equation 1. As a result, the solution computation proceeds along advective paths (characteristic curves) defined by equation 1. The boundary condition is incorporated by adding a new parcel with its centroid at the upstream boundary for each time step. This new fluid parcel contains all the water to flow into the reach during the time $t - \Delta t/2$ to $t + \Delta t/2$. Later the volume of the parcel may change as it moves past tributaries or diversion points.

The basic bookkeeping necessary to keep track of all the information about individual fluid parcels is accomplished by setting up parcel characteristic arrays $[PX(K), PV(K), PT(K)]$ where $K$ is the index for the particular water parcel; $PX(K)$ is the longitudinal location of the centroid of the parcel; $PV(K)$ is the parcel volume; and $PT(K)$ is the parcel concentration or temperature. The parcels are numbered in the order of their location, or time of entry to the reach, with parcel
number 1 occupying the upstream boundary and parcel NS occupying the
downstream boundary (fig. 3). In general, the total number of parcels
in the system, NS, will be different for each time step. The maximum
value of NS, which fixes the dimensions of the arrays, can be determined
as the longest traveltime of a parcel through the system divided by the
time-step size. The characteristics and identifying index, K, of each
parcel are updated during each time step of the model.

For convenience the parcel location is measured in Eulerian grid
units. For example, the parcel occupying the upstream boundary has a
location of 1.0 \([\text{PX}(1) = 1.0]\) and the parcel, K, located midway between
grids 4 and 5 (in subreach 4) has a location of 4.5 \([\text{PX}(K) = 4.5]\). The
Eulerian grids do not have to be equally spaced.

The basic solution algorithm can perhaps be best described by
giving a narrative of the steps involved for one-time iteration of a
conservative substance:

1. The first step is to determine the average hydraulic conditions
in each subreach, river reach between two grid points. The subreach-
average velocities, for example, are the average of four values,
the old and new velocities at each end of the subreach. (For extremely
non-uniform conditions, the average velocity can better be computed
as the average inflow to the subreach divided by the average area
in the subreach.) For steady flow, this step is performed outside the
time loop and only involves the averaging of values at each end of
the subreach.

2. The dispersion term is evaluated for each parcel. This
computation involves two basic steps.
   A. The rate of flow between Lagrangian parcels \([DQ(K)]\) is
determined for each parcel in the system. The value of DQ
is computed as \(DQQ \times \text{flow rate in the river evaluated}
at a point midway between adjacent parcels. The value of
DQQ is input to the program. After all values of DQ are
found, values are checked and limited in size, if necessary,
to force stability. The value of DQ is also set equal to zero
between parcels adjacent to tributaries.
   B. The dispersion term of equation 5 is evaluated for
each parcel in the system by use of equation 9, and
the results are stored in an array \(DF(K)\).

3. The upstream boundary condition is satisfied. The characteristics
for the parcel which will become parcel 1 are read and stored as
temporary variables, the names of which end with the letter U.
   A. The new concentration at the upstream boundary (TUP) and
all tributaries are read from input cards.
   B. The upstream characteristic arrays are set as:
      (1) \(\text{PXU} = 1.0\), the parcel enters at the upstream boundary;
      (2) \(\text{PVU} = Q \Delta T\) in which \(Q\) is the flow rate at the upstream
boundary at the end of the time step;
Figure 3.—Schematic of the computational scheme for the Lagrangian transport model.
(3) PTU = observed upstream concentration at the end of
the time step (the boundary condition);
(4) PHU = (J + JTS)\Delta t is the time at which the parcel
entered the system; J is the time step counter and
JTS is the number of time steps from midnight to time
zero of the model.
(5) PTRU = 0.0 is the effect of tributary inflow on
the parcel concentration, none yet;
(6) PTIU = initial concentration of the parcel. This is
also the observed upstream concentration at the end of the
time step but it will be remembered throughout the
parcel's travels without change.
(7) PDFU = 0.0 is the effect of dispersion on the
concentration. The array PDF(K) will be obtained
by integrating the dispersion term over the entire
traveltime (eq. 6); of course, it starts out as zero.

4. The characteristics of the parcel which will be centered
on the downstream boundary at the end of the time step (parcel NS
in fig. 3) are determined. This parcel (parcel "A") is unique
in that its characteristics are found by interpolation. The
characteristics are those which should occur at the present
location of parcel "A".
   A. In order to determine the present location of parcel
"A" (fig. 3), a term MX is defined as the subreach in which
the centroid of the parcel is found.
   B. It is first assumed that MX = NXSEC - 1, where NXSEC is
the total number of Eulerian grids.
   C. The traveltime through subreach MX is calculated as

\[
PDT = \frac{DX(MX)}{U(MX)}
\]

in which PDT is the time required for a parcel to traverse
subreach MX of length DX(MX) and in which the velocity
is U(MX).
   D. If the traveltime for the subreach, PDT, is greater than
the time remaining for movement, RDT, (RDT = \Delta t if MX = NXSEC - 1)
the parcel is known to have originated in subreach MX. If
PDT is less than RDT, the parcel originated upstream of subreach
MX; so MX is reduced by 1, RDT is reduced by PDT, and steps C
and D are repeated.
   E. Once the subreach in which parcel "A" originated is
found, the exact starting location of the centroid, XP (in
Eulerian grids), is determined.

\[
XP = MX + 1 - \frac{RDT}{PDT}
\]
F. The index number, K, of the water parcel presently located just upstream of the added parcel "A" is found (NS° - 2 in fig. 3) by comparing the location characteristic of each parcel (starting with NS° - 1) to XP.

G. The total number of parcels that will be within the system at the end of the time step, NS N , is determined as two more than the index, K, of the parcel just upstream of "A".

H. The locations of the added parcel "A" and the existing parcels just upstream and downstream of "A" are converted to real distances.

I. The old concentration of parcel "A" is obtained by linear interpolation between the adjacent parcels. The new concentration at the downstream boundary [PT(NS)] is computed by use of equation 5 wherein the old concentration of parcel "A" is used for C o .

J. All other parcel characteristics are obtained by similar interpolation with updating where necessary. The volume of the added parcel ("A") is set equal to the volume of the parcel just downstream of parcel "A".

5. Starting with parcel NS - 1 and working upstream, the characteristics and index number of each parcel are updated.

A. The subreach where the centroid of the parcel is located (MX) is determined first as the integer part of PX(K), the old value of PX(K) is stored as XØLD, and the index number is stored as XØ.

B. The distance within the subreach remaining to be traversed, PDX, is determined

PDX = [MX + 1 - PX(K)]*DX(MX)

where DX(MX) is the length of the subreach from grid point MX to MX + 1.

C. The time for the parcel to traverse this distance, PDT, is computed from the mean velocity in the subreach.

D. If the traveltime for the remaining part of the subreach, PDT, is greater than the time remaining for movement, RDT, the program jumps to step E. Otherwise,

(1) MX is increased by 1 (the parcel has passed a Eulerian grid);
(2) XØLD is set equal to MX;
(3) The value of RDT is reduced by the time required for the parcel to reach the grid, PDT;
(4) The information that parcel K passed Eulerian grid MX during the time step is stored in the arrays NPT (number of parcels to pass grid MX) and KPG (parcel numbers of parcels to pass grid MX);
(5) The program cycles to step C with PDX = DX(MX).
E. The parcel stopped in subreach MX so all parcel characteristics are updated

1. \[ PX(K) = X_{OLD} + RDT \times U(MX)/DX(MX) \]
2. \[ PT(K) = PT(K_0) + DF(K_0) \text{ and } PDF(K) = PDF(K_0) + DF(K_0) \]
3. All other characteristics (volume, time of entry to the system, effect of tributary dilution and initial temperature, PV, PH, PTR, and PTI, respectively) simply have their index number changed from K_0 to K.

6. The upstream boundary characteristics which were formerly stored in the temporary arrays (PXU, PTU, and so forth) are transferred to the characteristics arrays for index number 1. That is, PX(1) = PXU, and so forth.

7. For each tributary the program modifies the volume and concentration of each of the NPT parcels that pass the tributary location in proportion to the volume of the parcel in relation to the volume of all parcels to pass the tributary. If no parcels pass the tributary during the time step, the tributary inflow is added to the parcel which is nearest the tributary at the end of the time step.

8. For any specified interior grid (IG_0) the concentration and representative values of all parcel characteristics are determined by linear interpolation between parcels occurring just upstream and downstream of the grid.

9. Steps 2 through 8 are repeated for each time step and results are printed at specified time steps.

Flow charts and program listings will be given for each version of the program.

No model can be completely general. It is assumed that the location of all Eulerian grid points will be expressed in miles measured from some point below the downstream end of the reach. The program allows for no more than 50 grid points (49 subreaches) which are numbered starting with 1 at the upstream end. The cross-sectional area must be expressed in square meters. It is further assumed that no tributaries enter at either the first or last grid point (upstream or downstream end of the reach) and that all discharges are given in cubic meters per second. Finally, all parcel characteristic arrays are dimensioned only to 500 so no more than 500 parcels are allowable in the system at one time. One parcel is added to the system for each time step, so the maximum traveltime of a parcel through the system must be less than 500 time steps. This limitation can be removed in three ways. First, the time step size can be increased; second, the total reach length can be subdivided into two or more major sections and the program run for each section; or third, the dimensions for all arrays can be increased.
CONSERVATIVE TRANSPORT IN STEADY FLOW

The simplest possible transport problems involve the movement of a conservative type of substance, such as dye, through a river system. Although simple, the conservative transport model can be very useful for predicting concentrations which may result from spills of various pollutants which decay slowly. It is also an excellent place to start obtaining an understanding of the model itself.

Since the preceding section went into the detail of the conservative transport model, the material will not be repeated here. A generalized flow chart of the program is shown in figure 4 and a listing of the codes is shown in attachment A.

All input is by computer cards. Table 1 contains a description of the data input, sequence and arrangement used for all the models. The conservative transport model does not require all sets of data. The first card is an information card which will simply be printed back at the beginning of the output. This 80-column field will generally contain the name of the basin, period of record, date of run, and so forth.

The second card contains the number of cross sections (grid points) to be used (NXSEC), the number of time steps to be simulated (NHR), the time step size ($\Delta t$) expressed in hours, the discharge at the upstream end of the reach ($Q$) in cubic meters per second, the interior grid at which output is desired (IGO), the number of time steps between output lists (IOUT), the number of tributaries to enter the stream (NTRIB), and the number of time steps between midnight and the starting time of the model (JTS). If the value of IOUT is set equal to 1, output is printed for every time step; if its value is 3, output is printed every third time step, and so forth. The format for the second card is 2I5, 2F10.2, 4I5 (line 0033, attachment A).

All other input cards have a consistent format. Each card has a free field in the first 10 columns which can be used for card identification. Following this free field are 10 seven-column data fields with a format of I7 or F7.3. Of course, a decimal punched in the field takes precedence. All integers must be right justified. All variables are real (number with a decimal) or integer according to standard notation, that is, A-H, O-Z for real and I-N for integer. The conservative transport model does not require the labeling information in set 3. These data cards are only needed for the 10-parameter model as indicated in the second column of table 1.

The next group (set 4 in table 1) of data cards needed for the conservative transport model contains the X coordinates of the grid points, expressed in miles upstream of some origin such as the river
Figure 4.--Generalized flow chart for conservative transport model in steady flow.
### TABLE 1. -- A description of the data input, sequence, and arrangement

<table>
<thead>
<tr>
<th>Card no.</th>
<th>Models using</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SET 1 - INFORMATION CARD</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1,2,3,4</td>
<td>TITLE(20)</td>
<td>Information card, generally the basin name, period of record, date of run, and so forth</td>
</tr>
<tr>
<td><strong>SET 2 - HEADER CARD</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1,2,3,4</td>
<td>NXSEC</td>
<td>Number of grid points</td>
</tr>
<tr>
<td>1,2,3,4</td>
<td>NHR</td>
<td>Number of time steps the model is to be run</td>
<td>6-10</td>
</tr>
<tr>
<td>1,2,3,4</td>
<td>DT</td>
<td>Length of time step in hours</td>
<td>11-20</td>
</tr>
<tr>
<td>1,2,3,4</td>
<td>Q</td>
<td>Discharge at upstream boundary in cubic meters per second</td>
<td>21-30</td>
</tr>
<tr>
<td>1,2,3,4</td>
<td>IGØ</td>
<td>Interior grid number where output is desired</td>
<td>31-35</td>
</tr>
<tr>
<td>1,2,3,4</td>
<td>IØUT</td>
<td>Number of time steps between output listings</td>
<td>36-40</td>
</tr>
<tr>
<td>1,2,3,4</td>
<td>NTRIB</td>
<td>Number of tributaries</td>
<td>41-45</td>
</tr>
<tr>
<td>1,2,3,4</td>
<td>JTS</td>
<td>Number of time steps from midnight until time zero of the model</td>
<td>46-50</td>
</tr>
<tr>
<td>2,3,4</td>
<td>Al</td>
<td>Constant term in wind function relation which gives the evaporation in millimeters per day when the vapor pressure difference is given in kilopascals</td>
<td>51-60</td>
</tr>
<tr>
<td>2,3,4</td>
<td>B1</td>
<td>Mass-transfer coefficient in wind function relation which gives the evaporation in millimeters per day when the vapor pressure difference is given in kilopascals and the windspeed is given in meters per second</td>
<td>61-70</td>
</tr>
<tr>
<td>4</td>
<td>NEQ</td>
<td>Number of parameters being modeled</td>
<td>71-75</td>
</tr>
</tbody>
</table>

**SET 3 - LABELING INFORMATION FOR PARAMETER OUTPUT**

| 1 | 4 | ~ | Free field for card identification | 1-10 |
### TABLE 1—A description of the data input, sequence, and arrangement—Continued

<table>
<thead>
<tr>
<th>Card no.</th>
<th>Models using</th>
<th>Variable</th>
<th>Description</th>
<th>Columns</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SET 3</strong>—LABELING INFORMATION FOR PARAMETER OUTPUT—Continued</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>L</td>
<td>Parameter number which must start with number 1 and be in sequence</td>
<td>11-17</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>LABEL(M)</td>
<td>5 columns alpha numeric field for naming parameter L</td>
<td>20-24</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>LR(M)</td>
<td>Parameter number for which the effect on the concentration of parameter L is tabulated</td>
<td>25-31</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>SET 4</strong>—RIVER MILES OF GRID POINTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,2...</td>
</tr>
<tr>
<td>1,2,3,4</td>
</tr>
<tr>
<td>1,2,3,4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>SET 5</strong>—CROSS-SECTIONAL AREAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,2,...</td>
</tr>
<tr>
<td>1,2,3,4</td>
</tr>
<tr>
<td>1,2,3,4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>SET 6</strong>—TOP WIDTHS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,2,...</td>
</tr>
<tr>
<td>2,3,4</td>
</tr>
</tbody>
</table>
TABLE 1. -- A description of the data input, sequence, and arrangement -- Continued

<table>
<thead>
<tr>
<th>Card no.</th>
<th>Models using</th>
<th>Variable</th>
<th>Description</th>
<th>Columns</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>SET 6 - TOP WIDTHS--Continued</strong></td>
<td></td>
</tr>
<tr>
<td>2,3,4</td>
<td>1,2,3,4</td>
<td>FLOW(3,I)</td>
<td>Top widths of the river at the grid points in meters. Values are input in sequence starting at grid 1 and working downstream. For unsteady flow, the values used here are ignored; a blank card is acceptable.</td>
<td>11-17,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>18-24, ...</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>73-80</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>SET 7 - TRIBUTARY INFORMATION</strong></td>
<td></td>
</tr>
<tr>
<td>1,2,...</td>
<td>1,2,3,4</td>
<td>~</td>
<td>Free field for card identification</td>
<td>1-10</td>
</tr>
<tr>
<td>1,2,3,4</td>
<td>1,2,3,4</td>
<td>IGT(N)</td>
<td>Grid number where the tributary enters the stream. These must be input in sequence working downstream. Use one and only one card per tributary. If no tributaries exist, no cards are necessary.</td>
<td>11-17</td>
</tr>
<tr>
<td>1,2,3,4</td>
<td>1,2,3,4</td>
<td>FLOW(4,IGT(N))</td>
<td>Tributary inflow at grid IGT(N) in cubic meters per second. For unsteady flow, the value used here is ignored, and the tributary flow is obtained from the flow model output.</td>
<td>18-24</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>SET 8 - DISPERSION FACTORS</strong></td>
<td></td>
</tr>
<tr>
<td>1,2,...</td>
<td>1,2,3,4</td>
<td>~</td>
<td>Free field for card identification</td>
<td>1-10,</td>
</tr>
<tr>
<td>1,2,3,4</td>
<td>1,2,3,4</td>
<td>DQQ(I)</td>
<td>Dispersion factor at grid I. The dispersion factor is determined by use of equation 7. Any consistent units can be used.</td>
<td>11-17, 18-24,..., 73-80</td>
</tr>
</tbody>
</table>
### TABLE 1. A description of the data input, sequence, and arrangement—Continued

<table>
<thead>
<tr>
<th>Card no.</th>
<th>Models using</th>
<th>Variable</th>
<th>Description</th>
<th>Columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>SET 9 - INITIAL CONDITIONS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1,2,...</td>
<td>1,2,3,4</td>
<td>~</td>
<td>Free field for card identification</td>
<td>1-10, 11-17, 18-24,..., 73-80</td>
</tr>
<tr>
<td></td>
<td>1,2,3</td>
<td>PT(I)</td>
<td>Initial concentrations or temperatures at grid points. Data must be input in sequence starting with grid 1, the upstream end.</td>
<td>11-17, 18-24,..., 73-80</td>
</tr>
<tr>
<td></td>
<td>M+1,</td>
<td>4</td>
<td>Free field for card identification</td>
<td>1-10, 73-80</td>
</tr>
<tr>
<td></td>
<td>M(NEQ)</td>
<td>4</td>
<td>PT(NEQ,I)</td>
<td>Initial concentrations at grid points for parameter number NEQ. Data must be input in sequence starting with grid 1.</td>
</tr>
</tbody>
</table>

| SET 10 - RIVER LOCATION | | | | |
| 1 | 3 | ~ | Free field for card identification | 1-10, 11-17, 18-24, 73-80 |
| 3 | JDAT | Julian date for which shading computations are made. Fixed point variable. | 11-17, 18-24, 25-31, 32-38 |
| 3 | PHI | Latitude of the river in degrees | 18-24, 25-31, 32-38 |
| 3 | ALON | Longitude of the river in degrees | 18-24, 25-31, 32-38 |
| 3 | TZM | Longitude of the meridian of the time zone in degrees | 18-24, 25-31, 32-38 |
**TABLE 1.--A description of the data input, sequence, and arrangement--Continued**

<table>
<thead>
<tr>
<th>Card no. Models using</th>
<th>Variable</th>
<th>Description</th>
<th>Columns</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SET 11 - RIVER AZIMUTHS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1,2,... 3</td>
<td>~</td>
<td>Free field for card identification</td>
<td>1-10, 11-17, ...</td>
</tr>
<tr>
<td>3</td>
<td>AZ(I)</td>
<td>Azimuth of the river at grid I in degrees, clockwise from North. Use as many cards as necessary to input values for each grid starting with grid 1 on card 1.</td>
<td>18-24, ...</td>
</tr>
<tr>
<td><strong>SET 12 - BANK WIDTH</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1,2,... 3</td>
<td>~</td>
<td>Free field for card identification</td>
<td>1-10, 11-17, ...</td>
</tr>
<tr>
<td>3</td>
<td>BW(I)</td>
<td>Bank width at grid I in meters, see figure 10 for definition. Use as many cards as necessary starting with grid 1 on card 1.</td>
<td>18-24, ...</td>
</tr>
<tr>
<td><strong>SET 13 - EFFECTIVE BARRIER HEIGHT</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1,2,... 3</td>
<td>~</td>
<td>Free field for card identification</td>
<td>1-10, 11-17, ...</td>
</tr>
<tr>
<td>3</td>
<td>EBH(I)</td>
<td>Effective barrier height at grid I in meters, see figure 10 for definition. Use as many cards as needed starting with grid 1 on card 1.</td>
<td>18-24, ...</td>
</tr>
<tr>
<td><strong>SET 14 - BED PROPERTIES</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>~</td>
<td>Free field for card identification</td>
<td>1-10, 11-17, ...</td>
</tr>
<tr>
<td>3</td>
<td>DIF</td>
<td>Thermal diffusivity of the bed material, in square centimeters per hour</td>
<td>18-24, ...</td>
</tr>
<tr>
<td>3</td>
<td>CV</td>
<td>Heat storage capacity of the bed material, in calories per cubic centimeter per degree Celsius</td>
<td>18-24, ...</td>
</tr>
<tr>
<td>Card no.</td>
<td>Models using</td>
<td>Variable</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>--------------</td>
<td>----------</td>
<td>-------------</td>
</tr>
<tr>
<td>1Aa</td>
<td>1,2,3,4</td>
<td>~</td>
<td>Free field for card identification</td>
</tr>
<tr>
<td></td>
<td>1,2,3,4</td>
<td>TUP or</td>
<td>Concentration or temperature (Celsius) at the</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TUP(1)</td>
<td>upstream boundary at time 0 + ΔT</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>TRIB(IGT(N))</td>
<td>Concentrations or temperatures (Celsius) of tributary inflows during the first time step.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Values must be input in sequence working downstream. One value for each tributary must be entered, but no more than 9 values can be entered on the first card.</td>
</tr>
<tr>
<td>2,3,4</td>
<td>TA</td>
<td></td>
<td>Air temperature in degrees Celsius during the first time step</td>
</tr>
<tr>
<td>2,3,4</td>
<td>V</td>
<td></td>
<td>Windspeed in meters per second during the first time step</td>
</tr>
<tr>
<td>2,4</td>
<td>TRIB(IGT(N))</td>
<td></td>
<td>Concentrations or temperatures (Celsius) of tributary inflows during the first time step</td>
</tr>
<tr>
<td></td>
<td>or</td>
<td>TRIB(L,IGT(N))</td>
<td>Values must be input in sequence working downstream. One value for each tributary must be entered, but no more than 7 values can be entered on the first card.</td>
</tr>
<tr>
<td>3</td>
<td>HS</td>
<td></td>
<td>Total incoming solar radiation during the first time step, in calories per square centimeter per day</td>
</tr>
<tr>
<td>3</td>
<td>HL</td>
<td></td>
<td>Total incoming atmospheric radiation during the first time step, in calories per square centimeter per day</td>
</tr>
<tr>
<td>3</td>
<td>EA</td>
<td></td>
<td>Vapor pressure of the air during the first time period, in kilopascals</td>
</tr>
<tr>
<td>1Ab, 1Ac</td>
<td>1,2,3,4</td>
<td>~</td>
<td>Free field for card identification</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TRIB(IGT(N))</td>
<td>Concentrations or temperatures (Celsius) of tributary inflows during the first time step</td>
</tr>
</tbody>
</table>

**TABLE 1.**—A description of the data input, sequence, and arrangement—Continued
<table>
<thead>
<tr>
<th>Card no.</th>
<th>Models using</th>
<th>Variable</th>
<th>Description</th>
<th>Columns</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>TRIB(L,IGT(N))</td>
<td>Values must be input in sequence working downstream. No more than 10 values can be entered by use of this card. The first value will be for tributary 10 in model 1, tributary 8 in models 2 and 4, and tributary 1 in model 3. Use as many cards as necessary to enter all tributary values.</td>
<td>...</td>
</tr>
<tr>
<td>1Ba</td>
<td>4</td>
<td>~</td>
<td>Concentration of constituent 2 at upstream boundary at time 0 + ΔT</td>
<td>73-80</td>
</tr>
<tr>
<td>2Aa</td>
<td></td>
<td>TUP(2)</td>
<td>Concentrations of constituent 2 in tributary inflow during the first time step. Values must be input in sequence working downstream. One value for each tributary but only 9 values on this card.</td>
<td>...</td>
</tr>
<tr>
<td>1Bb, 1Bc</td>
<td>4</td>
<td>~</td>
<td>Free field for card identification</td>
<td>73-80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TRIB(L,IGT(N))</td>
<td>Additional tributary concentrations as needed</td>
<td>11-17,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Follow by identical card sequences for the other constituents</td>
<td>18-24,</td>
</tr>
<tr>
<td>2Aa</td>
<td></td>
<td></td>
<td>Same as card 1Aa, except for time 0 + 2ΔT.</td>
<td>73-80</td>
</tr>
<tr>
<td>2Ab</td>
<td></td>
<td></td>
<td>Same as card 1Ab, except for time 0 + 2ΔT.</td>
<td>73-80</td>
</tr>
</tbody>
</table>
TABLE 1.--A description of the data input, sequence, and arrangement--Continued

<table>
<thead>
<tr>
<th>Card no.</th>
<th>Models using</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SET 15 - BOUNDARY CONDITIONS--Continued</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2Ac</td>
<td>Same as card 1Ac, except for time $0 + 2\Delta T$.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2Ba</td>
<td>Same as card 1Ba, except for time $0 + 2\Delta T$.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2Bb</td>
<td>Same as card 1Bb, except for time $0 + 2\Delta T$.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>.</td>
<td></td>
<td>.</td>
</tr>
<tr>
<td></td>
<td>.</td>
<td></td>
<td>.</td>
</tr>
<tr>
<td></td>
<td>.</td>
<td></td>
<td>.</td>
</tr>
<tr>
<td></td>
<td>Follow by identical sequences of cards for each time step.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
mouth. The format for these cards is (10X, 10F7.3) where the first 10 spaces on each card is a free field (line 0035, attachment A). The grid point locations as well as all other grid information must be input in sequence starting at the upstream end and working downstream. Of course, only cards as needed are used.

The next group of data (set 5 in table 1) contains the cross-sectional area at each grid point expressed in square meters. The format for these data is the same as for the X-coordinates. The conservative transport model does not need the river top widths contained in the sixth set of cards.

The next group of data (set 7 in table 1) contains information concerning the location and flow for each tributary. One card is used for each tributary and on each card the location (grid number, IGT) and discharge [FLOW(4,1)] in cubic meters per second are given. The format is 10X, 17, F7.2 (line 0040, attachment A). If no tributaries are present, no cards are needed.

The next group of data (set 8 in table 1) contains the dispersion factor values (DQQ) representative of each grid point. The DQQ values (NXSEC values) are input with the standard format (10X, 10F7.3).

The next group of data (set 9 in table 1) contains the initial concentration at each grid point, PT(K), input with the standard format. Data sets 10, 11, 12, 13, and 14 are needed only for the complete temperature model.

Finally, the boundary conditions are read with at least one card for each time step (set 15 in table 1). The first card should contain information relative to the time 0 + Δt hours. The first piece of information on this card is the upstream concentration followed by the concentration at each tributary. The tributary concentrations must be in sequence with the upstream-most tributary being given first. The standard format is used. If 9 or less tributaries exist, all information for each time step will be on one card. If 10 or more tributaries exist, more than one card will be required. The concentrations for tributary number 10 will be the first number on card 2, the concentration of tributary 20 will be the first number on card 3, and so forth.

At the end of the program listed in attachment A is a listing of the data cards used to generate an example problem. This problem has eight grid points and runs for forty 1-hour time steps. The upstream discharge is 12.00 m³/s and the output is computed at grid 6 as well as at the downstream end. The print interval is every time step and one tributary exists. The third card contains the river mile of each of the eight grid points and the fourth card contains the cross-sectional areas.
in square meters. The fifth card indicates that a tributary enters at grid 5 with a discharge of 0.65 m$^3$/s. The mean velocity through the reach is expected to be about 0.5 m/s and the mean depth is about 0.4 m. Assuming a dispersion coefficient of 45 m$^2$/s, equation 7 gives the value of the dispersion factor to be 0.05. A dispersion coefficient of 45 m$^2$/s is 1,125 times the product of the depth and the shear velocity if the shear velocity is one-fifth of the mean velocity. All values of DQQ are equal to 0.05 as seen on the sixth card and all initial concentrations are zero, card 7. The rest of the cards are the boundary conditions with the time step number shown in columns 3 and 4.

The output of the example problem is shown in attachment A. The first part of the output is self explanatory. The output labeled "Initial Conditions" represents the steady-state flow conditions in the steady flow model. The computed data are contained in the third part of the output. The first column is time in days and hours with day 1 being the first day of the model simulation and the hour being clock time. The next 5 columns refer to the interior grid IGO (in this case grid 6). The second column is the concentration at grid 6 for the time in column 1. The traveltime is the time required for the parcel centroid to traverse the distance from grid 1 to grid IGO (grid 6 in the example). However, if the traveltime is more than the time lapsed since the start of the simulation, this lapsed time is given. The model simulation started at 4 hours past midnight (JTS = 4 since $\Delta t = 1$ hour), and the first output occurs at hour 5.00. Therefore, the traveltime for this entry is 1.00 hours. The traveltimes increase systematically for 8 hours, at grid 6, because it takes 8.56 hours for a parcel to traverse the reach. During the initial period when the traveltime equals the lapsed time, the computed concentration is highly dependent on the initial conditions.

The fourth column is the concentration the parcel had when it was at grid 1. Columns 5 and 6 are the changes in the parcel concentration which occurred during its transit from grid 1 due to dispersion and tributary dilution. The values in these columns were determined by evaluating the integrals on the righthand side of equation 5. To illustrate, consider the output on day 1 at 15.00 hours. The parcel at grid 6 on day 1, hour 15, entered the system 8.45 hours earlier (1 day, 6.55 hours) with an initial concentration of 30.0. During its 8.45-hour transit from grid 1, dispersion decreased its concentration by 0.87, while tributary dilution increased its concentration by 0.28. The parcel, therefore, arrived at grid 6 with a concentration of $30.00 - 0.87 + 0.28 = 29.41$ as shown in column 2.

The last 5 columns contain the same information except that this information pertains to the downstream most grid (grid 8 in the example). For example, the parcel which occupies grid 8 on day 2, hour 4.00, entered the system at grid 1 on day 1, hour 14.56, with a concentration
of 0.00. During its 13.44-hour transit, dispersion increased its concentration by 5.36, and tributary dilution increased its concentration by 1.66. The parcel arrived at grid 8 with a concentration of $0 + 5.36 + 1.66 = 7.02$ as shown in column 8.

Figure 5 contains a plot of input concentration as well as the computed concentrations at grids 6 and 8 for the entire time period. The peak concentration due to the center input pulse appears truncated at grids 6 and 8. This occurs because the concentration at these grids is obtained by linear interpolation between parcels on either side of the grid. By chance, the parcel with the peak concentration did not stop near grid 6 so the linear interpolation was poor. This apparent error could be corrected by using a shorter time step.

SIMPLIFIED TEMPERATURE MODEL

It is often necessary to be able to predict either natural or elevated river temperatures, but rarely are complete meteorological data available. The simplified temperature model allows one to simulate approximate river temperatures with a minimum of meteorologic data. Only equilibrium temperature and windspeed are required. And of these two the equilibrium temperature is by far the most important. It is believed that air temperature can be substituted for equilibrium temperature for most practical applications to predict water temperatures to within $\pm 1$ or $2^\circ C$.

Rewriting equation 1 where the transportable substance is heat, one obtains

$$\frac{\partial T}{\partial t} + \frac{\partial u'T'}{\partial x} = \frac{HW}{Ap} + \phi$$

(10)

in which $T =$ water temperature, $H =$ net addition of thermal energy to the water from the air per unit time and area of the parcel, respectively, or the width and area of the river at the location of the parcel, $p =$ density of water, $c =$ specific heat of water, and $\phi =$ additional source term to account for tributary inflow or heat sources. The solution procedure for equation 10 is identical to that for equation 1, except for the addition of the surface exchange term.

The rate of exchange of energy between the water and air is a complex subject which has been discussed many times. One of the first and most complete analyses of the processes involved has been presented by E. Anderson (1954). In general, the net exchange, $H$, can be expressed as the sum of several processes as

$$H = H_N - H_B - H_e - H_c$$

(11)
Figure 5.--Dye concentrations for steady and unsteady flow.
in which $H = \text{net heat flux caused by incoming radiation from the sun and the sky}$; $H_B = \text{heat flux caused by longwave radiation emitted by the water}$; $H = \text{heat flux utilized by evaporation}$; and $H_c = \text{heat flux conducted from the water to the air as sensible heat}$.

The net incoming radiation, $H$, is a completely independent variable which does not depend on the water temperature. Although difficult, a direct measurement of this component is possible.

The other three components, on the other hand, are dependent variables which are functions of the water temperature. In general, these components cannot be measured directly but must be calculated from expressions involving the water temperature and measurable meteorologic variables.

The longwave radiation emitted by a water surface can be accurately computed using the Stefan-Boltzmann law for black-body radiation

$$H_B = \varepsilon \sigma (T + 273.16)^4 \quad (12)$$

in which $\varepsilon = \text{emissivity of water (0.97 unitless)}$, $\sigma = \text{Stefan-Boltzmann constant } 1.171 \times 10^{-7} \text{ [cal/cm}^2\text{d (K)}^4\text{]}$ and 273.16 converts to the Kelvin temperature scale, when the temperature, $T$, is given in degrees Celsius.

The thermal energy utilized by evaporation is expressed as

$$H = \rho L \psi (e_o - e_a) \quad (13)$$

in which $\rho = \text{density of water (1 g/cm}^3\text{)}$, $L = \text{latent heat of vaporization (} L = 595.9 - 0.545T \text{ cal/g)}$, $\psi = \text{empirical function of windspeed (wind function)}$ which relates the rate of evaporation to the vapor gradient $(e_o - e_a)$, $e_o = \text{saturation vapor pressure of air at a temperature equal to that of the water surface, in kilopascals}$, and $e_a = \text{vapor pressure of the air above the water, in kilopascals}$. The actual rate of evaporation is assumed to be determined from the semiempirical mass-transfer equation, or Dalton's law, as

$$E = \psi (e_o - e_a) \quad (14)$$

where $E = \text{evaporation rate in cm/d}$. The wind function is generally assumed to be of the form

$$\psi = \alpha + NV \quad (15)$$

in which $\alpha$ is a constant, $N$ is the mass-transfer coefficient, and $V$ is the windspeed in meters per second. From the thermal balance of a
canal, Jobson (1977a) found the values of $a = 0.302$ cm/d kPa and $N = 0.113$ cm/d (m/s) kPa. The value of $e_0$ can be determined from the water temperature using the empirical equation

$$e_0 = \exp \left[ 54.721 - \frac{6788.6}{(T + 273.16)} - 5.0016 \ln (T + 273.16) \right]$$

in which the saturation vapor pressure is in kilopascals when the temperature, $T$, is in degrees Celsius.

Assuming the eddy diffusivities of heat and mass are identical, which leads directly to the Bowen ratio concept, the conduction term can be expressed as

$$H_c = \gamma \rho L \psi (T - T_a)$$

in which $\gamma$ = the psychrometric constant [about 0.06 (kPa/°C)] and $T_a$ = air temperature in degrees Celsius.

The evaluation of all the components which contribute to the net surface exchange requires a considerable amount of meteorologic data, net radiation (solar and atmospheric plus the reflected components of each), windspeed, vapor pressure of the air and air temperature. These data are difficult to obtain and can present significant data handling problems. The simplified temperature model, therefore, approximates the net surface exchange from the commonly available parameters of windspeed and air temperature, which is assumed to approximate the equilibrium temperature.

The assumption that air temperature can be used to approximate the equilibrium temperature is based on the observed fact that, if conditions remain stable for a long period of time, the water temperature usually approaches the air temperature within 1° or 2°C. This observation can be verified for natural streams unaffected by reservoirs or thermal additions, by plotting the monthly or weekly average water and air temperatures verses time. Figure 6 contains a plot of the mean water temperature in Pigeon Creek near Evansville, Ind. (Shampine, 1977), along with mean monthly air temperatures at Evansville, as reported by Thackston and Parker (1971, p. 76). Figure 7 illustrates the relationship between average water and air temperature for the Miami Canal, near Miami, Fla. (U.S. Geological Survey, 1973, p. 127). Finally, figure 8 illustrates the relationship for the Kansas River near Topeka, Kans. (Burns, 1975, p. 103). Lowham and others (1975, p. 27) states that the Green River averaged about 2°C warmer than the air temperature over a 22-year period and that the difference was nearly constant. According to Williams (1971) the water temperature of the Delaware River between Narrowsburg and Barryville normally relates well to the air temperature.
Figure 6.--Comparison of water temperature in Pigeon Creek to the mean monthly air temperature at Evansville, Ind.
Figure 7.--Comparison of monthly average water temperature in Miami Canal at S-31 to monthly average air temperature at Miami, Fla.
Figure 8.--Comparison of monthly mean temperature of the Kansas River at Topeka to monthly mean air temperature at Topeka, Kans.
at Port Jervis. After the analysis of water temperatures in 10 streams in Texas, Rawson (1970, p. 4) concludes that the monthly water and air temperatures seldom differ by more than 2°C and often differ by no more than 1°C. It is seen that the average natural water and air temperatures tend to be very nearly equal in many parts of the country. So "on the average," the difference between the natural air and water temperatures appears to be small.

Of course the diurnal range in air temperature is much larger than that of the water, so comparison of instantaneous temperatures is meaningless. A simplified expression for the net surface exchange is

\[ H = -K(T - T_a) \]  

in which \( K \) is a positive surface exchange coefficient. Notice that as \( T = T_a \), \( H = 0 \) and no further temperature change occurs. If \( T \) is greater than \( T_a \), \( H \) is negative, meaning the water is losing heat and \( \partial T/\partial t \) is negative. Equation 18 has been used successfully to predict surface exchange on the Saint Lawrence River by Adams (1976) and it has been verified on a canal in the Netherlands by Sweers (1974).

The complete expression for the heat flux is (equations 11, 12, 13, 14, and 17)

\[ H = H_N = \varepsilon\sigma(T + 273.16)^4 - \rho L\psi [(e_o - e_a) + \gamma(T - T_a)] \]  

The empirical observation implies that at \( T = T_a \), \( H = 0 \) or

\[ H_N = \varepsilon\sigma(T_a + 273.16)^4 + \rho L\psi [e_o - e_a] \]  

This is a statement that back radiation and evaporation just balance the net heat absorbed from incoming radiation. On the average, this is a reasonable assumption. In order for equation 18 to accurately represent the net heat exchange it must be valid when the water temperature differs from the air temperature as well as when the two are equal. To insure this, the change in heat exchange with a change in water temperature must be the same for both equations 18 and 19. Differentiating equations 18 and 19 with respect to water temperature and setting the slopes equal gives

\[ \frac{\partial H}{\partial T} = -K = -4\varepsilon\sigma(T + 273.16)^3 - \rho L\psi \left[ \frac{\partial e_o}{\partial T} + \gamma \right] \]
from which \( K \) can be determined

\[
K = 4\varepsilon_0(T + 273.16)^3 + \rho L' \left[ \frac{\partial e_o}{\partial T} + \gamma \right]
\]  
(21)

in which the slope \( \frac{\partial e_o}{\partial T} \) has been evaluated at the water temperature, because it is to serve as the reference temperature. An accurate empirical expression for the slope of the vapor pressure curve in kilopascals per degree Celsius is

\[
\left. \frac{\partial e_o}{\partial T} \right|_T = 1.1532 \times 10^{11} \exp \left[ -\frac{4271.1}{(T + 242.63)} \right] / (T + 242.63)
\]  
(22)

The simplified surface exchange equation is, therefore, equation 18 wherein the value of \( K \) is evaluated from equations 21 and 22. Although equation 18 appears linear in temperature, it really is not, because \( K \) is also a function of water temperature.

Expressing the conservation of thermal energy in a water parcel by use of equation 5, wherein the surface exchange is computed by use of equation 18, one obtains the equation

\[
C = C_0 - \int_0^t \frac{\partial (D \frac{\partial C}{\partial \xi})}{\partial \xi} dt' + \int_0^t \phi dt' + \int_0^t \kappa(C - T_a) dt'
\]  
(23)

in which \( C \) is temperature, and \( \kappa = \frac{K W}{A D C} \) is the kinematic surface exchange coefficient. Equation 23 is identical to equation 5 except for the added decay term, which accounts for heat transfer at the air-water interface. The solution procedure is likewise identical except for the added steps necessary to evaluate the last integral. Basically, this is accomplished by the addition of two subroutines, one called DECAY, which evaluates the last integral, and one called FINK, which finds the value of the kinematic decay coefficient (\( \kappa \)). These subroutines are called at least once for each parcel at each time step. Subroutine DECAY subdivides the time step into smaller values (DTM) such that in the time DTM the temperature never changes by more than 10 percent of the remaining deficit \( (T - T_a) \) or more than 0.3°C, whichever is larger. Since the value of \( \kappa \) may be different for each subreach, the subroutine DECAY is called each time a parcel passes an interior grid. For each partial time step a simple Runge-Kutta type integration is performed.

The basic program for the simplified temperature model is almost identical to the program for conservative transport with 3 exceptions. First, the additional parameters of top width, \( W(I) \), windspeed, \( V \), air
temperature, TA, and coefficients for the wind function $A_l$, $B_l$ must be read in. Second, an additional array $PDC(K)$ is set up to keep track of the total temperature change due to surface exchange, and finally subroutine DECAY is called each time a parcel passes a grid point or stops in a subreach. A flow chart of subroutine DECAY is shown in figure 9. A listing of the code is shown in attachment B.

Table 1 contains a description of the data input, sequence and arrangement used for all models including the simplified temperature model. The simplified temperature model requires only the data cards or data with a "2" in column 2 of table 1. The input is the same as used in the conservative transport model except as explained below.

The first card, the information card, is identical to that used previously. The second data card, the header card, includes all information included previously plus the constant term in the wind function ($A_l$), and the mass transfer coefficient in the wind function ($B_l$), which are added to the end of the variable list. The format for the header card is 2I5, 2F10.2, 4I5, 2F10.2 (line 0036 in attachment B). From the thermal balance of the San Diego Aqueduct, Jobson (1977a) found the values $A_l = .302$ cm/d kPa and $B_l = .113$ cm/d (m/s) kPa.

The third set of cards are not required, and the fourth and fifth sets are identical to those described previously.

The sixth set of cards contains the top widths of the river, in meters, at each grid point. This group of cards was not needed in the conservative transport model. The format is the same as the input of the areas and coordinates, with the width at grid 1 given first. The format for these data is the same as for most other sets, 10X, 10F7.3, with the first 10 spaces a free field for card identification (line 0038, attachment B).

The seventh, eighth, and ninth sets of cards are identical to those used previously while sets 10-14 are not required.

Finally, the boundary and meteorological conditions are read with data set 15. At least one card is needed for each time step. The first card contains information relative to time $0 + \Delta t$ hours. Each card contains the upstream temperature ($T_{UP}$) in degrees Celsius, the air temperature ($TA$) in degrees Celsius, the windspeed ($V$) in meters per second, and the temperature of each tributary ($TRIB(N)$) in degrees Celsius starting with the upstream most tributary. The format for the boundary condition cards is 10X, 10F7.3 (line 0038, attachment B). The upstream temperature, air temperature, and windspeed are input first, so if more than 7 tributaries exist, more than one card will be required for each time step. Tributary temperatures for tributaries number 8 through 17 would be input on the second card.
Figure 9.—Flow chart of subroutine DECAY in simplified temperature model. Variables ending in Ø designate old values. The value of XKN is evaluated at T1.
At the end of the program listed in attachment B is a listing of the data cards used in an example problem. The problem is identical to the one run for conservative transport except the data of upstream temperature, river width, air temperature, and windspeed have been added.

Finally, the output of the example problem is shown in attachment B. The first part of the output is self explanatory. The output labeled "Initial Conditions" lists the steady-state flow conditions in the steady-flow model. The model output is the third part of the listing. The first column is the time in days and hours. The next 6 columns refer to the interior grid IGØ (in this case grid 6). The second column is the temperature at grid 6 for the time in column 1. The traveltime is the time required for the parcel to traverse the distance from grid 1 to grid IGØ (6). If the model has been running less than the traveltime, this column represents the time the model has been running. The fourth column is the temperature the parcel had when it was at grid 1. Columns 5, 6, and 7 are the changes in the parcel temperature which occurred during its transit from grid 1 due to dispersion, tributary dilution, and surface exchange, respectively. The values in these columns were determined by evaluating the integrals on the right-hand side of equation 23. To illustrate, consider the output on day 2 at 16.00 hours. The parcel at grid 6 on day 2, hour 16.00, entered the system 8.45 hours earlier (day 2, 7.55 hours) with an initial temperature of 13.73°C. During its 8.45-hour transit from grid 1, dispersion had no measurable effect on its temperature, while tributary dilution increased its temperature by 0.09°C and heat exchange with the atmosphere increased its temperature by 6.22°C. The parcel, therefore, arrived at grid 6 with a temperature of 20.04°C as shown in column 2.

The last 6 columns contain the same information except that this information pertains to the downstream most grid (grid 8 in the example.) For example, the parcel which occupies grid 8 on day 2, hour 16.00, entered the system at grid 1 on day 2, hour 2.56, with a temperature of 10.94°C. During its 13.44-hour transit dispersion decreased its temperature by 0.03°C, tributary dilution increased its temperature by 0.25°C, and surface exchange increased its temperature by 9.92°C. The parcel arrived at grid 8 with a temperature of 10.94 - 0.03 + 0.25 + 9.92 = 21.08°C as shown in column 8.

COMPLETE TEMPERATURE MODEL

If meteorological data are available, the complete temperature model can give highly accurate results as shown by Jobson (1978), as well as Jobson and Keefer (1979). The additional data required for the complete temperature model include: incoming solar radiation, incoming atmospheric radiation, vapor pressure of the air, thermal heat capacity
and diffusivity of the bed material, longitude, latitude, the Julian date, the meridian of the time zone, and for each subreach, the azimuth of the river, the effective barrier height of the trees along the banks, and the bank width (distance from the water edge to the trees).

The basic transport equation and solution scheme are identical to that used for the simplified temperature model (equation 10). But the complete equation set for the surface exchange (equations 11, 12, 13, 14, 15, and 17) is used instead of the simplified expression (eq. 18). In addition, the heat exchange between the water and the bed material is included. The bed conduction term is treated just like the surface exchange terms in the model.

The incoming solar and atmospheric radiation should be observed in an open area. Three percent of the atmospheric radiation is assumed to be reflected (E. Anderson, 1954, p. 98). The procedure used to estimate the part of the measured solar radiation actually absorbed by the water can be briefly explained as follows. The first step is to determine the part of the available solar radiation which would be absorbed providing no shading occurs. This shade-free absorption is calculated using an expression proposed by E. Anderson (1954, p. 85) for clear sky conditions.

\[
RS = 1 - 1.18 S_A^{-0.77}
\]

(24)
in which \(RS\) is the portion of the incoming solar radiation absorbed by the water and \(S_A\) is the altitude of the sun in degrees. Next, the shade-free absorption is reduced to account for shading of the water due to trees and banks. It is assumed that the shaded part of the water surface will absorb 20 percent of the incoming solar radiation and that the clear part will absorb at the rate indicated by eq. 24. The part of the water surface in any subreach to be shaded at any time of day is determined from the geometric relation between the elevation and azimuth of the sun, the azimuth of the subreach, the water surface width, the bank width, and the effective barrier height. The physical relationship between these terms is illustrated in figure 10. The river cross section is assumed to be symmetric about the centerline. At the beginning of the program the RS values, adjusted for shading, are computed for each subreach at 15-minute intervals throughout the day. In the temperature simulation the RS value for the subreach and time of day (to the nearest 15 minutes) is selected from the array which has been previously set up. A flow chart of subroutine CRS, which computes the RS values, is shown in figure 11.

The bed conduction term is evaluated in the manner outlined by Jobson (1977b). In this method the heat exchange between the water and the bed is estimated by considering the bed material to be a homogeneous
Figure 10.—Schematic of river cross section used to determine the part of the water surface to be shaded by bank vegetation.
A B

Start

Read Geometric Data

Compute Declination of Sun and Convert Angles to Radians

DØ 10 Start Time Loop

Compute Hour Angle (HA)

Compute Elevation of the Sun (ELEV)

Compute Shade-Free Absorption (RSM)

Compute Azimuth of Sun (AZS)

Start Grid Loop

A B

IS SUN ABOVE HORIZON?

YES

Compute Normal Distance to Shade Point (x)

IS ANY WATER SHADED?

NO

RS = RSM

YES

IS ALL WATER SHADED?

NO

Compute Absorption for Partly Shaded River

NO

RS = 0.2

YES

RS = 0.2

Write Selected Results

Return

Figure 11.--Flow chart for subroutine CRS, which computes the absorption coefficients for solar radiation in the complete temperature model.

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conducting medium with a surface temperature equal to that of the overlying water and the bottom, at some large distance below the bed, insulated. The heat flux into or out of the bed is then determined as a function of the past history of the water temperature. Only the thermal diffusivity and heat storage capacity of the soil need to be known. The heat flux from the bed to the water, which would occur at time $t$ due to a unit decrease in surface temperature at time zero, is first computed for various values of $t$ using standard formulas (Carslaw and Jaeger, 1959, p. 101.) These terms, called response function ordinates, describe the time variation of the response of the bed to a unit change in water temperature. They are computed once at the beginning of the program by use of subroutine BEDFX. The values are stored for later use in an array called $RF\phi(K)$.

Since water temperature fluctuations can be represented by a series of step changes, the superposition principle is used to determine the heat flux from the bed to the water for any temperature history of the water by use of the equation

$$ \text{BED}(I) = \sum_{K=J-s}^{J} RF\phi(J-K) \cdot DBT(K, I) $$

in which $\text{BED}(I)$ is the heat flux to the water from the bed at grid $I$ and time $JDT$, $DBT(K, I)$ is the change in water temperature which occurred at $KDT$ and grid $I$, and $s$ determines the memory length of the system. The program truncates the response function ordinates after 24 hours, so the memory of the system is limited to 24 hours. Because most water temperature variations are diurnal in nature and because the thermal diffusivity of most soils is such that the response function ordinate has reached nearly a constant value after 24 hours it is believed that a 24-hour memory is sufficient for modeling temperature in rivers. The temperatures at each grid point are determined by interpolation between parcels at each time step. A flow chart of subroutine BEDFX, which computes the response function ordinates, temperatures at each Eulerian grid, and the bed flux at each grid is shown in figure 12.

The complete temperature model is very similar to the simplified temperature model except: (a) additional meteorological data are required on the boundary condition cards; (b) subroutine FINK is more complex because it computes the total surface exchange from equations 11, 12, 13, 14, 15, and 17 rather than simply equations 18, 21, and 22; (c) the absorption coefficients for each time of day and grid point are computed by subroutine CRS; and (d) the flux of heat from the bed to the water is computed for each grid point and time step by subroutine BEDFX.

The input data cards for the complete temperature model are similar to those of the simplified temperature model. The first two data cards are, in fact, identical to those used in the simplified temperature
Figure 12.--Flow chart of subroutine BEDFX, which computes the response function ordinates, water temperatures at Eulerian grids, and the heat flux from the bed to the water.
The format statements for these two cards are given as lines 0038 and 0040 in the listing of the main program of attachment C. Table 1 summarizes data input arrangements for all models. Only those cards or variables indicated for model 3 in column 2 of table 1 are necessary.

The third set of cards (Table 1) are not needed and the fourth, fifth, sixth, seventh, eighth, and ninth sets are identical to those of the simplified temperature model.

Data sets 10 through 13 contain information necessary to compute the absorption coefficient for solar radiation. Set 10 contains the Julian data (JDAT), the latitude (PHI in degrees), the longitude (ALN in degrees), and the longitude of the meridian of the time zone (TZM in degrees). The format is 10X,I7,3F7.1 (line 0006 in CRS of attachment C).

Data set 11 contains the azimuth of the river at each grid point measured clockwise from north in degrees. The format is 10X, 10F7.1 (line 0010 in CRS of attachment C).

Data set 12 contains the bank width of the river at each grid point expressed in meters. The bank width (BW) is the horizontal distance from the water's edge to the highest point in the shade barrier of the bank, see figure 10. The format for these data is also 10X, 10F7.1 (line 0010 in CRS of attachment C).

Data set 13 contains the effective barrier height, EBH, (figure 10) expressed in meters. The format for these data is also 10X, 10F7.1 (line 0010 in CRS of attachment C).

Data set 14 contains information necessary to compute the flux of heat from the bed. This card contains the thermal diffusivity of the bed (DIF in cm²/h) and the heat storage capacity of the bed material [CV in cal/(cm³°C)]. The format is 10X,2F7.3 (line 0008 in BEDFX of attachment C). Braslavskii and Vikulina (1963) suggest values of DIF = 27.72 cm²/h and CV = 0.68 cal/(cm³°C) for saturated sand. Troxell and others (1956) reported values of DIF to range from 21.96 cm²/h to 50.76 cm²/h and CV = 0.55 cal/(cm²°C) for concrete dams.

The final group of data cards (set 15) contains the boundary and meteorological data for each time step in the model. The first card in this group contains only the upstream temperature at the end of the first time step (TUP, in degrees Celsius), and meteorological data representative of conditions during the first time step. The meteorological data include the air temperature (TA, in degrees Celsius), the
windspeed ($V$, in meters per second), the incoming solar radiation ($HS$, in calories per square centimeters per day), the incoming atmospheric radiation ($HL$, in calories per square centimeter per day), and the vapor pressure of the air ($EA$, in kilopascals). The read statement is given in line 0120 of attachment C and the standard format (10X, 10F7.3) is given in line 0040. If no tributaries are present, only one card will be required for each time step. If tributaries are present the temperature of each tributary inflow at the time step is provided on cards following the meteorologic data for each time step. The tributary inflow temperatures are provided in sequence working downstream with 10 tributaries on each card (line 0121 in attachment C). The standard format is used. Lines 0120 and 0121 are executed once for each time step in the model so meteorologic data for time step 1 should be followed by the tributary inflow temperature cards for time step 1, which in turn is followed by the meteorologic data card for time step 2, and so forth.

At the end of the program listed in attachment C is a listing of the data cards used to generate the example problem. The problem is identical to the one run for the simplified temperature model except for the added data necessary for the complete temperature model. The output of the example problem is also shown in attachment C. The first part of the output is self explanatory. The second part of the output lists the portion of the incoming solar radiation absorbed at each grid and each hour of the day from 5 a.m. to 7 p.m. The effective barrier height, bank width and azimuth of the river is also shown for each grid point. The third part of the output shows the response of the bed in cal/cm$^2$h to a unit change in water temperature for various times (lags) after the water temperature change occurred. For example, 5 hours after a unit decrease in water temperature occurs (lag 5 and $DT =$ one hour) the bed would transfer heat to the water at a rate of $0.95$ cal/cm$^2$h ($RFO = 0.95$). If the time step size is less than 15 minutes the $RFO$ values will be tabulated at 15-minute intervals. The fourth part of the output is identical to that in previous programs in that it shows the hydraulic properties and initial temperature of the river at each grid point. The first column of the last part of the output is the current time in days and hours. The next 6 columns refer to the interior grid IGO (in this case grid 6). The second column is the temperature at grid 6 for the current time in column 1. The traveltime is the time required for the parcel to traverse the distance from grid 1 to grid IGO (6). If the model has run a sufficient time the fourth column is the temperature the parcel had when it was at grid 1. Columns 5, 6, and 7 are the changes in the parcel temperature which occurred during its transit from grid 1 due to dispersion, tributary dilution, and surface exchange (including bed conduction), respectively. To illustrate, consider the output on day 2 at 12.00 hours. The parcel at grid 6 on day 2, hour 12, entered the system 8.45 hours earlier (2 days, 3.55 hours) with an initial
temperature of 12.22°C. During its 8.45-hour transit from grid 1, dispersion decreased its temperature by 0.02°C, while tributary dilution increased its temperature by 0.38°C and heat exchange with the atmosphere and bed increased its temperature by 2.16°C. The parcel, therefore, arrived at grid 6 with a temperature of 14.71°C as shown in column 2.

The last 6 columns contain the same information except that this information pertains to the downstream-most grid (grid 8 in the example). For example, the parcel which occupies grid 8 on day 2, hour 16.00, entered the system at grid 1 on day 2, hour 2.56, with a temperature of 12.67°C. During its 13.44-hour transit, dispersion decreased its temperature by 0.07 °C, tributary dilution increased its temperature by 0.38°C, and heat exchange with the atmosphere and bed increased its temperature by 3.09°C. The parcel arrived at grid 8 with a temperature of 12.67 - 0.07 + 0.38 + 3.09 = 16.07°C as shown in column 8.

10-PARAMETER GENERAL TRANSPORT MODEL

Many water-quality parameters are interdependent. For example, the concentration of dissolved oxygen in a stream is a function of the concentration of several other parameters such as BOD, ammonia, nitrite, nitrate, and so forth. In order to model water quality, therefore, it is usually necessary to model several interdependent parameters simultaneously. This means that the conservation equation must be written for each constituent and then the equations must be solved simultaneously. The 10-parameter transport model was developed to accomplish this task.

To illustrate the procedure, a temperature, DO, BOD system will be used as an example. The first step is to write the transport equation, in the Lagrangian reference frame, for each constituent. For the temperature of a parcel, assuming the simplified temperature model is adequate,

\[
\frac{\partial T}{\partial t} + \frac{\partial}{\partial \xi} D \frac{\partial T}{\partial \xi} = \chi_{1,1} (T - T_a) - \phi_T + S_T
\]  

in which \( T = \) temperature, \( \chi_{1,1} = \chi \) of equation 23, \( S_T \) is a term to account for the production of heat within the water (generally zero), and all other terms are as defined in equation 23 except the tributary source term, \( \phi_T \), has been subscripted.

For dissolved oxygen

\[
\frac{\partial DO}{\partial t} + \frac{\partial}{\partial \xi} D \frac{\partial DO}{\partial \xi} = \chi_{2,2}(DO - DO_S) + \chi_{2,3} BOD + \phi_D + S_D
\]

in which \( DO = \) concentration of dissolved oxygen (mg/L), \( \chi_{2,2} = \) negative of the reaeration rate coefficient (commonly referred to as \( K_2 \)), \( DO_S = \) saturation value of dissolved oxygen (which is a function of temperature), \( BOD = \) biochemical oxygen demand, \( \chi_{2,3} = \) the negative of
the biochemical oxidation rate coefficient (commonly referred to as $K$), $S_D$ = distributed source of dissolved oxygen in the water, and $\phi_D$ = source of dissolved oxygen from point sources such as inflows.

For biochemical oxygen demand

$$\frac{\partial BOD}{\partial t} + \frac{\partial}{\partial x} D \frac{\partial BOD}{\partial x} = XK_{3,3} BOD + \phi_B + S_B \quad (28)$$

in which $XK_{3,3}$ = the sum of the biochemical oxidation rate coefficient ($-K$) and the sedimentation rate coefficient for BOD, $S_B$ = distributed sources of BOD in the water, and $\phi_B$ = sources of BOD from tributaries or point sources.

Equations 26, 27, and 28 are similar in form and can be written in consistent, but general, notation as follows.

Temperature

$$\frac{\partial C_1}{\partial t} + \frac{\partial}{\partial x} D \frac{\partial C_1}{\partial x} = XK_{1,1} (C_1 - CR_{1,1}) + XK_{1,2} (C_2 - CR_{1,2})$$

$$+ XK_{1,3} (C_3 - CR_{1,3}) + S_1 + \phi_1$$

DO

$$\frac{\partial C_2}{\partial t} + \frac{\partial}{\partial x} D \frac{\partial C_2}{\partial x} = XK_{2,1} (C_1 - CR_{2,1}) + XK_{2,2} (C_2 - CR_{2,2})$$

$$+ XK_{2,3} (C_3 - CR_{2,3}) + S_2 + \phi_2$$

BOD

$$\frac{\partial C_3}{\partial t} + \frac{\partial}{\partial x} D \frac{\partial C_3}{\partial x} = XK_{3,1} (C_1 - CR_{3,1}) + XK_{3,2} (C_2 - CR_{3,2})$$

$$+ XK_{3,3} (C_3 - CR_{3,3}) + S_3 + \phi_3 \quad (29)$$
in which \( C_1 = \) temperature, \( C_2 = \) DO, \( C_3 = \) BOD, and so forth. In particular, \( XK_{1,2} = XK_{1,3} = XK_{2,1} = XK_{2,3} = XK_{3,1} = XK_{3,2} = 0 \). The \( CR_{L,N} \) values represent the reference concentrations. For example, \( CR_{1,1} = TA, CR_{2,2} = \) saturation value of DO (DO\(_S\)) and \( CR_{3,3} = 0 \). Equation 29 can then be written concisely in a form convenient for computational manipulation.

\[
\frac{\partial C_L}{\partial t} + \frac{\partial}{\partial x} \left( D_L \frac{\partial C_L}{\partial x} \right) = S_L + \sum_{N=1}^{M} XK_{L,N} (C_N - CR_{L,N})
\] (30)

The values of \( XK_{L,N}, CR_{L,N}, \) or \( S_L \) may be a function of time, space or even the concentrations of other constituents.

The approach to solving the \( M \) equations represented by 30 is the same as that used for the simplified temperature model, that is, in subroutine DECAY the time step is subdivided into smaller values (DTM) such that in the time DTM the concentration of no parameter changes by more than 10 percent of the remaining deficit (\( C_N - CR_{L,N} \)) or more than 0.3 units, whichever is larger. Since the values of \( XK_{L,N} \) may differ from subreach to subreach, the subroutine DECAY is called each time a parcel passes an interior grid. For each part of the time step a simple Runge-Kutta type integration is performed. The value of each of the coefficients \( S_L, XK_{L,N}, CR_{L,N} \) is determined in subroutine FINK just as in the simplified or complete temperature model. Subroutine FINK is called twice for each part of the time step so that the values of the coefficients are updated in the event that they are functions of the concentration of the other constituents.

Figures 13, 14, and 15 contain simplified flow charts of the 10-parameter transport model, subroutine DECAY, and subroutine FINK, respectively. In general, the only difference between this model and the simplified temperature model is that subscripts have been added to temperature variables to designate the particular parameter. For example, the old variable \( PT(K) \), the temperature of parcel \( K \), becomes \( PT(L,K) \) in which \( L \) designates the particular constituent and \( K \) remains the parcel number. The program allows up to 10 constituents to be modeled, the number being modeled is designated by \( NEQ \) (number of equations). The model could be expanded to track more than 10 constituents simply by increasing the array sizes in the dimension and common statements. The model input and output is specifically set up assuming temperature will be modeled by the simplified model and will be constituent number one. Almost any model will require temperature, so this is not believed to be a serious limitation.

The main program and subroutine DECAY are completely general and simply solve equation 30 for any number of constituents. It is up to the modeler to define the coefficients \( S_L, XK_{L,N}, \) and \( CR_{L,N} \) in subroutine
10-Parameter Model

Define Variables

Dimensions And Preliminaries

Read Input

Process Input Data
Compute Reach Average Hydraulics

J=1, NHR Start Time Loop

Compute Dispersive Fluxes for Each Constituent

0.4

A

End

B

Compute Characteristics of Downstream Parcel

Call DECAY for Last Parcel

Move Interior Parcels, Call DECAY Each Time a Parcel Passes a Grid Point or Stops in a Subreach

Transfer Boundary Conditions to Parcel Characteristics

Dilute the Concentration of Each Constituent for Tributary Inflow

Interpolate Parcel Characteristics to the Interior Grid IGO

Print Results

Figure 13.--Generalized flow chart for the 10-parameter transport model.

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Figure 14.--Generalized flow chart for subroutine decay in the 10-parameter model.
SUBROUTINE FINK

Common Statement

Set Constants for Heat Exchange

Compute Surface Exchange Coefficient

Compute XK(1,1)

Set CR(1,1) Equal to Air Temperature

Set Other XK, CR, and S Values

Return

Figure 15.--Generalized flow chart for subroutine FINK in the 10-parameter model.
FINK such that equation 30 is a realistic description of the interaction of the constituents involved. These coefficients can be a function of the concentration of other constituents \([PT(L,K)]\), air temperature \((TA)\), windspeed \((V)\), cross-sectional area of the stream \([A(MX)]\), top width of the stream \([W(MX)]\), velocity of the stream \([U(MX)]\), or the time step number \((J)\) since all these variables are carried into subroutine FINK by use of a common statement. The change in concentration of each constituent due to any other single constituent can be tabulated.

In order to illustrate how to set the program up for a particular problem, attachment D contains a complete listing of the program which has been set up to model 3 parameters, temperature \((L=1)\), dissolved oxygen \((L=2)\), and biochemical oxygen demand \((L=3)\). All statements unique to these three parameters are in subroutine FINK. The temperature equation is developed first. Comparing equation 26 to equation 30 it is easily seen that all values of \(XK_{1,N}\) are zero except \(XK_{1,1}\) which is the surface exchange coefficient used formerly. Lines 3 through 10 of subroutine FINK compute the surface exchange coefficient. Notice that this coefficient is a function of the water temperature, and the windspeed, as well as the width and cross-sectional area of the river, which vary with time and location. The reference "concentration" for water temperature is the air temperature as seen in line 11. The source term for heat, \(S\), is zero so no definition is required. All values of the \(XK's\), \(CR's\) and \(S's\) are set equal to zero at the beginning of the program and will remain zero unless set otherwise in subroutine FINK.

The equation for dissolved oxygen (eq. 27) has more terms which are not zero. The river gains oxygen through reaeration at the surface with a rate dependent on the reaeration coefficient \(XK_{2,2}\) and the difference between the dissolved oxygen concentration \([PT(2,K)]\) and the saturation value for dissolved oxygen concentration \((CR_{2,2})\). The value of the reaeration coefficient is computed by use of an empirical formula in units of one per hour (Rathbun and Bennett, 1972, p. 58) in line 12. Notice this coefficient is also a function of the hydraulic properties of the stream. The saturation concentration of dissolved oxygen \((CR_{2,2})\) is computed as a nonlinear function of water temperature (statement 16). Oxygen is used up in the decay of the BOD. The rate coefficient is called \(XK_{2,3}\) in the model and has been assigned a value of \(-0.1\) per hour at \(20^\circ\text{C}\) (statement 14). The value is also corrected for temperature as shown in statement 13. The value assumed in this example is extremely large and should not be considered realistic. The large value was assumed so that a large part of the dissolved oxygen sag curve could be modeled in the 25-hour traveltime used in the example. The model suddenly stops the BOD decay when the dissolved oxygen level drops to 1 mg/L (statement 15). Again this is not necessarily a realistic representation of how the system behaves as the oxygen levels become very small, but it does illustrate how the model could be easily generalized to allow non-linear interactions.
Finally the equation for biochemical oxygen demand (BOD) (eq. 28) contains only one non-zero coefficient on the right side. The biochemical oxygen demand coefficient \( K_1 \) is also used as \( XK_{3,3} \). The value of \( XK_{3,3} \) is set equal to the value of \( XK_{2,3} \) in statement 17.

The example problem shown in attachment D has the same channel characteristics as used in the previous examples, except the upstream discharge is reduced to 6 m\(^3\)/s and the single tributary is assumed to occur at grid 2. The upstream temperature, as well as the air temperature and windspeed, are assumed to vary in the same manner as those assumed in the example for the simplified temperature model. The upstream concentration of DO and BOD are assumed constant at 10.0 and 2.0 mg/L, respectively. The tributary inflow of 0.65 m\(^3\)/s is assumed to have a constant temperature, DO, and BOD of 20°C, 3.0 mg/L and 100 mg/L, respectively.

The input cards for the 10-parameter model are similar to those for the previous models. The data input is summarized in table 1. The information card is identical to that used for all other models. The second data card contains the same information in the same format as in the temperature models, except that it has one additional parameter, the number of equations (parameters) to be modeled (\( NEQ \)). This number appears in columns 71-75, right justified. The format is given as statement number 0047 in the main program of attachment D.

The third set of cards contains labeling information and information about which part of the decay process the program is to tabulate. There must be one card for each parameter modeled (\( NEQ \) cards) and the cards must be in the same order as the equations to be modeled. That is, the label card for temperature must be first since temperature is always modeled as constituent number 1. For the example given above the dissolved oxygen card would be second and the BOD card would be third. Each card contains three items of information. The first is simply the parameter number (\( L \)), the second is an alphanumeric free field in which the parameter is named. In the example listed in attachment D the first parameter, temperature, is named TEMP, the second parameter, dissolved oxygen concentration, is named DO, and the third parameter, biochemical oxygen demand, is named BOD. The third item of information is a number which designates the particular decay process to be tabulated. The Lagrangian model integrates equation 30 with respect to time to obtain the parcel concentrations. The program is set up to retain the time integral of any single term of the summation on the right side of equation 30. The particular term \( N \), which is to be tracked, is designated by the number listed as the third parameter on the same card. For example, in the problem of attachment D the first name card is

\[
1 \quad TEMP \quad 1
\]

for which the first parameter is named TEMP and the time integral of the first term of the sum on the right of equation 30 is to be tabulated.
In this case the other two terms are identically zero. The decay term in the output for temperature is the change in temperature due to surface exchange. In the example the decay term in the DO parameter represents the integral of the second term, reaeration.

The fourth, fifth, sixth, seventh, and eighth sets of cards are identical to those of all previous models.

The ninth set of cards contains the initial conditions (temperature or concentration) at each grid point. The initial temperatures (parameter 1) are read first just as in the previous models. The format is 10X, 10F7.3 (line 0051, attachment D) for each parameter. After the initial temperatures are read the initial values of the concentrations of parameter 2 are read starting with a new card, then the initial conditions for parameter 3, and so forth.

The final group of data cards, set 15, contains the boundary conditions and meteorological data for each time step of the model. The first card in this group contains the upstream temperature at the end of the first time step [TUP(1), in degrees C], the air temperature (TAX, in degrees C), representative of conditions during the first time step, the windspeed (VX, in meters per second), representative of conditions during the first time step, and the temperature of as many as seven tributaries [TRIB(1,N)X, in degrees C], representative of inflow conditions during the first time step. If more than 7 tributaries exist, the second card will contain the temperatures of up to 10 more tributaries. The format for all boundary condition cards is 10X, 10F7.3 (line 0051, attachment D). The tributary temperatures must be input in sequence starting with the upstream-most tributary. After all tributary temperatures for time step 1 are input, the next card contains the upstream concentration of parameter 2 at the end of time step 1 followed by up to 9 tributary concentrations representative of time step 1. If more than 9 tributaries exist, the additional tributary concentrations are input by additional cards just like the tributary temperatures. Following the input of all tributary concentrations of parameter 2, time step 1, the upstream concentrations of parameter 3 is input followed by the concentrations of parameter 3 in all tributaries. After all boundary conditions are input for time step 1 the process is repeated for time step 2 and so on.

At the end of the program listed in attachment D is a listing of the data cards used to generate the example problem. The problem is identical to the one run for the simplified temperature model except the upstream discharge has been cut in half, and the tributary is input at grid 2 instead of grid 5. The river cross-sections are assumed to be the same as before. The output of the example problem is also shown
in attachment D. The first part of the output is self explanatory. The second part of the output contains the hydraulic and initial conditions at each grid. The initial values of all three parameters were assumed to be zero. The third part of the output contains the computed parameters for each time step where output is specified. The first line of each output step contains the time in days and hours, the traveltime from the upstream boundary to the output grid, either grid IGO or the downstream end of the reach. If this traveltime is equal to the total time the model has run, the parcel was in the system at time zero. The second line contains information relative to parameter 1 as described by the headings. The name of the parameter is listed first followed by the concentration or temperature of the parcel which currently occupies the location of the indicated grid. The concentration of the parcel as it entered the system is given in the third column and the change in concentration of the parcel during its travel from the upstream boundary to the indicated grid due to dispersion, tributary dilution, and decay, respectively, are given next. The decay term represents only the change in concentration due to interaction with the constituent listed following the decay term. The values of these terms are determined by evaluating the integral with respect to time of the terms on the righthand side of equation 30. The decay term represents only the integral of one term of the sum, however, and the particular term is the one involving the dependent variable named after the decay column.

In order to illustrate, consider the output on day 2, hour 10.00. The parcel at grid 6 entered the system 15.90 hours earlier (day 1, hour 18.10) with an initial temperature of 9.08°C (column 3, line 2), an initial DO concentration of 10.0 mg/L (column 3, line 3), and an initial BOD concentration of 2.00 mg/L (column 3, line 4). During its 15.90-hour transit time, dispersion increased its temperature by 0.23°C (column 3, line 2), decreased its DO by 0.06 mg/L (column 3, line 3), and decreased its BOD by 0.09 mg/L (column 3, line 4). Meanwhile, the tributary inflow at grid 2 increased its temperature by 1.03°C (column 4, line 2), decreased its DO by 0.72 mg/L (column 4, line 3), and increased its BOD by 9.61 mg/L. Surface exchange increased its temperature by 7.76°C (column 5, line 2). Since the temperature is not dependent on DO or BOD (the second and third terms in the sum of eq. 30 for parameter 1 are zero) the temperature of the water as it arrived at grid 6 was 9.08 + 0.23 + 1.03 + 7.76 = 18.10°C as shown in column 2, line 2. Looking next at the BOD parameter, the decay which was tabulated is due to the BOD term. Like temperature there is only one non-zero term in the summation indicated in equation 30. Therefore, the parcel at grid 6 started with a BOD of 2.0 mg/L, lost 0.09 mg/L due to dispersion, gained 9.61 mg/L due to tributary inflow, and lost 7.22 mg/L due to aerobic decay so it arrived at grid 6 with a BOD concentration of 2.0 - 0.09 + 9.61 - 7.22 = 4.30 mg/L as shown in column 2, line 4. The oxygen concentration,
on the other hand, changes both due to reaeration (the second term in the sum) as well as due to BOD decay (the third term in the sum). Only one of these terms can be tabulated in the model. The reaeration term was selected and the model indicated that the parcel gained 5.29 mg/L of DO due to reaeration. The model could be rerun while tabulating the BOD decay of oxygen (changing the last number on the second input name card from a 2 to a 3) but since there is a one-to-one relationship between BOD decay and oxygen demand, this is not necessary (the sedimentation rate was assumed zero). It is obvious that the oxygen loss due to BOD decay is 7.22 mg/L. Therefore, the water parcel entered the system with a DO level of 10 mg/L, lost 0.06 mg/L due to dispersion with adjacent parcels, lost 0.72 mg/L due to tributary inflow, gained 5.29 mg/L due to reaeration, and lost 7.22 mg/L which was consumed by the BOD decay, therefore, it arrived at grid 6 with a DO level of 10 - 0.06 - 0.72 + 5.29 - 7.22 = 7.29 mg/L as shown in column 1, line 3.

The output at the downstream end (grid 8) is interpreted in the same way.

For purposes of this example, the characteristics of all parcels are written after the last time step by the addition of statements 0296 through 0305 to the main program. The longitudinal variation of the heat budget terms are plotted in figure 16 in which the computed temperature is plotted as the top curve. The bottom curve represents the temperature of the water parcel as it entered the system and the centerline represents the temperature a parcel would have had providing no surface exchange had taken place, that is, the initial temperature plus the change in temperature due to tributary inflow. Notice the warming of the tributary inflow is large when the initial river temperature is low and small when the initial river temperature is large since the tributary inflow temperature is assumed constant at 20°C and the tributary is not far downstream of the upper end of the reach. Since the river is generally swift in the upstream part and sluggish in the downstream part, surface exchange is more apparent near the downstream end.

The longitudinal variation of the dissolved oxygen budget terms are plotted in figure 17. Here the computed value is the bottom curve. The DO minimum is apparent at about river mile 349 (between grids 5 and 6). The upstream DO and the DO of the tributary inflow were assumed constant so the initial DO and the tributary inflow effect are not a function of distance as was the initial temperature. The amount of oxygen added to the river by reaeration and the amount used in satisfying the BOD are indicated in the figure.

Finally, the longitudinal variation of the BOD budget terms are shown in figure 18. In this case the effect of dispersion, which is always small, is also shown. This term was ignored in figures 16 and 17 although the computed values can be obtained from the listing.
Figure 16.—Longitudinal variation in temperature for example problem, after 40 time steps.
Figure 17.---Longitudinal variation in dissolved oxygen for example problem, after 40 time steps.
Figure 18.--Longitudinal variation in BOD for example problem, after 40 time steps.
By use of these data an analysis similar to that carried out above for the parcel at grid 6 on day 2, hour 12.00, can be performed for any parcel in the system at the end of the run. Figures like those shown in figures 16 through 18 can be extremely useful in calibrating models, especially more complex nutrient models.

GENERALIZATION OF THE MODEL FOR USE WITH UNSTEADY FLOW

The preceding 4 models, as presented so far, can only be used for steady flow. A significant advantage of the Lagrangian reference frame is that the generalization of the model to accept unsteady flow is simple and straightforward. Like any finite difference model, the Lagrangian model assumes the flow is steady during any single time step. The generalization, therefore, simply involves reading a new set of hydraulic conditions at each time step and computing the appropriate average conditions that apply during the time step and subreach.

Although generalizing the transport model to accept unsteady flow conditions is simple and straightforward, the generation of accurate hydraulic data (velocity, area, top width, and tributary inflow) at each grid point can be quite involved. Some type of a flow model must be used to determine these hydraulic variables. The one-dimensional linear-implicit model documented by Land (1978) is recommended. Under special conditions much simpler models may also give acceptable results. Whatever model is used, however, it must be able to predict the velocity, area, top width, and tributary inflow at each grid point and time step.

Because it is almost always desirable to run the transport model several times for the same flow conditions, it is recommended that the flow model be run independently of the transport model. After the flow model has been calibrated the computed results are stored for use with the transport model. These results could be stored on computer cards but because of the many data involved, it is usually desirable to store the results on a magnetic disk.

Only four modifications are necessary to allow any of the preceding four models to handle unsteady flow. The first modification is that the second comment card in the deck should be changed to read ".. transport in unsteady flow" instead of "in steady flow". The second modification in the "Process Input Data" section is to read the complete flow field for time zero. This read statement should be placed right after the statement "I continue." The third modification is the major one but still only involves adding 15 cards. This modification computes the average velocity, area and width associated with each subreach during each time step. It also computes the average value of the tributary inflow at each grid point. This is accomplished by adding the group of...
cards shown in figure 19 to the deck immediately after the time step DO statement (see table 2 for statement numbers). The average value of the velocity, for example, in any subreach represents the average of four values, the old and the new values at each end of the subreach. The fourth correction involves adding a data definition statement after the program to give the computer sufficient information to find the flow data which has been stored on a magnetic disk. These four corrections are summarized in table 2. All data input needed for the steady flow models are also needed for the unsteady models, although some data, the area, top width, and tributary flow input from cards, are not used.

In order to illustrate the operation of the unsteady program, an example is given for the conservative transport model. The characteristics of the assumed channel are shown in figure 20. Each section was assumed trapezoidal in shape with the bottom width as shown at the bottom of figure 20 and with side slopes of 2 horizontal to 1 vertical. The center portion of figure 20 shows the water depth for a steady flow of 12.3 m/s and a tributary inflow at grid 5 of 0.65 m³/s. The Manning's roughness coefficient was assumed to be constant at 0.025. The profile of the bed is shown at the top of figure 20. The bed profile was computed such that the areas and velocities at 12 m³/s would very closely match the values assumed in the first 3 examples.

The shape of the assumed inflow hydrograph is shown on the top part of figure 21. This hydrograph was routed through the reach using the routing model presented by Dawdy and others (1978). The resulting hydrographs at grids 4 and 8 are also shown on figure 21. The kinematic-wave routing model of Dawdy and others was selected for use here because of its simplicity, but it is not necessarily recommended for general use in flow routing. The model was modified slightly such that it used a tabular form of the stage-discharge curve at each section rather than the analytic form assumed by Dawdy and others. The stage-discharge relation of each section was determined by use of a backwater program for various steady flow rates. The depth at the downstream end was assumed to be at normal depth for the channel section with a slope of 0.00015. A listing of the flow model with input and output data is shown in attachment E. The output data were stored on magnetic disk to be used by the transport model.

The conservative transport model was then modified, as outlined above, and run for this unsteady flow condition. A listing of the modified program, along with the output, is shown in attachment F. The output format is identical to that discussed previously. The variation of concentration with time at grids 1, 6, and 8 is shown in figure 5 for both the steady and unsteady flow cases. The low flow preceding the rise in the hydrograph slowed the arrival of the first concentration front at grid 6. At grid 8, on the other hand, the flood wave had
Compute reach average FLOW

DO 7 I = 1, INX
U(I) = FLOW(1,I) + FLOW(1,I+1)
A(I) = FLOW(2,I) + FLOW(2,I+1)
W(I) = FLOW(3,I) + FLOW(3,I+1)
7 QT(I) = FLOW(4,I)
READ (65,6500)((FLOW(K,I),K=1,4)I=1,NXSEC)
6500 FORMAT(8F10.3)
DO 12 I = 1, INX
U(I) = (U(I) + FLOW(1,I) + FLOW(1,I+1))*0.25
A(I) = (W(I) + FLOW(2,I) + FLOW(2,I+1))*0.25
W(I) = (W(I) + FLOW(3,I) + FLOW(3,I+1))*0.25
12 QT(I) = (QT(I) + FLOW(4,I))*0.5

Figure 19.--Code to compute time and subreach average values of flow conditions for use in the unsteady state model.
### TABLE 2.—Modifications to steady transport programs for unsteady flow simulations

<table>
<thead>
<tr>
<th>Statement preceding the required modification</th>
<th>Modification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservative transport temperature parameter</td>
<td>Change program name to indicate unsteady flow.</td>
</tr>
<tr>
<td>Simplified transport temperature parameter</td>
<td></td>
</tr>
<tr>
<td>Complete transport parameter</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Replaces first comment card</td>
<td></td>
</tr>
<tr>
<td>2 0059 0066 0068 0081</td>
<td>Read in complete flow field FLOW(K,I) at time zero.</td>
</tr>
<tr>
<td>3 0083 0091 0095 0106</td>
<td>Compute reach and time averaged velocities, area, depths, tributary inflow values for each subreach or grid point.</td>
</tr>
<tr>
<td>4 JCL JCL JCL JCL</td>
<td>Add a data definition card to define the flow data file.</td>
</tr>
</tbody>
</table>
Figure 20.--Characteristics of the assumed channel used in all example problems.
Figure 21.—Flow hydrographs for steady and unsteady runs.
overtaken the concentration front and the concentration rise occurred sooner for the unsteady flow case than for the steady flow case. Because of the rapid movement of the flood wave through the system, the width of the first concentration pulse was significantly shortened by the unsteady flow. The center dye pulse, injected on the recession of the hydrograph, traversed the system more rapidly under unsteady flow conditions because of the higher velocities. The third pulse, injected after most of the hydrograph rise had passed, was not affected significantly.

Modification of the other three models to allow for unsteady flow is accomplished in the same manner, as shown in table 2. Examples of these modifications will not be presented here.

SUMMARY

The 10-parameter transport model, modified for unsteady flow computation, is a general highly versatile modeling tool. Its main advantages are: it is conceptually and mathematically easy to understand, use, and modify; it is very accurate; it is very stable numerically; and it allows the tabulation of the effect of any individual process on the modeled output. This tabulation is extremely useful in model calibration and allows the model to be more effectively used as an aid in understanding natural systems.

If a single constituent is to be modeled, such as a conservative substance or heat, one of the simpler models can be used. It is recommended that a user who is not familiar with the model start with the conservative transport model and after mastering this model, progress through the other models becoming familiar with each in turn.

If the transport problem can be solved assuming steady flow conditions, the work is reduced by at least 50 percent because the operation of a flow model is generally the most complex part of the entire modeling effort in unsteady flows.

The transport models discretize the river into a number of subreaches separated by grid points. For steady flow applications only the discharge at the upstream end of the reach and the cross-sectional properties at the grid points (area, width, and tributary inflow) are needed as hydraulic input. For unsteady flow applications a streamflow model must be used to calculate the hydraulic properties at each grid point and time step. In addition to hydraulic data the model requires the concentrations of the modeled substances at the upstream end of the reach and in each tributary for discrete time steps. Certain rate coefficients and/or meteorological data are required to model specific substances.
SELECTED REFERENCES


ATTACHMENT A

Conservative Transport in Steady Flow
**DEFINITIONS**

- \( PX(i) \): Position of Lagrangian particle \((U/S, D/S, \text{ARC:EL K})\) in Eulerian grid units
- \( PT(i) \): Concentration of Lagrangian particle
- \( PV(i) \): Volume of Lagrangian particle
- \( PH(i) \): Time the parcel entered the system
- \( PTR(i) \): Change in concentration due to tributary inflow
- \( PTU(i) \): Concentration of parcel as it entered the system
- \( PDF(i) \): Change in parcel concentration due to dispersion
- \( FLOW(L, I) \): Flow field information \( L \) at Eulerian grid \( I \)
  - \( L = 1 \) for flow velocity in meters/hour
  - \( L = 2 \) for flow area in square meters
  - \( L = 3 \) for top width in meters
  - \( L = 4 \) for tributary inflow in cubic meters/second
- \( UX(I) \): Average velocity in subreach \( I \) in meters/hour
- \( X(I) \): Average area in subreach \( I \) in square meters
- \( DX(I) \): Distance between grid \( I \) and \( I+1 \)
- \( U(I) \): Dispersion factor \((\text{DIS} / (J*J*UT))\)
- \( UO(I) \): Velocity gradient between parcel \( K \) and \( K+1 \)
- \( DF(i) \): Concentration change of parcel \( K \) during \( DT \) due to dispersion
- \( TRIB(I) \): Tributary inflow in cubic meters per second at grid \( I \)
- \( DT \): Time step size (in hours)
- \( PDX \): Part of Eulerian subreach remaining to be traversed
- \( PDT \): Time required to traverse the remaining part of the subreach
- \( PXSECF \): Number of Eulerian grids
- \( INX \): Number of parcels in the system
- \( LP \): Last parcel to stay in the system at D/S end
- \( MX \): Grid U/S of parcel
- \( IGT(N) \): Grid number for tributary inflow
- \( NPT(i) \): Number of parcels to pass grid \( IGT(N) \) during \( DT \)
- \( KP(i) \): Number of parcel to pass grid \( IGT(N) \) during \( DT \)
- \( NXSEC \): Number of time steps
- \( NTRIB \): Number of actual tributaries
- \( ICUT \): Grid number where output is desired
- \( IOUT \): Number of time steps between output listings
- \( JTS \): Number of time steps from midnight to time zero in model
- \( TITLE(20) \): Title of program, 80 characters max.

**PRELIMINARIES**

- \( 0001 \) DIMENSION \( PX(500), PV(500), PT(500), PH(500), PTR(500), PTI(500) \)
- \( 0002 \) DIMENSION \( UX(50), JT(50), JTIM(50), IGT(50), KP(20+50), NPT(50) \)
- \( 0004 \) DIMENSION \( PDF(500), JU(50), JF(500), TITLE(20) \)
- \( 0005 \) DOUBLE \( PRECISION \( X(51) \)

70
MAXIMUM VALUE OF VASEC IS 50

STEP 5 TO 14 ARE TO ZERO ARRAYS.

DO 5 I=1,50
  X(I) = 0.0
  U(I) = 0.0

READ INPUT (STATEMENTS 0026-0046)*******************************

READ(6,1000)(TITLE(I),I=1,20)
WRITE(6,3003) (TITLE(I),I=1,20)
WRITE(6,3002) /3002 /
READ(6,1006) NXSEC,N1R,JTS
READ(5,1006) (X(I),I=1,NXSEC)
READ(6,1006) (FLOW(I),I=1,NXSEC)
READ(5,1006) (PT(I)+1=104XSEC)
WRITE(5,3006) N1ROT,NXSEC, T,I509NXSEC,
MODEL IC TO RUN 15+ TIME STEPS EACH 1100, 2+ HOURS LONG
1. THE RIVER IS DISCRETIZED BY 19, 15, 1 GRID POINTS,
2. THE INITIAL DISCHARGE IS CONSTANT AT 1100, 2+ CUBIC METERS PER SECOND
3. THE PRINTOUT WILL BE GIVEN FOR GRID15,15, AND 15, FOR
4. EACH 1+ TIME STEPS)

PROCESS INPUT DATA (STATEMENTS 0047-0082)*******************************

XUP=X(I)
X(NXSEC+1)=X(NXSEC)
DO 1 I=1,NXSEC
UX(I)=(X(I)-X(I+1))*1509.34
0051 \( x(i) = (x(jp-x(i)) \times 1609.34 \)
0052 \( px(i) = \text{FLOAT}(i) \)
0053 \( pm(i) = \text{FLOAT}(jt5) \times dt \)
0054 \( pt(i) = pt(i) \)
0055 \( pdf(i) = 0.0 \)
0056 \( ptr(i) = 0.0 \)
0057 \( \text{FLOW}(1,1) = 30000.0 \times q / \text{FLOW}(2,1) \)
0058 \( q = q + \text{FLOW}(4,1) \)

1 \text{ CONTINUE}

0060 \( \text{INX} = \text{NXSEC} - 1 \)
0061 \( pv(1) = \text{FLOW}(2,1) \times (dx(1) + dt \times \text{FLOW}(1,1)) / 2.0 \)
0062 \( do \ i = 1, \text{INX} \)
0063 \( u(i) = (\text{FLOW}(1,1) + \text{FLOW}(1,1+1)) / 2.0 \)
0064 \( a(i) = (\text{FLOW}(2,1) + \text{FLOW}(2,1+1)) / 2.0 \)
0065 \( qt(i) = \text{FLOW}(4,1) \)
0066 \( \text{PV}(1+1) = \text{FLOW}(2,1+1) \times (dx(i) + dt \times \text{FLOW}(1,1+1)) / 2.0 \)
0067 \( pv(\text{NXSEC}) = \text{FLOW}(2,\text{NXSEC}) \times (dx(\text{INX})) / 2.0 \)

0068 \( ns = \text{NXSEC} \)
0069 \( write(6,3002) \)
0070 \( write(b,3004) \)
0071 \( 3004 \text{ FORMAT}(1950x0,\text{INITIAL CONDITIONS}^{*}) \)
0072 \( write(6,3002) \)
0073 \( write(6,3010) \)
0074 \( 3010 \text{ FORMAT}(3x, \text{GRID RIVER VELOCITY AREA TRIB, FLOW DISP FACT} \)
0075 \( \text{INITIAL}^{*}, /, 10x, \text{MILE} \text{ M/HR} \text{ S} \text{ METERS} \text{ CU M/SEC}^{*}, 6x, \text{DQQ}^{*}, \)
0076 \( 28x, \text{CONC}) \)
0077 \( do \ j = 1, \text{NS} \)
0078 \( rm = x(u-x(1)) / 1609.34 \)
0079 \( write(6,3001)1, rm, \text{FLOW}(1,1) \times \text{FLOW}(2,1) \times qt(1) \times pt(1) \)
0080 \( 3001 \text{ FORMAT}(4x, i2, 1x, f7.3, 3x, f7.0, 3x, f8.1, 2x, f9.2, 14x, f7.2) \)
0081 \( write(6,3011) \)
0082 \( write(6,3007) \)
0083 \( write(6,3002) \)

C START TIME LOOP *********************************************

C DO 2 \( j = 1, \text{NH} \)

C COMPUTE DISPERSION FLUXES (STATEMENTS 0084-0107, LABEL
STATEMENTS 80-99)********************************************

C COMPUTE DISPERSIVE Q'S

LNS = NS - 1
0084 \( do \ 80 k = 1, \text{LNS} \)
0085 \( i = (px(k) + px(k+1)) / 2.0 \)

80 \( dq(k) = a d s(dq(i) \times u(i) \times a(i)) \)

C SET \( dq = 0 \) AT TRIBUTARY

K = 0
0088 \( \text{DO} 85 n = 1, \text{NTRIB} \)
0089 \( x(r) = \text{IGT}(n) \)
0090 \( 81 \text{ K = K + 1} \)
0091 \( \text{IF} (px(k) + \text{LT} + x(r)) \text{ GO TO 81} \)
0092 K = K - 1
0093 \( 85 \text{ DQ(K) = 0.0} \)

C LIMIT DQ TO FORCE STABILITY

\( \text{DO 82 k = 1, NS} \)
IF(K.EQ.1) GO TO 83
HAT=Q(K-1)*DT/PV(K)
IF(RATIO.GT.0.35) DQ(K-1)=0.35*PV(K)/DT
IF(K.EQ.NS) GO TO 92
RATIO=D4(K)*DT/PV(K)
IF(RATIO.GT.0.35) DQ(K-1)=0.35*PV(K)/DT
CONTINUE
C
IF(J.EQ.5) WRITE(6,793000) (DQ(K),K=1,NS)
C
DF(1)=DW(1)*(PT(2)-PT(1))*DT/PV(1)
DO 92 K=2,NS
DF(K)=WW(K-1)*(PT(K-1)-PT(K))*DQ(K)*(PT(K+1)-PT(K))*DT/PV(K)
94 IF(ABS(DF(K)).LT.1.0E-6) DF(K)=0.0
DF(NS)=DW(NS-1)*(PT(NS-1)-PT(NS))*DT/PV(NS)
IF(J.EQ.5) WRITE(6,793000) (DF(K),K=1,NS)
C
READ BOUNDARY CONDITIONS
READ((5,1006)) TUP,(TRIB(IPT(N)),N=1,NTRI)
PXU=1.0
PTU=1.0
PVU=TUP
PHU=1.0
PTRU=0.0
PTIU=TUP
PDFU=0.0
IF(J.EQ.5) WRITE(6,793000) PXU,PTU,PVU,PHU,PTRU
C
SET UPSTREAM BOUNDARY (STATEMENTS 0108-0115, LABEL STATEMENTS 40-59)
MX=NXSEC-1
RDT=DT
60 PDT=DX(MX)/U(MX)
IF(PUT.GE.RDT) GO TO 61
RDT=RDT-PDT
MX=MX-1
GO TO 60
61 XP=FLOAT(MX)+1.0-RDT/PDT
C
IF(PX(LP).GE.XP) GO TO 62
LP=LP-1
GO TO 62
63 NS=LP+2
P(X(NS))=FLOAT(NXSEC)
C
IFIX(XP)
XP=X(MX)+DX(MX)*(XP-FLOAT(MX))
MX=IFIX(PX(LP))
XL=X(MX)+DX(MX)*(PX(LP)-FLOAT(MX))
MX=IFIX(PX(LP+1))
XR=X(MX)+DX(MX)*(PX(LP+1)-FLOAT(MX))
COF=(XP-XL)/(XR-XL)
PT(NS)=(PT(LP)+DF(LP))*((1.0-COF)*(PT(LP+1)+DF(LP+1))*COF
PV(NS)=10.0
PH(NS)=PH(LP)*((1.0-COF)*PH(LP+1)*COF

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0140 0141 0142
PTR(NS)= PTR(LP)*(1.0—CDF)+PTR(LP+1)*COF
PTI(NS)=PTI(LP)*(1.0—CDF)+PTI(LP+1)*COF
PDF(NS)=(PDF(LP)+DF(LP))*(1.0—CDF)+(PDF(LP+1)+DF(LP+1))*COF

C IF(J.LT.7)WRITE(6,3000) RDT+PDT+XL+AR+CDT+PT(NS)+PH(NS)+
C $PTR(NS)+PDF(NS)
C IF(J.LT.7)WRITE(6,3001) LP,NS
C
C MOVE INTERIOR PARCELS (STATEMENTS 0143-0171, LABEL STATEMENTS 100-119)****************************************************************
C
0143 0144 0145 0146 0147 0148 0149 0150 0151 0152 0153 0154
LNS=NS-1
DO 103 I=1,NXSEC
103 NPT(I)= 0
DO 100 KK=2,LNS
K=LNS+2—KK
KO=K-1
XOLD=PX(KO)
MX=IFIX(XOLD)
ROT=DT
PDx=FLOAT(MX+1)—PX(KO)
102 PDT=PDX*UX(MX)/J(MX)
IF(PDT.GE.RDT) 30 TO 101
C
GASSED GRID
HDT=RDT—PDT
MX=MX+1
' XOLD=FLOAT(MX)
PCO=1.0
NPT(MX)= NPT(MX)+1
KPG(NPT(MX),MX)=K
GO TO 102
101 CONTINUE
C
STOPPED IN SUBREACH
PX(K)=XOLD+RDT*J(MX)/DX(MX)
PT(K)=PT(KO)+DF(KO)
PV(K)=PV(KO)
PH(K)=PH(KO)
PTR(K)=PTR(KO)
PTI(K)=PTI(KO)
PDF(K)=PDF(KO)+DF(KO)
C IF(J.LT.7)WRITE(6,3001) K,KO,MX,(NPT(I),I=1,NXSEC)
3001 FORMAT(12,10I)
100 CONTINUE
C
TRANSFERENCE BOUNDARY CONDITIONS TO PARCEL CHARACTERISTICS(STATEMENTS 0172-0178)**************************************************************************
C
0172 0173 0174 0175 0176 0177 0178
PX(1)=PXU
PT(1)=PTU
PV(1)=PVU
PM(1)=PMU
PTR(1)=PTRU
PTI(1)=PTIU
PDF(1)=PDFU
C
DILUTE FOR TRIBUTARY INFLOW (STATEMENTS 0179-0214, LABEL STATEMENTS 120-129)**************************************************************************
C
74
C

0179 IF(NTRI*EQ.0) 30 TO 123
0180 K=0
0181 DO 123 N=1,NTRI
0182 I=IGT(N)
C
0183 IF(J.LT.7) WRITE(6,3000)K,N,NTRI,VOL,I,NPT(I)
0184 DO 123 N=1,NTRI
0185 M=NPT(I)
0186 VOL=VOL+PV(KK)
0187 DO 121 K=1,4
0188 VOL=VOL+PV(KK)
0189 DO 121 K=1,4
0190 COF=PV(KK)/VOL
0191 DEL=(PT(K)*COF*QT(I)*3600.0+PT(K)*PV(KK))/((PV(KK)+QT(I))
0192 IF(J.LT.10) WRITE(6,3000)K,KK
0193 CONTINUE
0194 CONTINUE
0195 120 CONTINUE
C
C FIND NEAREST PARCEL
C
0200 K=K+1
0201 IF(PX(K).LT.FLOAT(I)) GO TO 124
0202 MX=IFIX(PX(K))
0203 XR=X(I)-MX*(PX(K)-FLOAT(MX))
0204 K=K-1
0205 MX=IFIX(PX(K))
0206 X=MX*(PX(K)-FLOAT(MX))
0207 IF(MX.LT.XL) K=K+1
0208 DEL=(PT(K)*COF*QT(I)*3600.0+PT(K)*PV(KK))/((PV(KK)+QT(I))
0209 IF(J.LT.10) WRITE(6,3000)XR,XL,PT(K),PV(KK),DEL
0210 CONTINUE
0211 CONTINUE
0212 CONTINUE
0213 K=K-1
0214 123 CONTINUE
C
C FIND CONCENTRATIONS AT ISO (STATEMENTS 0215-0228, LABEL STATEMENTS 130-139)*************
FORTRAN IV G1 RELEASE 2.0

0222 XL = X(I) - X(I) + DX(I) * (PX(K-1) - FLOAT(I))
0223 COF = XL / (XL + XR)
0224 CIGO = PT(K-1) + COF * (PT(K) - PT(K-1))
0225 CIIGO = PTI(K-1) + COF * (PTI(K) - PTI(K-1))
0226 CDIGO = PDF(K-1) + COF * (PDF(K) - PDF(K-1))
0227 CTIGO = PTR(K-1) + COF * (PTR(K) - PTR(K-1))
0228 TTIGO = TIME - COF * (PH(K) - PH(K-1))

C
C WRITE RESULTS (STATEMENTS 0229-0241) LABEL STATEMENTS 140-149
C
0229 IF (J.EQ.1) WRITE(6, 2000) ISU, NXSEC
0230 IF (M0) (J, IOUT), EQ. 0 GO TO 140
0231 GO TO 2
0232 140 IC = J / IOUT
0233 IF (MOD(IC + 50), 5) = 0 WRITE(6, 2000) ISU, NXSEC
0234 2000 FORMAT (' 5x, 'TIME, '7x, 'CONC AT, ' 3x, 'TRAVEL PARCEL, '3x, 'CHANGE IN PA
1x, 'CEL, '15x, 'CONC AT, '3x, 'TRAVEL PARCEL CHANGE IN PARCEL, '3x, '6x, 'GRID
2x, 'HOUR, ' 5x, 'TIME, '3x, 'CONC DUE TO, ' 21x, 'GRID
3x, 'TIME, 'CONC AT, '4x, 'CONC DUE TO, '16x, '7x, 'HOUR, ' 4x
4x, 'ENTRY, '6x, 'DISP, '5x, 'TRAVEL, '16x, '4x, 'ENTRY, '6x
5x, 'DISP, '5x, 'TRAVEL')
0235 IDAY = (TIME / 24.0) * 1
0236 HR = TIME - FLOAT(IDAY) * 24.0
0237 TT = TIME - PH(NS)
0238 WRITE(6, 2001) IDAY, HR, CIIGO, CTIGO, CIIGO, PT(NS), TT,
0239 2001 FORMAT (' 5x, 'TIME/24.0, '1x, 'HOUR, '15x, 'ENTRY, '6x, 'ENTRY, '6x
0240 3000 FORMAT (' 10E12.5')
0241 2 CONTINUE
0242 END
Input Data for

Conservative Transport in Steady Flow
## Model Documentation for a Conservative Substance in Steady Flow

### River Mile Values

| River Mile | R | L | C | 360.00 | 357.18 | 355.15 | 353.41 | 351.61 | 349.78 | 347.86 | 345.21 |
|------------|---|---|---|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| AREA 1     | 8.0 | 17.6 | 30.4 | 10.2 | 42.0 | 29.4 | 36.8 | 48.2 |

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Output of

Conservative Transport in Steady Flow
MODEL DOCUMENTATION FOR A CONSERVATIVE SUBSTANCE IN STEADY FLOW

MODEL IS TO RUN 40 TIME STEPS EACH 1.00 HOURS LONG. THE RIVER IS DISCRETIZED BY 9 GRID POINTS.
THE INITIAL UPSTREAM DISCHARGE IS CONSTANT AT 12.00 CUBIC METERS PER SECOND.
THE PRINTOUT WILL BE GIVEN FOR GRIDS 5 AND 8 FOR EACH 1 TIME STEPS.

INITIAL CONDITIONS

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ATTACHMENT B

Simplified Temperature Model in Steady Flow
C **************************TRANSPORT MODEL******************************
C SIMPLIFIED TEMPERATURE MODEL IN STEADY FLOW

C DEFINITIONS

PXU, PXD, PX(K) = POSITION OF LAGRANGIAN PARTICLE (U/S, D/S, PARCEL K) IN EULERIAN GRID UNITS

PTU, PTD, PT(K) = TEMPERATURE OF LAGRANGIAN PARCEL

PVU, PVD, PV(K) = VOLUME OF LAGRANGIAN PARCEL

PMU, PMD, PM(K) = TIME THE PARCEL ENTERED THE SYSTEM

PTRU, PTRD, PTR(K) = CHANGE IN TEMPERATURE DUE TO TRIBUTARY INFLOW

PTIU, PTID, PTI(K) = TEMPERATURE OF PARCEL AS IT ENTERED THE SYSTEM

PDFU, PDFD, PDF(K) = CHANGE IN PARCEL TEMPERATURE DUE TO DISPERSION

PD CU, PDDC, PDOC(K) = TEMPERATURE CHANGE OF PARCEL DUE TO SURFACE EXCHANGE

FLOW(L;I) = FLOW FIELD INFORMATION L AT GRID I

U(I) = AVERAGE VELOCITY IN SUBREACH I IN METERS / HOUR

A(I) = AVERAGE AREA IN SUBREACH I IN SQUARE METERS

W(I) = AVERAGE TOP WIDTH IN SUBREACH I IN METERS

X(I) = X COORDINATE OF EULERIAN GRID I

DX(I) = DISTANCE BETWEEN GRID I AND I+1

DQ(I) = DISPERSION FACTOR (DISP/(U*U*DT))

DQ(K) = FLOW RATE BETWEEN PARCEL K AND K+1 DUE TO VELOCITY GRADIENTS

DF(K) = TEMPERATURE CHANGE OF PARCEL K DURING DT DUE TO DISPERSION

TUP = OBSERVED TEMPERATURE AT UPSTREAM END OF REACH

QT(I) = TRIBUTARY INFLOW IN CUBIC METERS PER SECOND AT GRID I

TRIB(I) = OBSERVED TEMPERATURE OF TRIBUTARY INFLOW AT GRID I

Q = DISCHARGE AT UPSTREAM END IN CUBIC METERS PER SECOND

DT = TIME STEP SIZE (IN HOURS)

PDX = PART OF EULERIAN SUBREACH REMAINING TO BE TRAVERSED

PDT = TIME REQUIRED TO TRAVERSE THE REMAINING PART OF THE SUBREACH

RDT = TIME REMAINING FOR MOVEMENT

AI = CONSTANT IN WIND FUNCTION (MM/DAY, KPA)

BI = MASS TRANSFER COEFFICIENT (MM/DAY, KPA (M/S))

V = WIND SPEED IN M/S

TA = AIR TEMPERATURE IN DEGREES C

XK = SURFACE EXCHANGE COEFFICIENT

NXSEC = NUMBER OF EULERIAN GRIDS

INX = NXSEC-1

NS = NUMBER OF PARCLES IN THE SYSTEM

LNS = NS-1

LP = LAST PARCEL TO STAY IN THE SYSTEM AT D/S END

MX = GRID U/S OF PARCLE

IGT(N) = GRID NUMBER FOR TRIBUTARY INFLOW

NPT(I) = NUMBER OF PARCELS TO PASS GRID IGT(N) DURING DT

KPG(N,M) = PARCEL NUMBER OF PARCEL TO PASS GRID IGT(N) DURING DT

NMH = NUMBER OF TIME STEPS

NTRIB = NUMBER OF ACTUAL TRIBUTARIES

IGO = GRID NUMBER WHERE OUTPUT IS DESIRED

IOUT = NUMBER OF TIME STEPS BETWEEN OUTPUT LISTINGS

JTS = NUMBER OF TIME STEPS FROM MIDNIGHT TO TIME ZERO IN MODEL

TITLE(20) = TITLE OF PROGRAM, 80 CHARACTERS MAX

PRELIMINARIES (STATEMENTS 0001-0028, LABEL STATEMENTS 20-39)
DIMENSION PX(500), PV(500), PT(500), PH(500), PTR(500), PTI(500), PDF(500), TRIB(500), IGT(500), KP5(20), NPT(50)
DIMENSION DF(K), X(I), A(I), FLOW(4, I), W(I)

MAXIMUM VALUE OF NXSEC IS 50

STEP 7 TO 27 ARE TO ZERO ALWAYS.

DO 4 K = 1, 500
PX(K) = 0.0
PT(K) = 0.0
PV(K) = 0.0
PH(K) = 0.0
PTR(K) = 0.0
PDF(K) = 0.0
PTI(K) = 0.0
DF(K) = 0.0
X(I) = 0.0
FLOW(4, I) = 0.0
TRIB(I) = 0.0
IGT(I) = 0.0
DX(I) = 0.0
U(I) = 0.0
W(I) = 0.0
A(I) = 0.0

READ INPUT (STATEMENTS 0029-0052)
0050 FORMAT(' MODEL IS TO RUN 1.15, 0 TIME STEPS EACH, F10.2, * HOURS LONG
1. THE RIVER IS DISCRETIZED BY 1,150 GRID POINTS. ** THE INITIAL
2. UPSTREAM DISCHARGE IS CONSTANT AT *F10.2, * CUBIC METERS PER SECOND
3. ** THE WATERFLOW WILL BE GIVEN FOR GRIDS 150 AND 150 FOR
4. EACH, 150 TIME STEPS. **
0051 WRITE(6,1007) A1,81
0052 1007 FORMAT(' THE WIND FUNCTION IS, F10.2, **, F10.2, ** V IN MM/DAY <= 5A')

C PROCESS INPUT DATA (STATEMENTS 0053-0090)******************************
C
0053 XUP=X(1)
0054 X(NXSEC+1)=X(NXSEC)
0055 DO 1 I=1,NXSEC
0056 DX(I)=(X(I)-X(I+1))*1604.34
0057 X(I)=(XUP-X(I))*1609.34
0058 PX(I)=FLUXT(I)
0059 PH(I)=FLOAT(JTS)*DT
0060 PT(I)=PT(I)
0061 PDF(I)=0.0
0062 PT(I)=0.0
0063 PDC(I)=0.0
0064 FLOW(1,1)=3600.0*FLOW(2,1)
0065 Q= Q+FLOW(4,1)
0066 1 CONTINUE
0067 INX=NXSEC-1
0068 PV(I)= FLOW(2,1)*(DX(I)+DT*FLUW(I,1))/2.0
0069 DO 3 I=1,INX
0070 U(I)=(FLOW(1,1)+FLOW(1,1+1))/2.0
0071 A(I)=(FLOW(2,1)+FLOW(2,1+1))/2.0
0072 W(I)=(FLOW(3,1)+FLOW(3,1+1))/2.0
0073 WT(I)=FLOW(4,1)
0074 PV(I+1)= FLOW(2,1+1)*(DX(I)+DX(I+1))/2.0
0075 PV(NXSEC)= FLOW(2,NXSEC)*(DX(NXSEC))/2.0
0076 NS=NXSEC
0077 WRITE(6,3002)
0078 WRITE(6,3004)
0079 3004 FORMAT(' THE WIND FUNCTION IS, F10.2, **, F10.2, ** V IN MM/DAY <= 5A')
0080 WRITE(6,3002)
0081 WRITE(6,3010)
0082 3010 FORMAT(' DISPERSION FLUXES (STATEMENTS 0092-0115),
C LABEL STATEMENTS 80-99**************************************************************************
COMPUTE DISPERSIVE J'S

\[ DQ(K) = \text{ABS} \left( DQ(I) \ast J(I) \ast A(I) \right) \]

SET \[ DQ = 0 \text{ AT TRIBUTARY} \]

\[ K = 0 \]

DO 85 \( N = 1 \text{ TO } \text{NTRI} \)

\[ X_R = \text{IGT} \( N \) \]

IF \( P_X(K) < X_R \) GO TO 81

\( K = K + 1 \)

DO \( (K) = 0.0 \)

LIMIT \( DQ \) TO FORCE STABILITY

DO 82 \( K = 1 \text{ TO } \text{NS} \)

IF \( K = 1 \) \( \text{RATIO} = D_W(K-1) \ast 07 \text{ TO } \text{PV}(K) \)

IF \( \text{RATIO} > 0.35 \) \( D_A(K-1) = 0.35 \ast \text{PV}(K) / D_T \)

IF \( K = \text{NS} \) GO TO 82

\( \text{RATIO} = \text{O4}(K) \ast 07 \text{ TO } \text{PV}(K) \)

IF \( \text{RATIO} > 0.35 \) \( D_A(K) = 0.35 \ast \text{PV}(K) / D_T \)

82 CONTINUE

IF \( J < 7 \) \( \text{WRITE} (6, 3000) \ (D_O(K) \ast K = 1 \text{ TO } \text{NS}) \)

SET UPSTREAM BOUNDARY (STATEMENTS 0116-0124, LABEL STATEMENTS 40-59)

READ \( BOUNDARY CONDITIONS \)

\[ \text{READ} 5(5, 1005) \ T_U^\text{P}, \text{T}, \text{A}, \text{V} \text{S} \text{RIB}(\text{IST}(N)) \ast N = 1 \text{ TO } \text{NTRIS} \)

\[ P_XU = 1.0 \]

\[ P_TU = T_JP \]

\[ P_VU = \text{FLOW}(1, 1) \text{ TO } \text{FLOW}(2, 1) \times D_T \]

\[ P_MU = 0.0 \]

\[ P_TRU = 0.0 \]

\[ P_DCU = 0.0 \]

IF \( J = 7 \) \( \text{WRITE}(6, 3000) \ P_XU, P_TU, P_VU, P_MU, P_TRU \)

SET D/S BOUNDARY (STATEMENTS 0125-0154, LABEL STATEMENTS 60-79)

MX = NXSEC - 1

PDT = D_T

IF \( PDT > 0 \) GO TO 61

M_X = MX - 1

GO TO 60

IF \( \text{FLOAT}(\text{MX}) + 1.0 = \text{RDT} / \text{PDT} \)

FIND PARCEL U/S OF XP
FORTRAN IV GI RELEASE 2.0  MAIW  DATE = 00288  12/36/06

0133 LP=NS-1  0134 62 IF(PX(LP).LT.XP)GO TO 63
0135 LP=LP-1  0136 GO TO 62
0137 NS=LP+2
0138 PX(NS)=FLOAT(NXSEC)

C FIND OLD CONCENTRATION OF PARCEL WHICH WILL FALL OUT
0139 MX=IFIX(XP)
0140 XP=FMX+DX(MX)*XP-FLOAT(MX)
0141 MX=IFIX(PX(LP))
0142 XL=FMX+DX(MX)*PX(LP)-FLOAT(MX)
0143 MX=IFIX(PX(LP+1))
0144 XR=FMX+DX(MX)*PX(LP+1)-FLOAT(MX)
0145 COF=(XP-XL)/(XR-XL)
0146 PT(NS)=(PT(LP)+DF(LP))+(1.0-COF)*(PT(LP+1)+DF(LP+1))*COF
0147 PV(NS)= PV(LP+1)
0148 PH(NS)= PH(LP)*1.0-COF)*PH(LP+1)*COF
0149 PTI(NS)= PTI(LP)*1.0-COF)*PTI(LP+1)*COF
0150 PDF(NS)=(PDF(LP)+DF(LP))*(1.0-COF)*(PDF(LP+1)+DF(LP+1))*COF
0151 PDC(NS)=PDC(LP)*(1.0-COF)*PDC(LP+1)*COF
0152 C
0153 IF(J.LT.7)WRITE(6,3000) RDT,PDT,XP,XL,XR,COF,PT(NS),PH(NS),
0154 C
0155 LNS=NS-1
0156 DO 103 I=1,NXSEC
0157 NPT(I)= 0
0158 DO 100 KK=2,LNS
0159 K=LNS+2-KK
0160 KO=K-1
0161 XOLD=PX(KO)
0162 MX=IFIX(XOLD)
0163 RDTR=DT
0164 PDT=FLOAT(MX+1)-PX(KO)
0165 102 PDT=PD*X/(MX+1)/J(MX)
0166 IF(PDT.GE.RDT) 30 TO 101
0167 CALL DECAY(PDT,KO,MX,J)
0168 RDTR=RDTR-PDT
0169 MX=MX+1
0170 XOLD=FLOAT(MX)
0171 PDT=PD+0
0172 NPT(MX)= NPT(MX)+1
0173 KPG(NPT(MX)+MX)=K
0174 GO TO 102
0175 CONTINUE

C STOPPED IN SUBREAC
0176 CALL DECAY(RDT,KO,MX,J)
0177 PX(KO)=XOLD+RDT*J(MX)/DX(MX)
0178 PT(KO)=PT(KO)+DF(KO)
0179 PV(KO)= PV(KO)

86
C IF(J.T.7) WRITE(6,3001) K,K0,MAX(NPT(I),I=1,NXSEC)
0183 3001 FORMAT('   0.12110)
C IF(J.T.7)WRITE(6,3000) XOLD,ROT,PJT,PUX,PK(K),PK(K),PK(K),PK(K),PK(K),
C SPTR(K),P0C(K)
0184 100 CONTINUE
C
C TRANSFER BOUNDARY CONDITIONS TO PARCEL CHARACTERISTICS (STATEMENTS
C 0187-0194)*************************************************************************
C
C PX(1)=PUX
0187 PT(1)=PTU
0188 PV(1)=PVU
0190 PH(1)=PHU
0191 PTR(1)=PTRU
0192 PTI(1)=PTIU
0193 PDF(1)=PUFU
0194 PDC(1)=PDCU
C
C DILUTE FOR THIJBUTY IN=LOW (STATEMENTS 0195-0230, LABEL
C STATEMENTS 120-129)*************************************************************************
C
C IF(NTRI3.EQ.0) 30 TO 123
0193 K=0
0195 DO 123 N=1,NTRI3
0197 I= IGT(N)
C IF(J.LT.7) WRITE(6,3001)K,N,NTRIB.IGT(N),III,NPT(I)
0198 IF(NPT(I).EQ.0) 30 TO 120
0200 VOL=0.0
0201 M=NPT(I)
0202 DO 121 K=1,4
0203 KK=KP3(K,I)
0204 VOL=VOL+PV(KK)
0205 DO 122 K=1,4
0206 KK=KP3(K,I)
0207 COF=PV(KK)/VOL
0208 DEL=1TRB(I)*COF*QT(I)*3600.0/DT+PT(KK)*PV(KK))/(PV(KK)+QT(I)
0209 X=3600.0*COF/DT)-PT(KK)
0210 IF(QT(I).LE.0.0) DEL=0.0
0211 PT(KK)=PT(KK)+DEL
0212 PTK(KK)=PT(KK)+DEL
0213 PV(KK)=PV(KK)+COF*QT(I)*DT*3600.0
C IF(J.LT.10) WRITE(6,3000) VOL,COF,PT(KK),PV(KK),DEL
C IF(J.LT.10) WRITE(6,3000)K,KK
0214 122 CONTINUE
0215 Go TO 123
120 CONTINUE
C FIND NEAREST PARCEL
C
0216 K=K+1
0217 IF(PX(K)*LT.FLT(I)) GO TO 124
0218 MX=IFIX(PX(K))
0219 XR=X(MX)-(PX(K)-FLOAT(MX))*DX(MX)-X(I)
C
87
K = K - 1
MX = IFIX(PX(K))
XL = X(I) - X(MX) - (PX(K) - FLOAT(MX)) * DX(MX)
IF(XL < 0) XL = 0
DEL = (TRI8(I) * QT(I) * 3600.0 + PT(K) * PV(K)) / (PV(K) + QT(I) * 3600.0)
$ = PT(K)
IF(J + LT10) WRITE(6,3000) XR, XL, PT(K), PV(K), PTR(K), DEL
IF(J + LT10) WRITE(6,3001) K, MX, 1
K = K - 1
123 CONTINUE

C FIND CONCENTRATIONS AT ISO (STATEMENTS 0231-0245, LABEL STATEMENTS 130-139)************************
C
TIME = FLAT(J + JTS) * DT
K = 0
130 K = K + 1
IF(PX(K) < FLAT(I)) GO TO 30 TO 130
IX = IFIX(PX(K))
XR = X(IX) + DX(IX) * (PX(K) - FLOAT(IX)) - X(I)
IX = IFIX(PX(K - 1))
XL = X(IX) + DX(IX) * (PX(K - 1) - FLOAT(IX))

C COF = XL / (XL + XR)
CJG0 = PT(K - 1) + COF * (PT(K) - PT(K - 1))
CJG0 = PTI(K - 1) + COF * (PTI(K) - PTI(K - 1))
CDG0 = PUF(K - 1) + COF * (PDF(K - 1) - PDF(K - 1))
CJG0 = PTR(K - 1) + COF * (PTR(K) - PTR(K - 1))
DCG0 = PUC(K - 1) + COF * (PDC(K) - PDC(K - 1))
CTG0 = TIME - PM(K - 1) - COF * (PM(K) - PM(K - 1))

C WRITE RESULTS (STATEMENTS 0246-0255, LABEL STATEMENTS 140-149)***
C
IF(J + EQ1) WRITE(6,2000) IG0, NXSEC
IF(MOD(J + IOUT) * EQ0) GO TO 140
GO TO 2
140 IC = J + IOUT
IF(MOD(1, I50) * EQ0) WRITE(6, 2000) IG0, NXSEC
2000 FORMAT(6X, 'TIME = ', 6X, 'TEMP AT TRAVEL PARCEL CHANGE IN PARC
1EL TEMP + 6X, 'TEMP AT TRAVEL PARCEL TEM
1 CHANGE IN PARCEL TEM
4 DISP', 12X, 'TRIB DECAY', 6X, 'MOUR ENTRY DISP',
55X, 'TRIB DECAY')
IDAY = (TIME / 24.0) + 1
HR = TIME - FLAT(IDAY) * 24.0
TT = TIME - PH(NS)
WRITE(6, 2001) IDAY, HR, CJG0, CJG0, CJG0, CJG0, DJG0, DJG0, DJG0, PT(NS), TT,
PTI(NS) + PDF(NS), PTR(NS) + PDC(NS)
2001 FORMAT(6X, 'TIME = ', 6X, 'TEMP AT TRAVEL PARCEL CHANGE IN PARC
1EL TEMP + 6X, 'TEMP AT TRAVEL PARCEL TEM
1 CHANGE IN PARCEL TEM
4 DISP', 12X, 'TRIB DECAY', 6X, 'MOUR ENTRY DISP',
55X, 'TRIB DECAY')
3000 FORMAT(' ', 10E12.5)
2 CONTINUE
END
SUBROUTINE DECAY (DT, K, MX, J)

COMMON XK, PDC(300), PT(300), TA

DUT = DT

DM = ROT

C FIND MAXIMUM DECAY TIME STEP

SUM = XK*(PT(K) - TA)

DTL = ROT

REF = PT(K) - TA

IF (SUM .NE. 0.0 .AND. ABS (REF) .GT. 0.3) DTL = ABS (0.1*REF/SUM)

IF (DTL .LT. DTM) DTM = DTL

COM = 0.999*DT

IF (DTM .GT. COM) DTM = DTM

C UPDATE TEMPERATURE

PTI = PT(K)

PT(K) = PT(K) + SUM*DTM

IF (J .LT. 6) WRITE (6, 1000) PTI, PT(K), SUM, DTM, XK

1000 FORMAT (' DECAY OUTPUT', 9E12.5)

CALL FINK (K, MX)

SUM2 = XK*(PT(K) - TA)

PT(K) = PTI + 0.5*DTM*(SUM + SUM2)

PDC(K) = PDC(K) + 0.5*(SUM + SUM2)*DTM

C WRITE (6, 1000) XK, SUM2, PT(K), PDC(K)

IF (J .LT. 6) WRITE (6, 1000) XK, SUM2, PT(K), DTM

IF (DTM .EQ. DTM) 30 TO 5

30 HUT = DTM - DTM

GO TO 1

5 RETURN

END
SUBROUTINE FINK(K, MX)
COMMON XX, XJC(500), PT(500), TA, V, A(50), W(50), AL, B1
CPH = 100.0
SIu = 1.171E-7/240
AL = 545.0/PT(K)
PSI = (AL+AL)/24.0*10.0
TAH = PT(K)+273.16
DFT = 1.532E11*EXP(-4271.1/(PT(K)+242.63))/((PT(K)+242.63)**2)
XX = 4.0*0.97*SIG*(TA8/(TA8+0.06))
XX = -XX*(MX)/(A(MX)*CR)
RETURN
END
Input Data for

Simplified Temperature Model in Steady Flow
<table>
<thead>
<tr>
<th>RIVER MILE</th>
<th>360.00</th>
<th>357.18</th>
<th>355.15</th>
<th>353.41</th>
<th>351.61</th>
<th>349.78</th>
<th>347.86</th>
<th>345.21</th>
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<tbody>
<tr>
<td>AREA 1</td>
<td>8.0</td>
<td>17.6</td>
<td>30.4</td>
<td>10.2</td>
<td>42.0</td>
<td>29.4</td>
<td>36.8</td>
<td>48.2</td>
</tr>
<tr>
<td>WIDTH 1</td>
<td>17.1</td>
<td>39.5</td>
<td>61.9</td>
<td>81.8</td>
<td>89.1</td>
<td>92.5</td>
<td>115.4</td>
<td>123.2</td>
</tr>
<tr>
<td>TREB 1</td>
<td>5</td>
<td>0.65</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DQ2 VALUES</td>
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<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
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<td>INIT CONC1</td>
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<td>0.0</td>
<td>0.0</td>
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<td>0.0</td>
</tr>
</tbody>
</table>

| BC1        | 1.30   | 28.0   | 1.90   | 20.0   |        |        |        |        |
| BC 2       | 4.80   | 26.0   | 1.90   | 20.0   |        |        |        |        |
| BC3        | 8.00   | 24.0   | 2.00   | 20.0   |        |        |        |        |
| BC4        | 11.00  | 22.0   | 1.80   | 20.0   |        |        |        |        |
| BC5        | 12.10  | 19.0   | 1.70   | 20.0   |        |        |        |        |
| BC6        | 11.80  | 16.0   | 1.60   | 20.0   |        |        |        |        |
| BC7        | 11.00  | 13.0   | 1.50   | 20.0   |        |        |        |        |
| BC8        | 10.20  | 12.0   | 1.60   | 20.0   |        |        |        |        |
| BC9        | 9.60   | 10.0   | 1.70   | 20.0   |        |        |        |        |
| BC10       | 9.10   | 10.0   | 1.60   | 20.0   |        |        |        |        |
| BC11       | 8.90   | 10.0   | 1.50   | 20.0   |        |        |        |        |
| BC12       | 8.80   | 11.0   | 1.40   | 20.0   |        |        |        |        |
| BC13       | 8.90   | 12.0   | 1.30   | 20.0   |        |        |        |        |
| BC14       | 9.10   | 13.0   | 1.30   | 20.0   |        |        |        |        |
| BC15       | 9.30   | 15.0   | 1.20   | 20.0   |        |        |        |        |
| BC16       | 9.80   | 16.0   | 1.20   | 20.0   |        |        |        |        |
| BC17       | 10.10  | 18.0   | 1.30   | 20.0   |        |        |        |        |
| BC18       | 10.60  | 20.0   | 1.40   | 20.0   |        |        |        |        |
| BC19       | 11.20  | 21.0   | 1.50   | 20.0   |        |        |        |        |
| BC20       | 11.70  | 23.0   | 1.60   | 20.0   |        |        |        |        |
| BC21       | 12.30  | 25.0   | 1.50   | 20.0   |        |        |        |        |
| BC22       | 12.90  | 27.0   | 1.40   | 20.0   |        |        |        |        |
| BC23       | 13.40  | 29.0   | 1.50   | 20.0   |        |        |        |        |
| BC24       | 14.00  | 30.0   | 1.60   | 20.0   |        |        |        |        |
| BC25       | 14.50  | 30.0   | 1.70   | 20.0   |        |        |        |        |
| BC26       | 14.80  | 30.0   | 1.80   | 20.0   |        |        |        |        |
| BC27       | 15.00  | 29.0   | 1.70   | 20.0   |        |        |        |        |
| BC28       | 15.00  | 29.0   | 1.80   | 20.0   |        |        |        |        |
| BC29       | 14.90  | 28.0   | 1.90   | 20.0   |        |        |        |        |
| BC30       | 14.70  | 27.0   | 1.80   | 20.0   |        |        |        |        |
| BC31       | 14.50  | 26.0   | 1.90   | 20.0   |        |        |        |        |
| BC32       | 14.20  | 24.0   | 2.00   | 20.0   |        |        |        |        |
| BC33       | 13.80  | 22.0   | 2.10   | 20.0   |        |        |        |        |
| BC34       | 13.40  | 21.0   | 2.20   | 20.0   |        |        |        |        |
| BC35       | 12.90  | 19.0   | 2.30   | 20.0   |        |        |        |        |
| BC36       | 12.50  | 18.0   | 2.50   | 20.0   |        |        |        |        |
| BC37       | 12.00  | 16.0   | 2.40   | 20.0   |        |        |        |        |
| BC38       | 11.50  | 15.0   | 2.40   | 20.0   |        |        |        |        |
| BC39       | 11.00  | 14.0   | 2.30   | 20.0   |        |        |        |        |
| BC40       | 10.60  | 13.0   | 2.50   | 20.0   |        |        |        |        |
Output of

Simplified Temperature Model in Steady Flow
MODEL DOCUMENTATION FOR THE SIMPLIFIED TEMPERATURE MODEL

The model is to run 40 time steps each 1.00 hours long. The river is discretized by 9 grid points. The initial upstream discharge is constant at 12.00 cubic meters per second. The printout will be given for grids 5 and 8 for each 2 time steps.

The wino function is 3.01 * 1.13 * V in mm/day kPa.

### INITIAL CONDITIONS

<table>
<thead>
<tr>
<th>MILE</th>
<th>KMH</th>
<th>SQ METERS</th>
<th>METERS</th>
<th>CUB M/SEC</th>
<th>DUQ</th>
<th>TEMP</th>
<th>DISP FACT</th>
<th>INITIAL TEMP</th>
<th>TEMP AT TRAVEL PARCEL CHANGE IN PARCEL TEMP</th>
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<tr>
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<td>3400</td>
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### TIME TEMPERATURE AT TRAVEL PARCEL CHANGE IN PARCEL TEMP

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<tr>
<th>DAY</th>
<th>TEMP</th>
<th>TRAVEL</th>
<th>PARCEL</th>
<th>CHANGE IN PARCEL TEMP</th>
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<td>2.34</td>
<td>2.00</td>
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<td>2</td>
<td>12.00</td>
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<td>4.00</td>
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<td>3</td>
<td>14.00</td>
<td>6.35</td>
<td>6.00</td>
<td>0.0</td>
</tr>
<tr>
<td>4</td>
<td>16.00</td>
<td>8.45</td>
<td>3.24</td>
<td>0.0</td>
</tr>
<tr>
<td>5</td>
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### TEMPERATURE AT TRAVEL PARCEL CHANGE IN PARCEL TEMP

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ATTACHMENT C

Complete Temperature Model in Steady Flow
**DEFINITIONS**

- \( \text{PXU,PXD, PX(K)} \): Position of Lagrangian particle (U/S, D/S, parcel K) in Eulerian grid units.
- \( \text{PTU, PTD, PT(K)} \): Temperature of Lagrangian parcel.
- \( \text{PVU, PVD, PV(K)} \): Volume of Lagrangian parcel.
- \( \text{PHU, PHT, PH(K)} \): Time the parcel entered the system.
- \( \text{PTRU, PTRD, PTR(K)} \): Change in temperature due to tributary inflow.
- \( \text{PTIU, PTD, PTI(K)} \): Temperature of parcel as it entered the system.
- \( \text{PDFU, PDFD, PDF(K)} \): Change in parcel temperature due to dispersion.
- \( \text{PDCU, PDCD, PDC(K)} \): Temperature change of parcel due to surface exchange.

**FLOW**

- \( L=1 \) for flow velocity in meters per hour.
- \( L=2 \) for flow area in square meters.
- \( L=3 \) for top width in meters.
- \( L=4 \) for tributary inflow in cubic meters/second.

**U(I)**: Average velocity in subreach I in meters/hour.

**A(I)**: Average area in subreach I in square meters.

**W(I)**: Average top width in subreach I in meters.

**X(I)**: X coordinate of Eulerian grid I in river miles.

**DX(I)**: Distance between grid I and I+1.

**DQQ(I)**: Dispersion factor (\( \text{DISP/(U*U*DT)} \)).

**DQ(K)**: Flowrate between parcel K and K+1 due to velocity gradients.

**DF(K)**: Temperature change of parcel K during DT due to dispersion.

**TUP**: Observed temperature at upstream end of reach.

**QT(I)**: Tributary inflow in cubic meters per second at grid I.

**THIB(I)**: Observed temperature of tributary inflow at grid I.

**Q**: Discharge at upstream end in cubic meters per second.

**DT**: Time step size (in hours).

**PDX**: Part of Eulerian subreach remaining to be traversed.

**PDT**: Time required to traverse the remaining part of the subreach.

**RDT**: Time remaining for movement.

**A1**: Constant in wind function (mm/day kPa).

**B1**: Mass transfer coefficient (mm/day kPa(m/s)).

**V**: Wind speed in m/s.

**TA**: Air temperature in degrees C.

**HS**: Incoming solar radiation cal/sq. cm/day.

**HL**: Incoming atmospheric radiation cal/sq. cm/day.

**EA**: Vapor pressure of air in kPa.

**RS(I,J)**: Portion of incoming solar radiation absorbed by water at time J DT and at grid I.

**BED(I)**: Heat flow from the bed to the water in cal/sq cm/day at grid I.

**AZ(I)**: Azimuth of river at grid I in degrees clockwise from north.

**BW(I)**: Bank width at grid I in meters.

**EBH(I)**: Effective barrier height at I in meters.

**H**: Total surface exchange including bed conduction.

**JRS**: Time step for RS values to nearest 15 minutes.

**NXSEC**: Number of Eulerian grids.

**INX**: NXSEC-1.

**NS**: Number of parcels in the system.

**LNS**: NS-1.

**LP**: Last parcel to stay in the system at D/S end.

**MX**: Grid U/S of parcel.
DIMENSION PX(500), PV(500), PT(500), PH(500), PTR(500), PDC(500)

DIMENSION DX(50), J(50), A(50), FLOW(4950), W(50)

DIMENSION OQ(50), QT(50), TRIB(50), IGT(50), KPG(20950), NPT(50)

DIMENSION PDF(500), DQ(500), DF(500), TITLE(20)

DOUBLE PRECISION X(51)

COMMON/T/ X, U, PDC, PV, PT

COMMON/H, PDC, PX, PV, PT

MAXIMUM VALUE OF NXSEC IS 50

STEP 9 TO 28 ARE TO ZERO ARRAYS.

DO 4 I=1,500

PX(K) = 0.0

PT(K) = 0.0

PV(K) = 0.0

PH(K) = 0.0

PTR(K) = 0.0

PDF(K) = 0.0

PTI(K) = 0.0

DQ(K) = 0.0

PDC(K) = 0.0

FLOW(4, I) = 0.0

TRIB(I) = 0.0

IGT(I) = 0.0

DX(I) = 0.0

U(I) = 0.0

W(I) = 0.0

A(I) = 0.0

READ INPUT (STATEMENTS 0031-0054)

READ(5, 1000) (TITLE(K), K=1,20)

1000 FORMAT(20A4)

WRITE(6, 3003) (TITLE(K), K=1,20)

3003 FORMAT(1H1, 20X, 20A4)

WRITE(6, 3002)

3002 FORMAT(/)

READ(5, 1005) NXSEC, NHR, IT, QT, IGO, IDJ, TRIB, JTS, A1, B1

1005 FORMAT(215, 2F10.2, 4I5, 2F10.2)
0034      READ(5,1006) (X(I),I=1,NXSEC)
0040      1006 FORMAT(10X,10F7.3)
0041      READ(5,1006)(FLOW(2.1),I=1,NXSEC)
0042      READ(5,1006)(FLOW(3.1),I=1,NXSEC)
0043      IF (NTRI.EQ.0) GO TO 8
0044      DO 7 N=1,NTRI
0045      7 FLOW(W,N)=QTT
0046      8 READ(5,1006) (Q(I),I=1,NXSEC)
0047      READ(5,1006) (Q(I),I=1,NXSEC)
0048      WRITE(6,3005) N1R,D,T,NXSEC,D,I50,4XSEC.IOJT
0049      3005 FORMAT(' MODEL IS TO RUN',15,' TIME STEPS EACH',F10.2,' HOUS LONG
0050      THE RIVER IS DISCRETIZED BY',N5,' GRID POINTS.',/,' THE INITIAL
0051      2005 ' THE PRINTOUT WILL BE GIVEN FOR GRIDS',N5,' AND',N5,' FOR
0052      EACH',N5,' TIME STEPS."
0053      WRITE(6,1007) A,B
0054      1007 FORMAT(1H 'THE WIND FUNCTION IS',F10.2+',F10.20*V IN MM/DAY KPa'
0055      PROCESS INPJ DAT (STATEMENTS 0055-0094)**************************
0056      XUP=X(1)
0057      X(NXSEC+1)=X(NXSEC)
0058      DO 1 I=1,NXSEC
0059      DX(I)=(X(I)-X(I+1))*1609.34
0060      X(I)=(X(I)-X(I+1))*1609.34
0061      PH(I)=FLUAT(I)*DT
0062      PT(I)=PT(I)
0063      PF(I)=PF(I)
0064      PV(I)=FLOW(2,1)*DX(I)/2.0
0065      Q= Q+FLOW(4,1)
0066      1 CONTINUE
0067      INX=NXSEC-1
0068      PV(1)=FLOW(2,1)*(DX(I)+DX(I+1))/2.0
0069      CALL CRS(NXSEC)
0070      CALL 3EDFX(NXSEC,DT)
0071      CALL CRS(NXSEC)
0072      CALL 3EDFX(NXSEC,DT)
0073      DO 3 I=1,INX
0074      3 PV(I)=FLOW(2.1+1)*(DX(I)+DX(I+1))/2.0
0075      CALL CRS(NXSEC)
0076      CALL 3EDFX(NXSEC,DT)
0077      3 PV(INX)=FLOW(2,1+1)*(DX(I)+DX(I+1))/2.0
0078      NS=NXSEC
0079      WRITE(6,3002)
0080      WRITE(6,3003)
0081      3003 FORMAT(' INITIAL CONDITIONS')
0082      WRITE(6,3002)
0083      WRITE(6,3003)
0084      WRITE(6,3003)
0085      WRITE(6,3003)
0086      3010 FORMAT(3X,'GRID RIVER VELOCITY AREA TOP WIDTH TRIB. FLOW')
C START TIME LOOP **************************************************
C
C COMPUTE DISPERSION FLUXES (STATEMENTS 0096-0119, LABEL
C STATEMENTS 90-93)********************************************
C
C COMPUTE DISPERSIVE D'S
LNS=NS-1
DO 80 K=1,NS-1
IX=(PX(K)+PX(K+1))/2.0
80 DQ(K)=ABS(DQ(K))+U(IX)*A(IX))
C SET DQ=0 AT TRIBUTARY
K=0
DO 85 N=1,NTRIB
XR=IGT(N)
81 K=K+1
IF(PX(K).LT.XR) GO TO 81
K= K-1
85 DQ(K)= U.0
C LIMIT DQ TO FORCE STABILITY
82 CONTINUE
C IF(J.LT.5) WRITE(6,3000) (DQ(K),K=1,LNS)
C DISPERSE HEAT
DF(1)=DQ(1)*(PT(2)-PT(1))*DT/PV(1)
DO 84 K=2,LNS
DF(K)=ABS(DQ(K)+DQ(K+1)+DQ(K-1)-DQ(K))*DT/PV(K)
84 CONTINUE
C IF(J.LT.5) WRITE(6,3000) (DF(K),K=1,LNS)
C SET UPSTREAM BOUNDARY (STATEMENTS 0120-0129, LABEL
C STATEMENTS 40-59)********************************************
C READ BOUNDARY CONDITIONS
READ(5,1006) TUP,TAV,NS,ML,EA
IF(NTRIB.GT.0)READ(5,1006)(TRIB(IGT(N)),N=1,NTRIB)
PXX=1.0
PTU=TJP
PVU=FLOW(1,1)*FLOW(2,1)*DT
C SET U/S BOUNDARY (STATEMENTS 0130-0161, LABEL STATEMENTS 50-79)

C

MX=NXSEC-1
HD=DT
60 PDT=DX(MX)/J(MX)
0133 IF(PDT>=DT) GO TO 61
HDT=HDT-PDT
MX=MX-1
GO TO 60
61 XP=FLOAT(MX)+1.0-RDT/PDT
C FIND PARCEL U/S OF XP
LP=NS-1
52 IF(PX(LP).LT.XP) GO TO 63
LP=LP-1
GO TO 62
63 NS=LP+2
PX(NS)=FLOAT(NXSEC)

C FIND DLO CONCENTRATION OF PARCEL WHICH WILL FALL OUT
MX=IFI(XP)
XP=X(MX)+DX(MX)*(XP-FLOAT(MX))
MX=IFI(PX(LP))
XL=X(MX)+DX(MX)*(PX(LP)-FLOAT(MX))
MX=IFI(PX(LP+1))
XR=X(MX)+DX(MX)*(PX(LP+1)-FLOAT(MX))
150 COF=(XP-XL)/(XR-XL)
151 NPT(NS)=(PT(LP)*OF(LP)+(PT(LP+1)*DF(LP+1))*COF
152 PV(NS)= PV(LP+1)
153 PM(NS)= PM(LP)* (1.0-COF)*PM(LP+1)*COF
154 PTH(NS)= PTH(LP)* (1.0-COF)*PTH(LP+1)*COF
155 PTI(NS)= PTI(LP)* (1.0-COF)*PTI(LP+1)*COF
156 PDF(NS)= PDF(LP)* (1.0-COF)*PDF(LP+1)*COF
157 PDC(NS)= PDC(LP)* (1.0-COF)*PDC(LP+1)*COF
C IF(JL.T<=7) WRITE(6,3000) RDT, PDT, XP, XL, XR, COF, PT(NS), PM(NS),
C $PTH(NS), PDF(NS), PDC(NS)
158 MX= (IFI(PX(LP))+NXSEC)/2
C IF(JL.T<=7) WRITE(6,3000) LP, NS, MX
159 TIME= FLOAT(J+JTS)*DT/24.0
160 JRS= IFIX((TIME-IFI(TIME)) +0.0052)*96.0
161 CALL DECAY(DTeNS,MX,J,JRS)

C MOVE INTERIOR PARCELS (STATEMENTS 0162-0193, LABEL STATEMENTS 100-119)

C

LNS=NS-1
DO 103 I=1,NXSEC
103 NPT(I)=0
DO 100 KK=2,LNS
K=LNS+2-KK
100
0164 XOLD=PX(KO)
0165 MX=FIX(XOLD)
0170 PDT=DT
0171 PDX=FLOAT(MX+1)-PX(KJ)
0172 PDT=PDX*DX(MX)/J(MX)
0173 IF(PUT.GE.RDT) 30 TO 101
0174 CALL DECAY(PDT,<0,MX,J,JRS)
0175 RDT=P3T-PDT
0176 XOLD=FLOAT(MX)
0177 MX=MX+1
0178 NPT(MX)=NPT(MX)+1
0180 KPG(NPT(MX),MX)=K
0181 GO TO 102
0182 CONTINUE
C STOPPED IN SUBREACH
CALL DECAY(RDT,<0,MX,J,JRS)
PX(K)=XOLD*RDT*J(MX)/DX(MX)
PT(K)=PT(K0)+DF(KO)
PV(K)=PV(K0)
PH(K)=PH(K0)
PTM(K)=PTM(K0)
PTI(K)=PTI(K0)
PDF(K)=PDF(K0)+DF(K0)
PDC(K)=PDC(K0)
C IF(J.LT.7) WRITE(6,3001) K,KO,MX,(NPT(I),I=1,NXSEC)
C 3001 FORMAT('1.12I10)
C IF(J.LT.7) WRITE(6,3000) XOLD,RDT,PDT,PDX,PX(K),PT(K),PV(K),PH(K),
C PTH(K),PTI(K),PDF(K),PDC(K)
0193 100 CONTINUE
C TRANSFER BOUNDARY CONDITIONS TO PARCEL CHARACTERISTICS(STATEMENTS
C 0194-0201)****************************************************************
0194 PX(1)=PAU
0195 PT(1)=PTU
0196 PV(1)=PVU
0197 PH(1)=PHU
0198 PTH(1)=PTHU
0199 PTI(1)=PTIU
0200 PDF(1)=PDFU
0201 PDC(1)=PDCU
C DILUTE FOR TRIBUTARY INFLOW (STATEMENTS 0202-0235, LABEL
C *****DILUTE FOR TRIBUTARY INFLOW (STATEMENTS 0201-0234,REFERENCE
C STATEMENTS 120-129)****************************************************************
0202 IF(NTRIB.EQ.0) 30 TO 123
0203 K=0
0204 DO 123 N=1,NTRIB
I=IGT(N)
C IF(J.LT.7) WRITE(6,3001) K,KO,MX,(NPT(I),I=1,NXSEC)
C 3001 FORMAT('1.12I10)
C IF(NPT(I).EQ.0) 30 TO 120
0206 VOL=0.0
0208 M=NPT(I)
0209 DO 121 K=1,N
0210 KK=KPG(K,I)
VOL=VOL+PV(KK)
DO 122 K=1,M
KK=KP3(K.K)
COF=PV(KK)/VOL
DEL=(TRI8(K)*COF*QT(I)*3600.0*DT+PT(KK)*PV(KK))/(PV(KK)+QT(I)*3600.0)*COF*DT-PT(KK)
IF(QT(I).GE.0.0) DEL=0.0
PT(KK)=PT(KK)+DEL
PTR(K)=PTR(K)+DEL
PV(KK)=PV(KK)+COF*T(I)*3600.0
IF(J T.10) WRITE(6,3000) VOL,00F.PT(KK),2 TR(KK),PV(KK),UEL
IF(J L.10) WRITE(6,3001) K,KK
122 CONTINUE
GO TO 123
120 CONTINUE
C
C FIND NEAREST PA+CEL
C
K=K+1
IF(PX(K)+LT.FLOT(I)) GO TO 124
M=IFIX(PX(K))
XR=X(M)+DX(M)*(PX(K)-FLOAT(M))
K=K-1
MX=IFIX(PX(K))
XL=X(I)-X(MX)-(PX(K)-FLOAT(MX))*DX(MX)
IF(XR.LT.XL) K=K+1
DEL=(TRI8(I)*QT(I)*3600.0*DT+PT(KK)*PV(KK))/(PV(KK)+QT(I)*3600.0)*COF*DT-PT(KK)
IF(QT(I).GE.0.0) DEL=0.0
PT(KK)=PT(KK)+DEL
PTR(K)=PTR(K)+DEL
PV(KK)=PV(KK)+COF*T(I)*3600.0
IF(J T.10) WRITE(6,3000) XR,XL,PT(KK),PV(KK),PTR(K),DEL
IF(J.LT.10) WRITE(6,3001) K,MX,I
K= K-1
123 CONTINUE
C
C FIND CONCENTRATIONS AT IGO (STATEMENTS 0238-0253. LABEL
STATEMENTS 130-139)******************************************************
C
TIME=FLOT(I+JTS)*DT
K= 0
130 K= K +1
IF(PX(K)+LE.FLOT(IG0)) GO TO 130
IX=IFIX(PX(K))
X=X(IX)+DX(IX)*(PX(K)-FLOAT(IX))-X(IG0)
IX= IFIX(PX(K-1))
XL=X(IG0)-X(IX)-DX(IX)*(PX(K-1))-FLOAT(IX)
COF= XL/(XL+XR)
CIGO= PT(K-1)+COF*(PT(K)-PT(K-1))
CII0= PTI(K-1)+COF*(PTI(K)-PTI(K-1))
CDDIG0= PUF(K-1)+COF*(PUF(K)-PUF(K-1))
CTI0= PTR(K-1)+COF*(PTR(K)-PTR(K-1))
DCIGO= PUC(K-1)+COF*(PUC(K)-PUC(K-1))
TTIGO= TIME- PH(K-1)-COF*(PH(K)-PH(K-1))
CALL 3EDC(NS)
C
WRITE RESULTS (STATEMENTS 0254-0255. LABEL
C STATEMENTS 140-149)**************************************************
C
0254 IF(J.EQ.1)WRITE(6,2000) IGO,NXSEC
0255 IF(MOD(J,JOJT).EQ.0) GO TO 140
0257 Go TO 2
0257 140 IC=J/JOJT
0259 IF(MOD(IC,50).EQ.0) WRITE(6,2000) IGO,NXSEC
0259 2000 FORMAT(6X,TIME,6X,TEMP AT TRAVEL PARCEL CHANGE IN PARCEL TC
11L TEMP,6X,TEMP AT TRAVEL PARCEL CHANGE IN PARCEL TC
2PH,/+5X,1AY MOI HT+6X,3RDU TIME TEMP AT+12X,DUE TO+17X,
3K8I9O TIME TEMP AT+12X,DUE 10/+17X+6X+15X+9HOUR ENTRY
4 DISP TR/3 DECAY,7X+5X+6X+10HOUR ENTRY : IDISP,55X,TR/3 DECAY)
0260 IDAY= (TIME/24.0)+1
0261 HR= TIME-FLOAT(IDAY-1)*24.0
0262 TT= TIME-PH(NS)
0264 WRITE(6,2001)IDAY,HR,CI30,TITIG0,CIIGO,CTIGO,DCIAGO,PT(NS),TT,
#PTI(NS),PDF(NS),PTP(NS),PDC(NS)
0264 2001 FORMAT(5X,12X,F5.2,5X,F5.2,F5.2,F5.2,F5.2,F5.2,F5.2,F5.2,F5.2,
0265 3000 FORMAT(10E12.3)
0267 2 CONTINUE
0267 END
SUBROUTINE DECAY (K, MX, JRS)

COMMON H, PDC(500), PT(500)

HOT = UT

1    UTM = R01

CALL FINK (K, MX, JRS)

C FIND MAXIMUM DECAY TIME STEP

SUM = 4

UTL = R01

REF = PT(K)

IF(SUM.WE.0, AND, ABS(REF) .GT. 0, 3) UTL = ABS(0, 1*REF/SUM)

IF(UTL .LT. UTM) UTM = UTL

COM = 0, 999*UT

IF(UTM .GT. COM) UTM = R0T

C UPDATE TEMPERATURE

PT1 = PT(K)

PT(K) = PT(K) + SUM*UT

IF(J .GT. 3) WRITE(6, 1000) PT1, PT(K), H, SUM+DTM, REF

1000 FORMAT(' DECAY OUTPUT', 9E12.5)

CALL FINK (K, MX, JRS)

SUM2 = 4

PT(K) = PT1 + 0, 5*UTM = (SUM + SUM2)

PDC(K) = PDC(K) + 0, 5*(SUM*SUM2)*UTM

C IF(J .GT. 3) WRITE(6, 1000) XK*SUM2, PT(K), PDC(K)

IF(UTM .EQ. R0T) 30 TO 5

RDT = R0T - UTM

GO TO 1

5 RETURN

END
SUBROUTINE FINK(K, MX, JT)
DIMENSION RS(97.50), 6E0(50)
COMMON /PDC(500), PT(500)
COMMON /A/ TA, V, A(50), W(50), A1, 81, HS, HL, EA, FLOW(4, 50)
COMMON /C/ RS
COMM/A/
COMMON /D/
CPK = 100.0
SIG = 1.171E-7/24.0
AL = 595.9 - 0.545*PT(K)
TAd = PT(K) + 273.16
PSI = (A1 + 81*V)/(24.0*10.0)
SP = EXP(52.418 - 5788.6/TAd - 5.0016*ALOG(TAd))
H1 = (HS + S(JT, MX) + HL)*0.97)/24.0
H2 = H1 - 0.47*SIG*((PT(K) + 273.16)**4)
H3 = H2 - PSI*AL*((SP - EA) + 0.06*(PT(K) - TA)) + 3ED(MX)
H = H3*M/(A(MX)*CPK)
IF(K < JT) GO TO 30
WRITE(6, 3001) K, MX, JT
WRITE(6, 3000) TA, V, A(MX), HS, AL, TAB, PSI, SP, H
WRITE(6, 3000) W(MX), 41, HP, 1-12.EA, H Ltd, 3ED(MX)
3001 FORMAT(1H9, 7 12.4)
3000 FORMAT(1H9, 7 12.4)
1 RETURN
SUBROUTINE CRS(NXSEC)
C SUBROUTINE FOR COMPUTING ABSORPTION COEFFICIENTS ON A RIVER
C VARIABLE DEFINITIONS
C J= 1,196 TIME STEP AT 15 MINUTE INCREMENTS
C I= 1,50 GRID NUMBERS
C RS(J,I)=ABSORPTION COEFFICIENT FOR TIME J, GRID I
C EBM(I)=TREE HEIGHT OR EFFECTIVE BARRIER HEIGHT FOR EACH SUBREACH
C AZ(I)=AZIMUTH OF RIVER SUBREACH, DEGREES
C AZS=AZIMUTH OF SUN, DEGREES
C BW(I)=BANK WIDTH, DISTANCE FROM TREES TO WATERS EDGE, METERS
C THE= ANGLE BETWEEN SUN AND STREAM AXIS, DEGREES
C BET= ANGLE BETWEEN SUN AND A NORMAL TO THE STREAM AXIS, DEGREES
C ELEV=ELEVATION OF THE SUN, DEGREES
C XN= NORMAL DISTANCE FROM TREES TO EDGE OF SHADOW, METERS
C X= DISTANCE FROM TREES TO SHADOW ALONG A BEAM OF LIGHT, METERS
C DEL= DECLINATION OF THE SUN, DEGREES
C HA= HOUR ANGLE FROM ZENITH TO SUN, DEGREES
C M= HOUR ANGLE AT MIDNIGHT, DEGREES
C PHI= ATTITUDE OF RIVER, DEGREES
C ALON= LONGITUDE OF RIVER, DEGREES
C TZM= TIME ZONE MERIDIAN
C JDAT= JULIAN DATE FOR WHICH SHADING COMPUTATIONS ARE MADE
C DEG= DEGREE TO RADIAn CONVERSION
C
DIMENSION EdH(50),AZ(50),BW(50),T(50)
COMMON/TA/V3A(50),A131,H5,ML,EA,FLOW(4,50)
COMMON/H(97,50)
READ(5,1000) JOAT,P1I9A_ON,TZM
1000 FORMAT(10X9I73=7.1)
READ(5,1001) (AZ(I),I=1,50)
1001 FORMAT(10X910F7.1)
OR= 3.14159/180.0
DMA= 3./5*04
PHI= Doll*DR
DEL= DR*23.45*COS(6.283P*(172.0—FLOAT(JDAT))/365.0)
HAD= (140.0+ALON—TLM)*DR.
SDSP= SIN(DEL)*SIN(PHI)
CDCP= COS(DEL)*COS(PHI)
DO 10 J=1,96
10 M= J-1
IF(HA.LT.0.0) AZS= 360.D—AZS
WRITE(693001) J,HA,S9EL=W,RSM,AZS,DEL,HAD,SDSP,COCP
1001 FORMAT(H STEP,I599E12.(9)
DO 10 I=1,NXSEC
IF(ELEV.GT.1.5) GO TO 1
RS(J,I)= 0.2
GO TO 10

1 THE = FE((AZS - AZ(I)) * G)

IF THE < 0.1 (10.0 * G X) THE = THE - 150.0 * G X

THE = E5(I)/TAN(E6(I) * G X)

IF(COS (THE) < 0.01) GO TO 2

HS(J+I) = RS4

GO TO 10

2 XN = X * COS (THE)

IF (XN < FLOW (1)) GO TO 3

HS(J+I) = RS4

GO TO 10

3 IF (XN < (HW(I) + FLOW (1))) GO TO 4

RS(J,1) = 0.2

GO TO 10

4 RS(J,1) = RS4 * (Ow(1) + 3W(I) - XN) / FLOW (1) + 0.2 * (XN - HW(I)) / FLOW (1)

WRITE (6, 3002) I, THE, BET, X, XN, FLOW (1), RS(J+1)

3002 FORMAT (5H GRID0, 15/12.4)

CONTINUE

RETURN

END

WRITE (6,00) I, THE, BET, X, XN, FLOW (1), RS(J+1)

000 FORMAT (5H GRID0, 15/12.4)

CONTINUE

RETURN
SUBROUTINE 3EDFX(VXSEC,*T)

C DEFINE VARIABLES
C
C RFJ(J) = RESPONSE FUNCTION ORDINATE FOR FLOW OF HEAT TO THE WATER
C TO THE BED DUE TO A UNIT CHANGE IN TEMPERATURE
C DFT(J,I) = CHANGE IN WATER TEMPERATURE AT GRID I AND TIME T-JDT
C T0(I) = INITIAL TEMPERATURE AT GRID I
C CV = HEAT STORAGE CAPACITY OF THE BED MATERIAL IN CAL/(CJ C4 3ELi C)
C DIF= THERMAL DIFFUSIVITY OF THE BED MATERIAL SW CM/HR
C NRFO= NUMBER OF RESPONSE FUNCTION ORDINATES
C X= DEPTH IN SE AT WHICH IT IS ASSUMED THAT NO HEAT TRANSFER OCCURS
C
C DIMENSION RFJ(45),3DT(95,50),T0(50),T3(50)
C DOUHD>PRECISION X(51)
C COMMON/ 1,PDC(500),PT(500)
C COMMON/ J/ DEJ(50)
C RE0(5.e000) DI=DIV
C 2000 FORMAT(10x*2F7.3)
C
C SET DFT'S EQUAL TO ZERO
C
C DO 1 I=1,NXSEC
C DO 1 J=1,96
C DFT(J,I) = 0.0
C 1 DIST(J,I)= 0.0
C
C COMPUTE RESPONSE FUNCTION ORDINATES
C
C XL = 300.0
C DT= JT
C IF(DT<.LT.0.25) DT=0.25
C NRFO = 24/DT3
C HO= 1.0
C A= -DIF*9.86959*DT3/(4.0*XL*XL)
C DO 2 J=1,NRFO
C 8= 0.0
C H= 0.0
C CA= 1.0
C 2 CONTINUE
C
C UPDATE SUMS
C
C TNPI= 2.0*8+1
C UH=(SIN(TNPI*1.3708))*(*EXP(A*TNPI*TNPI*FLOAT(J)))*CA/(TNPI*TNPI)
C M= M+H
C H= B+1
C CA= -CA
C
C CHECK CONVERGENCE
C IF(ABS(BM).GT.1.0E-6) GO TO 3
C
C FINAL COMPUTATIONS
C
C RFJ(J)= -(MU-M)*CV*XL
C
C 2 CONTINUE
C
C WRITE RESULTS

C
C WRITE (6, 3000) CV, DIF
C
0030   J000 FORMAT (1M0, 33X, 'RESPONSE FUNCTION ORDINATES FOR HEAT CONDUCTION',
C 1'TERM (RF0 IN CAL/(CM4 SEC)), ', ', 3M3X, 'HEAT STORAGE CAPACITY OF ',
C 3'= ', ', FT, ', ', 'CAL/(CM4 SEC) sec)', ', ', 2X, 'LAG', ', ', 4X, 'RF0 LAG RF0 LAG RF0 LAG RF0',
C 42X, 'LAG RF0 LAG RF0 LAG RF0 LAG RF0',
C 52X, 'LAG RF0 LAG RF0 LAG RF0',
C
0035   WRITE (6, 3004) (., RF0(I), I=1, NRFO)
C
0037   J004 FORMAT (1M5, 10(13, F5.2)), /

0038   RETURN

C ENTRY REDUC(NS)

C
C UPDATE OLD TEMPERATURES
C
0040   DO 4 I=1, NXSEC
C 0041   IF (DT .LT. 0.34) TO(I) = TO(I) + DT *.04*(TN(I) - TO(I))
C 0042   ELSE IF (DT .LT. 0.25) TO(I) = TN(I)
C
C COMPUTE NEW TEMPERATURES
C
0043   TN(I) = PT(I)
C 0044   K=0
C 0045   IX = NXSEC-1
C 0046   DO 6 I=2, IX
C 0047       K=K+1
C 0048       IF (PX(K) .LE. FLOAT(I)) GOTO 5
C 0049       IX = IFIX(PX(K))
C 0050       XR = X(IX) + X(IX) * (PX(K) - FLOAT(I)) - X(1)
C 0051       K=K-1
C 0052       IX = IFIX(PX(K))
C 0053       XL = X(IX) - XR
C 0054       COF = XL / XR
C 0055       TN(I) = PT(K) + COF * (PT(K+1) - PT(K))
C 0056   6 TN(NXSEC) = PT(NS)
C 0057   DO 7 I=1, NXSEC
C 0058       IE = NRFO - 1
C 0059       DO 8 IE = IE-1
C 0060       8 DBT(I) = DBT(I+1) - DT(I) 
C 0061       DBT(I+1) = TN(I) - TO(I)
C
C COMPUTE NEW FLUX
C
0062   BDD(I) = 0.0
C 0063   DO 7 IE = IE-1
C 0064       BDD(I) = BDD(I) + RF0(I) * DT(I)
C 0065       7 CONTINUE
C 0066   RETURN
C 0067 END
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Output of

Complete Temperature Model in Steady Flow
MODEL DOCUMENTATION FOR THE COMPLETE TEMPERATURE MODEL

MODEL IS TO RUN 40 TIME STEPS EACH 1.00 HOURS LONG. THE RIVER IS DISCRETIZED BY 8 GRID POINTS.
THE INITIAL UPSTREAM DISCHARGE IS CONSTANT AT 12.00 CUBIC METERS PER SECOND.
THE PRINTOUT WILL BE GIVEN FOR GRID 5 AND 6 FOR EACH 2 TIME STEPS.
THE WINU FUNCTION IS 3.01 in MEAN DAY KPA.

ASSUMPTION COEFFICIENTS FOR SOLAR RADIATION

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ATTACHMENT D

10-Parameter Model in Steady Flow
DEFINITIONS

PXU, PXD, PX(K) = POSITION OF LAGRANGIAN PARTICLE (U/S, D/S, EULERIAN GRID UNITS)
PVU, PVD, PV(K) = VOLUME OF LAGRANGIAN PARCEL
PHU, PHO, PH(K) = TIME THE PARCEL ENTERED THE SYSTEM
PTU, PTD, PT(L, K) = CONCENTRATION OF CONSTITUENT L IN PARCEL K
PTRU, PTRD, PTR(L, K) = CHANGE IN CONC. OF CONSTITUENT L DUE TO TRIB. INFLOW
PTIU, PTID, PT(I(L, K) = CONC. OF CONSTITUENT L IN PARCEL K AS IT ENTERED SYSTEM
PDFU, PDFD, PDF(L, K) = CHANGE OF CONC. OF CONSTITUENT L DUE TO DISPERSION
PDCU, PDCD, PDC(L, K) = CONCENTRATION CHANGE OF CONSTITUENT L DUE TO A SPECIFIED REACTION
FLOW(L, I) = FLOW FIELD INFORMATION L AT GRID I
L=1 FOR FLOW VELOCITY IN METERS PER HR.
L=2 FOR FLOW AREA IN SQUARE METERS
L=3 FOR TOP WIDTH IN METERS
L=4 FOR TRIBUTARY INFLOW IN CU METERS/SECOND
U(I) = AVERAGE VELOCITY IN SUBREACH I IN METERS / HOUR
A(I) = AVERAGE AREA IN SUBREACH IN SQUARE METERS
W(I) = AVERAGE TOP WIDTH IN SUBREACH I IN METERS
X(I) = RIVER MILE OF GRID I
DX(I) = DISTANCE BETWEEN GRID I AND I+1
OQU(I) = DISPERSION FACTOR (DISP/(J*U*UT))
OQ(K) = FLOW RATE BETWEEN PARCEL K AND K+1 DUE TO VELOCITY GRADIENTS
UF(L, K) = CONC. CHANGE OF CONSTITUENT L IN PARCEL K DUE TO DISPERSION
TRH(L, I) = OBSERVED CONC. OF CONSTITUENT L AT UPSTREAM END OF REACH
TRH(L, I) = OBSERVED CONC. AT GRID I
QTI(I) = TRIBUTARY INFLOW IN CUBIC METERS PER SECOND AT GRID I
QTI = DISCHARGE AT UPSTREAM END IN CUBIC METERS PER SECOND
DT = TIME STEP SIZE (IN HOURS)
PDX = PART OF EULERIAN SUBREACH REMAINING TO BE TRAVERSED
PDT = TIME REQUIRED TO TRAVERSE THE REMAINING PART OF THE SUBREACH
HDT = TIME REMAINING FOR MOVEMENT
A1 = CONSTANT IN WIND FUNCTION (MM/DAY KPA)
B1 = MASS TRANSFER COEFFICIENT (MM/DAY KPA(M/S))
V = WIND SPEED IN M/S
TA = AIR TEMPERATURE IN DEGREES C
CPH = HEAT CAPACITY (100 CAL PER SQ CM M)
NXSEC = NUMBER OF EULERIAN GRIDS
INX = NXSEC-1
NS = NUMBER OF PARCELS IN THE SYSTEM
NSL = NS-1
LP = LAST PARCEL TO STAY IN THE SYSTEM AT D/S END
MX = GRID U/S OF PARCEL
IGT(N) = GRID NUMBER FOR TRIBUTARY INFLOW
NPT(I) = NUMBER OF PARCELS TO PASS GRID IGT(N) DURING DT
KPG(N, M) = PARCEL NUMBER OF PARCEL TO PASS GRID IGT(N) DURING DT
NEQ = NUMBER OF EQUATIONS
NMHR = NUMBER OF TIME STEPS
C  **PRELIMINARIES (STATEMENTS 0001-0038, LABEL STATEMENTS 20-39)**********
C
0001 DIMENSION PX(500),PV(500),PT(10,500),PH(500),PTR(10,500),
    PDC(10,500),PTI(10,500),
0002 DIMENSION DX(50),J(50),A(50),FLOW(4,50),W(50),LR(10)
0003 DIMENSION UQW(50),T(50),TRH(10,500),IGT(50),KPG(20,500),NPT(50)
0004 DIMENSION PDF(10,500),DF(500),DF(10,500),TITLE(20)
0005 DIMENSION TUP(10),X(10),S(10),J(10),PTU(10),PTRU(10),
    PTIJ(10),PUDU(10),LABEL(10),PDCU(20)
0006 DIMENSION CIG0(10),C1(G0(10),CD1G0(10),CT1G0(10),OC1G0(10)
0007 DOUBLE PRECISION X(51)
C  MAXIMUM VALUE OF VASEC IS 50
C
C  STEP 1 TO 37 ARE TO ZERO ARRAYS.
C
0009 DO 4 =1,500
0010 PX(K) = 0.0
0011 DJ(K) = 0.0
0012 PV(K) = 0.0
0013 PH(K) = 0.0
0014 PM(K) = 0.0
0015 UO = 0.0
0016 PT(10) = 0.0
0017 PTW(L,K) = 0.0
0018 PDF(L,K) = 0.0
0019 PT(L,K) = 0.0
0020 PDC(L,K) = 0.0
0021 DF(L,K) = 0.0
0022 DO 5 I=1,50
0023 X(I) = 0.0
0024 UQW(I) = 0.0
0025 RT(I) = 0.0
0026 FLOW(4,I) = 0.0
0027 IGT(I) = 0.0
0028 UX(I) = 0.0
0029 U(I) = 0.0
0030 W(I) = 0.0
0031 A(I) = 0.0
0032 UO = 0.0
0033 TRH(L) = 0.0
0034 UO = 0.0
0035 S(L) = 0.0
0036 UO = 0.0
0037 KK(L,K) = 0.0
0038 CR(L,K) = 0.0
C
C  **HEAD INPUT (STATEMENTS 0039-0066)********************************************************

C

118
SUBROUTINE WIND (STATEMENTS 0067-0104)***********************
C
0067 X(NXSEC+1)=X(NXSEC)
0068 XUP=X(I)
0069 DO 1 I=1,NXSEC
0070 DX(I)=(X(I)-X(I+1))*1603.34
0071 X(I)=(X(I)-X(I+1))*1603.34
0072 PX(I)=FLOAT(I)
0073 PM(I)=FLOAT(JTS)*DT
0074 FLOW(1,1)=3600.0*Q/FLJW(2,1)
0075 Q=3*FLOW(4,1)
0076 DO 1 I=1,NEQ
0077 PTL(L+I)=PT(L+I)
0078 POF(L+I)= 0.0
0079 PDC(L+I)= 0.0
0080 CONTINUE
0081 INX=NXSEC-1
0082 PW(I)=FLOW(2,1)*DX(I)+PFLW(1,1)/2.0
0083 DO 3 I=1,INX
0084 U(I)=(FLOW(1,1)+FJW(1,1+1))/2.0
0085 A(I)=(FLOW(2,1)+FJW(2,1+1))/2.0
0086 W(I)=(FLOW(3,1)+FJW(3,1+1))/2.0
0087 QT(I)=FLOW(4,1)

MODEL IS TO RUN 15+ TIME STEPS EACH 10.2, 4 HOURS LONG
1. THE RIVER IS DISCRETIZED BY 150 GRID POINTS. 4+4 THE INITIAL
2+5+5=5 DISCHARGE IS CONSTANT AT 10.2+ CUBIC METERS PER SECOND
5+4+4 THE PRINTOUT WILL BE GIVEN FOR 410.2+ AND 4+4 FOR
5+10+4 EACH 1+ TIME STEPS.

THE WIND FUNCTION IS F10.2+ F10.2+ F10.2+ F10.2+ F10.2+ IN MH/DAY KP
5+4+4
0089 3 PV(I+1) = FLOW(2+I+1)*(DX(I)+DX(I+1))/2.0
0090 PV(NXSEC)= FLOW(2+NXSEC)*(DX(INX))/2.0
0091 NS=NXSEC
0092 WRITE(6,3002)
0093 WRITE(6,3004)
0094 3004 FORMAT(1H0950X0INITIAL CONDITIONS')
0095 WRITE(6,3002)
0096 WRITE(6,3010)
0097 3010 FORMAT(1 1 1093X03kI) RIVER VELOCITY AREA TOP WIDTH TRIB.
   #FLOW',1X,
   1' DISP. FACT',2X,3'INITIAL TEMP OK CONC',1/10X,9MILE W/HR',
   2 5' METERS METER',5X,9CU W/SEC DQQ 1 2 4 5 6 7 8 9 10*/
0098 NS=NS-1
0099 NS=NS-1
0100 WRITE(6,3011) I.K4.FLOW(I+1) , FLOW(I)9FLOW(3,I),QT(I)9(PT(L,I)
   $ +L=1,4EQ)
0101 3011 FORMAT( 4X.12.1X.F7.293X,F7.0,1X,F9.192X9F9.2.5X,F7.2912X910F5.2)
0102 IF(I.LT.NS) WRITE(6,3007)
0103 3007 FORMAT(63X,F5.2)
0104 CONTINUE
0105 WRITE(h+3002)
0106 C START TIME LOOP ****************************************************
0107 C COMPUTE DISPERSION FLUXES (STATEMENTS 0107-0162, LABEL
0108 C STATEMENTS 00-99)************************************************
0109 C COMPUTE DISPERSION Q'S
0110 LNS=NS-1
0111 DO 80 K=1,LNS
0112 IX=(PX(K)+PX(K+1))/2.0
0113 DO 80 K=1,LNS
0114 DQ(K)=ABS(D(VJ)(IX)+J(IX)*A(IX))
0115 SET DQ=0 AT TRIBUTARY
0116 K=0
0117 DO 85 N=1,NTRIB
0118 XR=IGT(N)
0119 IF(PX(K).LT.XR) GO TO 81
0120 IF(K.EQ.1) GO TO 83
0121 HATIO=DQ(K-1)*UT/PV(K)
0122 IF(K.EQ.NS) GO TO 82
0123 HATIO=DQ(K)*UT/PV(K)
0124 IF(HATIO.GT.0.35) DQ(K)=0.35*PV(K)/DT
0125 82 CONTINUE
0126 81 K=K+1
0127 80 CONTINUE
0128 LIMIT DQ TO FUNCTION STABILITY
0129 DO 92 H=1.0
0130 IF(K.EQ.1) GO TO 93
0131 HATIO=DQ(K-1)*UT/PV(K)
0132 IF(HATIO.GT.0.35) DQ(K)=0.35*PV(K)/DT
0133 92 CONTINUE
0134 IF(K,GT.35) WRITE(6,3000) (DQ(K),K=1,LNS)
0135 DISPENSE HEAT
0136 DO 96 L=1,NEQ
0137 DF(L,1)=DQ(1)*(PT(L,2)-PT(L,1))*DT*PV(1)
0138 DO 96 H=2,NEQ
0139 DF(L,H)=DQ(H-1)*(PT(L,H-1)-PT(L,H))*DT*PV(H)
0132 96 CONTINUE
0133 96 97 08288 12/31/52
FORTRAN IV G1 RELEASE 2.0

```
0130 IF(ABS(DF(L,K)) .LT. 1.0E-6) OF(L,K) = 0.0
0131 OF(L,NS) = OF(L,NS-1) * DF(L,NS-1) * DT / PV(NS)
0132 CONTINUE

0133 WRITE(6,3000) (DF(L,K), K=1,NS)
0134 CONTINUE

0135 READ BDUNDARY CONDITIONS
0136 DO 40 L=1,NEU
0137 IF(LeEpel) READ(5,1006) TjP(1),TA.V9(TRIB(1,IGT(N)), N=1,NTRI9)
0138 IF(L.3Tel) READ(5,1006) TUP(L),(TRIB(L,IGT(N)),N=1,NTRIB)
0139 CONTINUE

0137 PXU=1.0
0138 PVU= FLOW(1,1)*FLO*(2,1)*DT
0139 PHU= DT*FLOAT(J•JTS)
0140 DO 41 L=1,NEU
0141 PTU(L)=TUP(L)
0142 PTRU(L)=0.0
0143 PTIU(L)=TUP(L)
0144 PDFU(L)=0.0
0145 PDFU(L)=U.°
0146 IF(J.3Te30) WRITE(6,3000) PXU,PTU(N)+PVJ,PHU,PTRU(L)
0147 CONTINUE

0147 SET D/S BOUNDARY (STATEMENTS 0147-0178, LABEL STATEMENTS 60-69)

0149 MX=NXSEC-1
0150 PDT=D(4X)/D(4X)
0151 IF(PDT.GE.RDT) GOTO 61
0152 HDT=RDT-PDT
0153 MX=M-1
0154 XP=FLOAT(MX)+1.0-HDT/PDT
0155 LP=NS-1
0156 IF(PX(LP).LT.XP) GOTO 63
0157 LP=LP-1
0158 GO TO 62
0159 NS=LP+2
0160 PX(NS)=FLOAT(NXSEC)

0161 MX=IFIX(XP)
0162 XP=X(MX)+DX(MX)*(XP-FLOAT(MX))
0163 MX=IFIX(PX(LP))
0164 XL=X(MX)+DX(X)(MX)*(PX(LP)-FLOAT(MX))
0165 MX=IFIX(PX(LP))
0166 XR=X(MX)+DX(MX)*(PX(LP)-FLOAT(MX))
0167 COF=(XP-XL)/(XR-XL)
0168 PV(NS)= PV(LP+1)
0169 PH(NS)= PH(LP)*(*L,0-COF)*PH(LP+1)*COF
0170 DO 66 L=1,NEW
0171 PT(L,NS) = PT(L,LP)*DF(L,LP) / (L,0-COF) * PT(L+LP+1) * DF(L+LP+1) * COF
0172 CONTINUE

0173 CONTINUE

0174-121
```
*CJF*  

0172

*C*  

0174

*CONTINUE*  

0177

*C*  

0179

C MOVE INTERIOR PARCELS (STATEMENTS 0179-0212, LABEL STATEMENTS 100-119)**************************************************

C  

0179

LNS=NS-1

0180

U1 103 1 = 1, NXSEC

0181

103 NPT(I) = 0

0182

DO 100 LK=2, LNS

0183

K=-LK-1

0185

XOLD=PX(KD)

0186

MX=IFIX(XOLD)

0187

RDT=DT

0188

PDX=PDX(MX)-PX(KD)

0189

102 PUT=PDX*UX(MX)/J(MX)

0190

IF(PDX.RT)GO TO 101

C PASSED GRID

0191

CALL DECAY(PXT,KD), MX,J, NEQ)

0192

J=NXT-PDT

0193

MX=MX+1

0194

XOLD=PX(MX)

0195

PDX=1.0

0196

NPT(MX)=NPT(MX)+1

0197

KPG(NPT(MX),MX)=K

0198

GO TO 102

0199

STOPPE IN SUBHEAT

C CALL DECAY(PXT,KD), MX,J, NEQ)

0200

PX(K)=X3D+PDT*J(3X)/DX(3X)

0201

PV(K)=PV(K)

0202

PH(K)=PH(K)

0203

DO 104 L=1, NEQ

0204

PT(L,K)=PT(L,K)+DF(L,K)

0205

PTL(K)=PTL(K)

0206

PT(K,L)=PT(K,L)

0207

DF(L,K)=DF(L,K)

0208

PDC(L,K)=PDC(L,K)

0209

IF(J vết.35)WRIT(5,3000) PT(L,K),PRT(L,K),PT1(L,K),PDF(L,K)*

C PDC(L,K)

0210

CONTINUE

0211

104 CONTINUE

0212

3001 FORMAT("", +12I10)

C IF(J\_35)WRIT(5,3000) XOLD, RDT, PDT, PX, PV(K), PH(K)

0213

CONTINUE

C TRANSFER BOUNDARY CONDITIONS TO PARCEL CHARACTERISTICS

C (STATEMENTS 0213-0221)******************************************

C  

0214

PX(1)=UX

0215

PV(1)=PVU
FORTRAN IV G1 ,RELEASE 2.0

PH(1)=P1U
DO 105 L=1,NVT
  PTH(L,1)=PTU(L)
  PTI(L,1)=PITU(L)
  PPDF(L,1)=PPDFU(L)
105 PDC(L,1)=PDCU(L)
C DILUTE FOR TRIBUTARY INFLOW (STATEMENTS 0222-0262, LABEL STATEMENTS 120-129)**************************************
C
IF(NTRIB*EQ*0) 30 TO 123
  K=0
  DO 123 N=1,NTRIB
   I= IGTV(N)
   IF(J*ST*GT*7) WRITE(6,3001P('NTRIB:*I,15X,NPT(I)
   IF(NPT(I)*EQ*0) 30 TO 120
   VOL=0.0
   DO 121 NN=1,NPT(I)
    KK=KP3(NN,I)
    VOL=VOL+PV(KK)
    CONTINUE
   DO 122 NN=1,NPT(I)
    KK=KP3(NN,I)
    COF=PV(KK)/VOL
    CONTINUE
   DEL=(TRIB(L,1)*COF*QT(I)*3600.0*DT+PT(L,K)*PV(KK))/(PV(KK)+3T(I)*3600.0*COF*QT(I))
   IF(QT(I)*LE*0.0) DEL=0.0
   PT(L,K)=PT(L,K)+DEL
   WRITE(6,3000) VOL,C3P,PT(L,K),PTR(L,K),DEL
   CONTINUE
   VOL=PV(KK)+C3F*3T(I)*DT*3600.0
   WRITE(6,3000) PV(KK)
   CONTINUE
GO TO 123
C FINL) NEAREST PARCEL
C
124 K=K+1
125 IF(PX(K)*LT*FLOAT(I)) GO TO 124
   MX=FIX(PX(K))
   XR=X(MX)+(PX(K)-FLAT(MK))*DX(MX)-K(I)
   K=K-1
126 IF(PX(K)*LT*FLOAT(I)) GO TO 124
   XL=X(I)-X(MX)-(PX(K)-FLAT(MX))*DX(MX)
   DEL=(TIRB(L,1)*QT(I)*3600.0*DT+PT(L,K)*PV(K))/PV(KK)+3T(I)*3600.0*PV(KK)
   IF(QT(I)*LE*0.0) DEL=0.0
   PT(L,K)=PT(L,K)+DEL
   WRITE(6,3000) XR,XL,PT(L,K),PV(KK),DEL
   CONTINUE
   PV(KK)=PV(KK)+C3F*3T(I)*DT*3600.0
   CONTINUE
C IF(J*ST*GT*7) WRITE(6,3001) K,KON
C 122 CONTINUE
GO TO 123
120 CONTINUE
C FIND NEAREST PARCEL
C
124 K=K+1
125 IF(PX(K)*LT*FLOAT(I)) GO TO 124
   MX=FIX(PX(K))
   XR=X(MX)+(PX(K)-FLAT(MX))*DX(MX)-K(I)
   K=K-1
126 IF(PX(K)*LT*FLOAT(I)) GO TO 124
   XL=X(I)-X(MX)-(PX(K)-FLAT(MX))*DX(MX)
   DEL=(TIRB(L,1)*QT(I)*3600.0*DT+PT(L,K)*PV(K))/PV(KK)+3T(I)*3600.0*PV(KK)
   IF(QT(I)*LE*0.0) DEL=0.0
   PT(L,K)=PT(L,K)+DEL
   WRITE(6,3000) XR,XL,PT(L,K),PV(KK),DEL
   CONTINUE
   PV(KK)=PV(KK)+C3F*3T(I)*DT*3600.0
   CONTINUE
C IF(J*ST*GT*7) WRITE(6,3001) XR,VL+PT(L,K),PV(KK),PTR(L,K),DEL*TRIB(L,I)
C 126 CONTINUE
0259 PV(K) = PV(K) + UT(I) * DT * 3600.0
0260 IF (J * JT > 0) WRITE(6,3000) K, MX
0261 K = K - 1
0262 123 CONTINUE

C
C FIND CONCENTRATIONS AT IGO (STATEMENTS 0263-0279, LABEL
C STATEMENTS 130-139)***************************************
C
0263 TIME = FLOAT(J+JTS) * DT
0264 K = 0
0265 130 IF (PX(K) * FLOAT(IGO)) 30 TO 130
0266 IX = IFIX(PX(K))
0267 XR = X(IX) + UX(IX) * (PX(K) - FLOAT(IX)) - X(IGO)
0268 IX = IFIX(PX(K-1))
0269 XL = X(IGO) - X(IX) - DX(IX) * (PX(K-1) - FLOAT(IX))
0270 COF = XL / (XL + XR)
0271 DO 131 L = 1, N0
0272 CIG0(L) = PT(L, K-1) + COF * (PT(L, K) - PT(L, K-1))
0273 CIIGO(L) = PTI(L, K-1) + COF * (PTI(L, K) - PTI(L, K-1))
0274 CDIGO(L) = PDF(L, K-1) + COF * (PDF(L, K) - PDF(L, K-1))
0275 CTIGO(L) = PTR(L, K-1) + COF * (PTR(L, K) - PTR(L, K-1))
0276 DCIGU(L) = P3C(L, K-1) + COF * (P3C(L, K) - P3C(L, K-1))
0277 131 CONTINUE

C
C WRITE RESULTS (STATEMENTS 0280-0305, LABEL STATEMENTS 140-149)
C
0280 IF (J .EQ. 1) WRITE(6,2000) IGO, NXSEC
0281 IF (MOD(J, JOUT) .EQ. 0) 60 TO 140
0282 GO TO 2
0283 140 IC = J / JOUT
0284 IF (MOD(IC*50), 1EQ.0) WRITE(6,2000) IGO, NXSEC

2000 FORMAT (X, TIME CONC. AT PARCEL CHANGE IN CONCENTRATION
1**13X**1CONC. AT PARCEL CHANGE IN CONCENTRATION**1/4, **
20**2H GRID ENTRY OF PARCEL DUE TO**1/20X**GRID ENTRY OF PARCEL DUE TO**1/20X**GRID ENTRY OF PARCEL DUE TO
3ENTRY OF PARCEL DUE TO**1/15X**5X**CONC. DIF.
TRIB**1/10X**5X**CONC. DIF.
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A 'CUBIC METERS AND PARCEL ENTERED SYSTEM AT HOUR', F10.2)

0302 WRITE(6,5001)

0303 5001 FORMAT(1HO, 'PARAMETER CONC, INT CONC, DEL DISP, DEL TRIB',

0304 ' DECAY DUE TO',

0304 DO 150 L=1, N_EQ

0305 150 WRITE(6,2002) LABEL(L), T(L,K), PTI(L,K), PDF(L,K), PTR(L,K), PDC(L,K)

END
SUBROUTINE DECAY (OT,K, MX, J, NEQ)

DIMENSION SJM(10), PT1(10), SUM2(10), DC(10), DC2(10)

COMMON XK(10, 10), PDC(10, 500), PT(10, 500), TAV, A(50), W(50), A1, 31,

? S(10), CR(10, 10), LR(10), U(50)

RDT = DT

1 DTM = RDT

CALL FINK (K, MX, J, NEQ)

C FIND MAXIMUM DECAY TIME STEP

2 SUM(L) = S(L)

3 SUM(L) = SUM(L) * XK(L, LL) * (PT(L, K) - CR(L, LL))

4 DT = RDT

C IF (SUM(L) * NEQ, 0.0) AND ABS (REF) GT 0.3) DTL = ABS (0.1 * REF / SUM(L))

5 IF (DTM LT DT) DTM = DT

2 CONTINUE

C UTM = 4 * DT

6 CALL = INK (K, MX, J, NEQ)

7 SUM2(L) = S(L)

DO 10 L = 1, NEQ

8 SUM2(L) = SUM2(L) + XK(L, LL) * (PT(L, K) - CR(L, LL))

9 LL = LR(L)

10 DC2(L) = XK(L, LL) * (PT(L, K) - CR(L, LL))

11 DC2(L, K) = PT1(L, K) * 0.5 * DT

C IF (J > T-5) WRITE (6, 1000) PT1(L, K), SUM2(L), DC2(L)

13 CONTINUE

C DO 4 = 1, NEQ

14 LL = LR(L)

15 PT1(L, K) = PT1(L, K) + SUM(L) * 4 * DT

16 IF (J > T-6) WRITE (6, 1000) PT1(L, K), SUM2(L), DC2(L)

17 RETURN

END
SUBROUTINE FINK(K, MX, JOEQ)

COMMON XK(10,10), PDC(10,500), PT(10,500), TA, V, A(50), W(50), AL, 31, S(10), CR(10), LR(10), U(50)

CPR = 100.0
SIG = 1.171E-7/24.0
AL = 595.9-0.545*PT(1,K)
PSI = (AL+31*V)/(24.0*10.0)
TA3 = PT(1,K)**3
UFT = 1.532E11*EXP(-4271.1/(PT(1,K)+242.63))/((PT(1,K)+242.63)**2)
XKX = 4.0*0.97*S3*(TA3**3)*AL*PSI*(UFT**0.06)
XK(1,1) = XKX**W(4X)/(A(MX)*CPR)
CR(1,1) = TA
CR(2,1) = XK(2,2) = 0.00161*(U(4X)**0.607)/((A(MX)/W(4X))**1.689)
CORT = 1.047**((PT(1,K)-20.0)
XK(2,3) = -0.1*CORT
IF(PT(2,K)*LT1*0) XK(2,3) = 0.0
CH(2,2) = 468.0/(PT(1,K)+31.6)
XK(3,3) = XK(2,3)
RETURN
END
Input Data for

10-Parameter Model in Steady Flow
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Output of

10-Parameter Model in Steady Flow
DOCUMENTATION FOR 10 PARAMETER MODEL

MODEL IS TO RUN 40 TIME STEPS EACH 1.00 HOURS LONG. THE RIVER IS DISCRETIZED BY 9 GRID POINTS.

THE INITIAL UPSTREAM DISCHARGE IS CONSTANT AT 6.00 CUBIC METERS PER SECOND.

THE PRINTOUT WILL BE GIVEN FOR GRIDS 5 AND 8 FOR EACH 2 TIME STEPS.

THE $w$ FUNCTION IS $3.01 + 1.13X$ IN MM/DAY <KPA>

**INITIAL CONDITIONS**

| GRID MILE | VELOCITY | AREA | TOP WIDTH | TRIB. FLOW | DISP.FACT | UDG | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|-----------|----------|------|-----------|------------|-----------|-----|---|---|---|---|---|---|---|---|---|
| 1         | 355.00   | 17.10| 17.10     | 0.0        | 0.20      | 0.0 | 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0|
| 2         | 357.18   | 1227. | 39.50     | 0.05       | 0.20      | 0.0 | 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0|
| 3         | 355.15   | 788. | 30.4      | 61.90      | 0.20      | 0.0 | 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0|
| 4         | 353.41   | 2347. | 10.2      | 81.80      | 0.20      | 0.0 | 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0|
| 5         | 351.61   | 570. | 42.0      | 89.10      | 0.20      | 0.0 | 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0|
| 6         | 348.78   | 814. | 29.4      | 82.50      | 0.20      | 0.0 | 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0|
| 7         | 347.06   | 601. | 36.8      | 115.40     | 0.20      | 0.0 | 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0|
| 8         | 345.21   | 497. | 48.2      | 123.20     | 0.20      | 0.0 | 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0|

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<th>PARCEL ENTRY</th>
<th>CHANGE IN CONCENTRATION</th>
<th>TRAVEL TIME TO GRID 6 IS 2.00 HOURS</th>
<th>TRAVEL TIME TO GRID 8 IS 2.00 HOURS</th>
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<td>DU 9.91 0.00 -0.09 0.3 11.04 DU</td>
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<td>SO 0.98 0.00 1.12 0.3 -0.23 SIMD</td>
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<td>1 20:00 TRAVEL TIME TO GRID 6 IS 12.00 HOURS</td>
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<td>TEMP 7.54 0.00 -0.10 0.33 7.11 TEMP</td>
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<td>DU 10.16 0.00 -0.18 0.02 11.46 DU</td>
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<td>1 21:00 TRAVEL TIME TO GRID 6 IS 14.00 HOURS</td>
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<td>SO 3.79 0.00 0.03 5.25 -2.49 SIMD</td>
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<td>2 0:00 TRAVEL TIME TO GRID 6 IS 15.90 HOURS</td>
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<td>TEMP 9.30 0.13 0.16 2.36 6.66 TEMP</td>
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<td>DU 6.19 10.00 0.34 -0.70 5.43 DU</td>
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<td>SO 4.65 2.00 -0.06 9.51 -6.90 SIMD</td>
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River Mile 32: Parcel Volume = 23960 cubic meters and parcel entered system at hour 36.00

Parameter: Conc. Int Conc. Del Disp. Del Trib. Decay Due To
Temp: 15.50 14.20 0.18 0.67 0.65 Temp
DO: 2.00
BOD: 9.62

River Mile 33: Parcel Volume = 23960 cubic meters and parcel entered system at hour 35.00

Parameter: Conc. Int Conc. Del Disp. Del Trib. Decay Due To
Temp: 15.50 14.20 0.18 0.67 0.65 Temp
DO: 2.00
BOD: 9.62

River Mile 34: Parcel Volume = 23960 cubic meters and parcel entered system at hour 34.00

Parameter: Conc. Int Conc. Del Disp. Del Trib. Decay Due To
Temp: 15.50 14.20 0.18 0.67 0.65 Temp
DO: 2.00
BOD: 9.62

River Mile 35: Parcel Volume = 23960 cubic meters and parcel entered system at hour 33.00

Parameter: Conc. Int Conc. Del Disp. Del Trib. Decay Due To
Temp: 15.50 14.20 0.18 0.67 0.65 Temp
DO: 2.00
BOD: 9.62

River Mile 36: Parcel Volume = 23960 cubic meters and parcel entered system at hour 32.00

Parameter: Conc. Int Conc. Del Disp. Del Trib. Decay Due To
Temp: 15.50 14.20 0.18 0.67 0.65 Temp
DO: 2.00
BOD: 9.62

River Mile 37: Parcel Volume = 23960 cubic meters and parcel entered system at hour 31.00

Parameter: Conc. Int Conc. Del Disp. Del Trib. Decay Due To
Temp: 15.50 14.20 0.18 0.67 0.65 Temp
DO: 2.00
BOD: 9.62

River Mile 38: Parcel Volume = 23960 cubic meters and parcel entered system at hour 30.00

Parameter: Conc. Int Conc. Del Disp. Del Trib. Decay Due To
Temp: 15.50 14.20 0.18 0.67 0.65 Temp
DO: 2.00
BOD: 9.62

River Mile 39: Parcel Volume = 23960 cubic meters and parcel entered system at hour 29.00

Parameter: Conc. Int Conc. Del Disp. Del Trib. Decay Due To
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DO: 2.00
BOD: 9.62
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<th>Parameter 3</th>
<th>Parameter 4</th>
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ATTACHMENT E

Flow Routing Model of Dawdy and others
C*******************************************************************************
C FLOW ROUTING DAWDY ET AL
C*******************************************************************************
C X(I) = X COORDINATE IN RIVER MILES
C Q0(I),Q(I) = OLD/NEW DISCHARGE AT GRID I, TRIBS ENTER JUST D/S OF GRID
C A(I) = OLD/NEW AREA IN SUBREACH I
C W(I) = WIDTH AT SECTION I IN METERS
C QT(I) = TRIBUTARY INFLOW AT GRID I
C DT = TIME STEP IN SECONDS
C DX(I) = DISTANCE BETWEEN GRIDS IN METERS
C NXSEC = NUMBER OF CROSS SECTIONS (INX = NXSEC - 1)
C FLOW(L,I) = FLOW FIELD AT GRID I
C L = 1 FOR VELOCITY IN METERS/SEC
C L = 2 FOR AREA IN SQ. METERS
C L = 3 FOR TOP WIDTH IN METERS
C L = 4 FOR TRIBUTARY INFLOW IN CU. METERS/SEC
C*******************************************************************************
C
0001 DIMENSION Q0(50),Q(50),A(50),X(50),W(50)
0002 DIMENSION FLOW(4,50)
0003 DATA FLOW/200 4 0.0/
0004 DATA Q0,W,A,DT,DX/50*0.0,50*0.0,50*0.0,50*0.0,50*0.0,50*0.0,50*0.0/ 0005 Q0(1)=6.0
0006 QT(5)=0.65
0007 DT=3600.0
0008 NXSEC=8
0009 INX=NXSEC-1
0010 HEAD(I,5,0000) (X(I),I=1,NXSEC)
0011 4000 FORMAT(10X.10F7.2)

C***** CONVERST MILES TO METERS IN THE DX ARRAY
C
0012 DO 100 I=1,INX
0013 DX(I)=(X(I)-X(I+1))*1609.34
0014 Q0(I+1)=Q0(I)+QT(I)
0015 100 CONTINUE

C****** INITIALIZE SUBROUTINE XSEC
C
0016 CALL XSEC(NXSEC)
0017 DO 200 I=1,NXSEC
0018 CALL QTA(I,Q0(I),A(I))
0019 CALL ATW(I,A(I),W(I))
0020 FLOW(1,I)=3600.0*Q0(I)/A(I)
0021 FLOW(2,I)=A(I)
0022 FLOW(3,I)=W(I)
0023 FLOW(4,I)=QT(I)
0024 200 CONTINUE

C***** WRITE FLOW AT TIME ZERO
C
0025 WRITE(6,9001)
0026 9001 FORMAT(999,E15.7)
0027 WRITE(6,8001)
0028 8001 FORMAT(999,E15.7)
0029 DO 202 I=1,NXSEC
0030 WRITE(6,8000) I,FLOW(I,5),FLOd(I,4),K=1,4
0031 202 CONTINUE
C*****BEGIN TIME LOOP
C
DO 2 J=1,40
READ(5,3000) Q(I)
3000 FORMAT(10X,F8.1,4(F6.1))
CALL QTA(I,Q(I),A(I))
DO 3 I=2,NXSEC
II=I-1
U=QO(I)/AQ(I)
THETA=U*DT/DX(II)
IF (THETA.LT.1.0) GO TO 4
CALL QTA(II,W(II),A(II))
Q(I)=2(II)-DX(II)*(A(II)-AQ(II))/DT*QT(I)
CALL QTA(I,Q(I),A(I))
GO TO 3
4 V(V=(QO(I-1)+QT(I-1))*DT
VO=QO(I)*DT
DELS=VI-VO
A(II)=AQ(I)*DELS/DX(II)
CALL ATQ(II,A(II),Q(II))
3 CONTINUE
DO 7 I=1,NXSEC
AO(I)=A(I)
CALL ATW(I, AO(I), W(I))
FLOW(I,1)=3600.0*O(I)/A(I)
FLOW(2,I)=A(I)
FLOW(3,I)=W(I)
FLOW(4,5)=0.65
7 CONTINUE
WRITE(6,4001)TIME
4001 FORMAT(' ', 'TIME=',F6.2,'HOURS')
DO 77 I=1,NXSEC
WRITE(6,8000) J,FLOW(I),K=1,4
8000 FORMAT(1X,13,3X,F12.3)
77 CONTINUE
WRITE(5,6500)((FLOW(K,I),K=1,4),I=1,NXSEC)
6500 FORMAT(8F10.3)
5 CONTINUE
2 STOP
END
SUBROUTINE XSEC(NXSEC)

C*****YP(N,I)= DEPTH OF CROSS SECTION AT BREAK POINT N
C*****QP(N,I)= DISCHARGE OF CROSS SECTION I AT BREAK POINT N
C*****AP(N,I)= AREA OF CROSS SECTION I BELOW BREAK POINT N
C*****WP(N,I)= WIDTH OF CROSS SECTION AT BREAK POINT N

DIMENSION AP(24,50), QP(24,50), YP(24,50), WP(24,50)

DO 1 I=1,NXSEC
READ(5,1000) (YP(N,I), N=1,11)
READ(5,1000) (QP(N,I), N=1,11)
READ(5,1000) (AP(N,I), N=1,11)
READ(5,1000) (WP(N,I), N=1,11)
1000 FORMAT(12X,11F6.2)
CONTINUE
RETURN

ENTRY OTA(I,Q,A)

QTA CONVERTS FROM DISCHARGES TO AREAS
N=0
20 N=N+1
IF(Q.GT.QP(N,I)) GO TO 20
A=AP(N-1,I)+(Q-QP(N-1,I))*(AP(N,I)-AP(N-1,I))/(QP(N,I)-QP(N-1,I))
RETURN

ENTRY ATQ(I,A,Q)

ATQ CONVERTS FROM AREAS TO DISCHARGE
N=0
22 N=N+1
IF(A.GT.AP(N,I)) GO TO 22
Q=QP(N-1,I)+(A-AP(N-1,I))*(QP(N,I)-QP(N-1,I))/(AP(N,I)-AP(N-1,I))
RETURN

ENTRY ATW(I,A,W)

ATW CONVERTS FROM AREA TO TOP WIDTH
N=0
23 N=N+1
IF(A.GT.AP(N,I)) GO TO 23
W=AP(N-1,I)+(A-AP(N-1,I))*(WP(N,I)-WP(N-1,I))/(AP(N,I)-AP(N-1,I))
RETURN

END
Input Data for

Flow Routing Model of Dawdy and others
| RIVER MILE | 360.00 | 357.18 | 355.41 | 353.41 | 351.51 | 349.78 | 347.86 | 345.21 |
| DEPTH SEC | 1 | 1.34 | 3.43 | 5.26 | 7.37 | 11.31 | 16.30 | 24.82 |
| DISCH SEC | 1 | 36.32 | 54.20 | 69.42 | 116.41 |
| AREA SEC | 1 | 2.4 | 3.7 | 4.7 | 5.6 | 7.2 | 8.8 | 11.3 |
| WIDTH SEC | 1 | 15.8 | 16.1 | 16.3 | 16.5 | 16.7 | 18.5 | 19.3 |
| DEPTH SEC | 2 | 3.6 | 7.2 | 9.7 | 12.2 | 16.3 | 20.8 | 27.5 |
| DISCH SEC | 2 | 1.149 | 1.337 | 1.840 | 24.82 | 36.32 | 54.20 | 69.42 |
| AREA SEC | 2 | 3.6 | 7.2 | 9.7 | 12.2 | 16.3 | 20.8 | 27.5 |
| WIDTH SEC | 2 | 15.8 | 16.1 | 16.3 | 16.5 | 16.7 | 18.5 | 19.3 |
| DEPTH SEC | 3 | 3.6 | 7.2 | 9.7 | 12.2 | 16.3 | 20.8 | 27.5 |
| DISCH SEC | 3 | 1.149 | 1.337 | 1.840 | 24.82 | 36.32 | 54.20 | 69.42 |
| AREA SEC | 3 | 3.6 | 7.2 | 9.7 | 12.2 | 16.3 | 20.8 | 27.5 |
| WIDTH SEC | 3 | 15.8 | 16.1 | 16.3 | 16.5 | 16.7 | 18.5 | 19.3 |
| DEPTH SEC | 4 | 3.6 | 7.2 | 9.7 | 12.2 | 16.3 | 20.8 | 27.5 |
| DISCH SEC | 4 | 1.149 | 1.337 | 1.840 | 24.82 | 36.32 | 54.20 | 69.42 |
| AREA SEC | 4 | 3.6 | 7.2 | 9.7 | 12.2 | 16.3 | 20.8 | 27.5 |
| WIDTH SEC | 4 | 15.8 | 16.1 | 16.3 | 16.5 | 16.7 | 18.5 | 19.3 |
| DEPTH SEC | 5 | 3.6 | 7.2 | 9.7 | 12.2 | 16.3 | 20.8 | 27.5 |
| DISCH SEC | 5 | 1.149 | 1.337 | 1.840 | 24.82 | 36.32 | 54.20 | 69.42 |
| AREA SEC | 5 | 3.6 | 7.2 | 9.7 | 12.2 | 16.3 | 20.8 | 27.5 |
| WIDTH SEC | 5 | 15.8 | 16.1 | 16.3 | 16.5 | 16.7 | 18.5 | 19.3 |
| DEPTH SEC | 6 | 3.6 | 7.2 | 9.7 | 12.2 | 16.3 | 20.8 | 27.5 |
| DISCH SEC | 6 | 1.149 | 1.337 | 1.840 | 24.82 | 36.32 | 54.20 | 69.42 |
| AREA SEC | 6 | 3.6 | 7.2 | 9.7 | 12.2 | 16.3 | 20.8 | 27.5 |
| WIDTH SEC | 6 | 15.8 | 16.1 | 16.3 | 16.5 | 16.7 | 18.5 | 19.3 |
| DEPTH SEC | 7 | 3.6 | 7.2 | 9.7 | 12.2 | 16.3 | 20.8 | 27.5 |
| DISCH SEC | 7 | 1.149 | 1.337 | 1.840 | 24.82 | 36.32 | 54.20 | 69.42 |
| AREA SEC | 7 | 3.6 | 7.2 | 9.7 | 12.2 | 16.3 | 20.8 | 27.5 |
| WIDTH SEC | 7 | 15.8 | 16.1 | 16.3 | 16.5 | 16.7 | 18.5 | 19.3 |
| DEPTH SEC | 8 | 3.6 | 7.2 | 9.7 | 12.2 | 16.3 | 20.8 | 27.5 |
| DISCH SEC | 8 | 1.149 | 1.337 | 1.840 | 24.82 | 36.32 | 54.20 | 69.42 |
| AREA SEC | 8 | 3.6 | 7.2 | 9.7 | 12.2 | 16.3 | 20.8 | 27.5 |
| WIDTH SEC | 8 | 15.8 | 16.1 | 16.3 | 16.5 | 16.7 | 18.5 | 19.3 |

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3 6.0
4 6.0
5 32.11
6 71.28
7 100.0
8 90.86
9 71.28
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13 27.54
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15 22.97
16 21.01
17 19.06
18 18.66
19 17.36
20 15.79
21 14.62
22 13.57
23 12.53
24 12.14
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26 10.70
27 9.92
28 9.0
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30 8.09

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Output of

Flow Routing Model of Dawdy and others
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| 6.00 HOURS | 1 | 12092.391 | 21.221 | 20.959 | 0.0   |
|            | 2 | 3490.243  | 31.288 | 27.884 | 0.0   |
|            | 3 | 1069.432  | 20.198 | 19.005 | 0.0   |
|            | 4 | 3414.441  | 6.326  | 5.835  | 0.0   |
|            | 5 | 833.274   | 25.922 | 25.709 | 0.650 |
|            | 6 | 1201.354  | 19.927 | 18.770 | 0.0   |
|            | 7 | 999.650   | 23.948 | 22.335 | 0.0   |
|            | 8 | 728.226   | 32.874 | 30.770 | 0.0   |

| 7.00 HOURS | 1 | 13755.535 | 26.171 | 21.876 | 0.0   |
|            | 2 | 5048.656  | 63.757 | 55.294 | 0.0   |
|            | 3 | 2210.372  | 47.012 | 43.811 | 0.0   |
|            | 4 | 3749.479  | 7.688  | 7.316  | 0.0   |
|            | 5 | 833.274   | 25.922 | 25.709 | 0.650 |
|            | 6 | 1201.354  | 19.927 | 18.770 | 0.0   |
|            | 7 | 999.650   | 23.948 | 22.335 | 0.0   |
|            | 8 | 728.226   | 32.874 | 30.770 | 0.0   |

| 8.00 HOURS | 1 | 13290.883 | 24.596 | 21.584 | 0.0   |
|            | 2 | 5113.316  | 65.358 | 55.447 | 0.0   |
|            | 3 | 3420.212  | 75.637 | 74.567 | 0.0   |
|            | 4 | 6940.102  | 25.725 | 21.123 | 0.0   |
|            | 5 | 888.375   | 28.417 | 25.805 | 0.650 |
|            | 6 | 1201.354  | 19.927 | 18.770 | 0.0   |
|            | 7 | 999.650   | 23.948 | 22.335 | 0.0   |
|            | 8 | 728.226   | 32.874 | 30.770 | 0.0   |

<p>| 9.00 HOURS | VELOCITY | AREA    | WIDTH  | TRIB. |
|            | GMD       | (M/HR.) | (SQ. M.) | (METERS) | (CU. M./SEC.) |</p>
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<th>(METERS)</th>
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<tr>
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**TIME = 10.00 HOURS**

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\[ TIME= 39.00HOURS \]

\[ TIME= 40.00HOURS \]
ATTACHMENT F

Conservative Transport in Unsteady Flow
**DEFINITIONS**

- **PX**: Position of Lagrangian particle (U/S, D/S, parcel K) in Eulerian grid units
- **PT**: Concentration of Lagrangian parcel
- **PV**: Volume of Lagrangian parcel
- **PH**: Time the parcel entered the system
- **PTU**: Change in concentration due to tributary inflow
- **PTI**: Concentration of parcel as it entered the system
- **PDF**: Concentration change of parcel K during DT due to dispersion
- **FLOW**: Flow field information at Eulerian grid I
  - L=1 for flow velocity in meters/hour
  - L=2 for flow area in square meters
  - L=3 for top width in meters
  - L=4 for tributary inflow in cu meters/second
- **U**: Average velocity in sub-reach I in meters/hour
- **A**: Average area in sub-reach I in square meters
- **X**: Coordinate of sub-reach grid I in river miles
- **DOW**: Distance between grid I and I+1
- **DQ**: Dispersion factor (DISP/(J*J*T))
- **DW**: Flowrate between parcel K and K+1 due to velocity gradients
- **DF**: Concentration change of parcel K during DT due to dispersion
- **UP**: Observed concentration at upstream end of reach
- **WT**: TrIBUTARY INFLOW IN CUBIC METERS PER SECOND AT GRID I
- **THI**: Observed concentration of tributary inflow at grid I
- **Q**: Discharge at upstream end in cubic meters per second
- **DT**: Time step size (in hours)
- **PD**: PART OF THERMIAN SUBREACH REMAINING TO BE TRAVERSED
- **PD**: TIME REQUIRED TO TRAVERSE THE REMAINING PART OF THE SUBREACH
- **N**: NUMBER OF EULERIAN GRIDS
- **NSEC**: NUMBER OF EULERIAN GRIDS
- **NS**: NUMBER OF PARCELS IN THE SYSTEM
- **LNS**: NS-1
- **LP**: LAST PARCEL TO STAY IN THE SYSTEM AT J/S END
- **MX**: GRID U/S OF PARCEL
- **IGT**: Number for tributary inflow
- **NPT**: Number of parcels to pass grid IGT during DT
- **KPG**: Number of parcels to pass grid IGT during DT
- **NTRI**: NUMBER OF ACTUAL TRIBUTARIES
- **IOUT**: NUMBER OF TIME STEPS BETWEEN OUTPUT LISTINGS
- **JTS**: NUMBER OF TIME STEPS FROM MIDSUM TO TIME ZERO IN MODEL
- **TITLE**: TITLE OF PROGRAM, 80 CHARACTERS MAX.

**PRELIMINARIES**

1. DIMENSION PX(500), PT(500), PV(500), PH(500), PTU(500), PTI(500)
2. DIMENSION JX(50), J(50), A(50), FLOW(4,50), W(50)
3. DIMENSION DOW(50), JT(50), TRIB(50), IGT(50), KPG(20,50), NPT(50)
4. DIMENSION PDF(500), DW(500), DF(500), TITLE(20)
5. DOUBLE PRECISION X(51)
C
C MAXIMUM VALUE OF NXSEC IS 50
C
STEP 5 TO 74 ARE TO ZERO ARRAYS.
DO 4 K=1,50
PT(K)= 0.0
PV(K)= 0.0
PH(K)= 0.0
PTH(K)= 0.0
PDF(K)= 0.0
PTI(K)= 0.0
DF(K)= 0.0
DO 5 I=1,50
X(I)= 0.0
UT(I)= 0.0
FLOW(4,I)= 0.0
X(I)= X(I+1)*1609.34
READ INPUT (STATEMENTS 0026-0046)***********************
READ(5,1000) TITLE(K),K=1,20
WRITE(6,3003) TITLE(K),K=1,20
READ(5,1005) 4 (SECOHR,OT.4,130,IOJT,NTRI8,JTS
IF (NTRI8.EQ.0) GO TO 8
DO 7 I=1,NTRIB
READ(5,1010) IGT(I),JTT
FLOW(4,I)= IGT(I)
READ(5,1006) (U2(I),I=1,NXSEC)
READ(5,1006) (PT(I),I=1,NXSEC)
WRITE(6,3005) NR,DT,NXSEC,GT,150,NXSEC,JTS
IF (NTRI8.EQ.0) GO TO 8
DO 7 I=1,NTRIB
HEAD(5,1010) IGT(I),JTT
I= IGT(I)
FLOW(4,I)= IGT(I)
READ(5,1006) 4 (U2(I),I=1,NXSEC)
READ(5,1006) (PT(I),I=1,NXSEC)
WRITE(6,3005) NR,DT,NXSEC,GT,150,NXSEC,JTS
READ INPUT DATA (STATEMENTS 0047-0082)***********************
XUP=X(1)
X(NXSEC+1)=X(NXSEC)
DO 1 I=1,NXSEC
DX(I)=(X(I)-X(I+1))*1609.34
X(I) = (XJ - X(I)) * 1609.34
PX(I) = FLOAT(I)
PM(I) = FLOAT(JT) * JT
PT(I) = P(T(I))
PDF(I) = 0.0
P(T(I)) = 0.0
FLOW(I,1) = 3500.0 * Q / FLOW(2,1)
Q = 0 * FLOW(4,1)
CONTINUE

READ(55,6500) ((FLOW(K,I), K = 1,4), I = 1,NXSEC)
6500 FORMAT(3F10.3)
INX = NXSEC - 1
PV(I) = FLOW(2,1) * ((X(I) + DT * FLOW(1,1)) / 2.0
DO 3 I = 1, INX
U(I) = (FLOW(1,I) + FLOW(1,I+1)) / 2.0
A(I) = (FLOW(2,I) + FLOW(2,I+1)) / 2.0
QT(I) = FLOW(4,I)
3 PV(NXSEC) = FLOW(2,NXSEC) * (DX(INX)) / 2.0
NS = NXSEC
WRITE(6,3002)
3002 FORMAT(3X, 10D12.2, 1X, 10D12.2)
WRITE(5,3007) (AGI(I), I = 1, NX)
3007 FORMAT(30X, 1D12.2)
CONTINUE
WRITE(6,3010)
3010 FORMAT(1M0.50x, 1X, 'INITIAL CONDITIONS')
WRITE(5,3011) 1, RM, FLOW(1,1), FLOW(2,1), QT(1), PT(1)
CONTINUE
WRITE(6,3002)
C
START TIME LOOP
DO 2 J = 1, NS

DO 14 I = 1, INX
U(I) = FLOW(1,I) + FLOW(1,I+1)
A(I) = FLOW(2,I) + FLOW(2,I+1)
QT(I) = FLOW(4,I)
14 CONTINUE

HEAD(55,6500) ((FLOW(K,I), K = 1,4), I = INX, NXSEC)
DO 12 I = INX
U(I) = (U(I) + FLOW(1,I) + FLOW(1,I+1)) * 0.25
A(I) = (A(I) + FLOW(2,I) + FLOW(2,I+1)) * 0.25
QT(I) = (QT(I) + FLOW(4,I)) * 0.5
12 CONTINUE

C
COMPUTE DISPERSION FLUXES (STATEMENTS 0097-0120, LABEL
STATEMENTS 90-99)
C COMPUTE DISPENSIVE J'S
LNS=NS-1
006 DO 80 K=1,LNS
007 IX=(RX(K)+PX(K+1))/2.0
010 DO 80 (JU(IX)*J(IX)*A(IX))
C SET JU=0 AT LIMIT
C LIMIT JQ TO FORCE STABILITY
U0 H2 X=1,NS
IF(K.EQ.1) GO TO 83
NATIU=DQ(K-1)*DT/PV(K)
IF(NATIU.GT.0.35) QJ(K-1)=0.35*PV(K)/UT
IF(K.EQ.NS) GO TO 92
NATIU=DQ(K)*DT/PV(K)
IF(NATIU.GT.0.35) QJ(K)=0.35*PV(K)/DT
C CONTINUE
C IF(J.LT.5) WRITE(6,3000) (DQ(K),K=1,LNS)
C DISPERSE HEAT
DF(1)=DQ(1)*PT(1)*DT/PV(1)
DO 84 K=2,LNS
DF(K)=(JU(K-1)*PT(K-1)-PT(K))*DQ(K)*A(K)*DT/PV(K)
IF(A6S(JF(K)).LT.1.0Ef5) DF(K)=0.0
DF(NS)=DQ(NS-1)*PT(NS)*DT/PV(NS)
C IF(J>.T.5) WRITE(6,3000) (DF(K),K=1:NS)
C SET UPSTREAM BOUNDARY (STATEMENTS 0121-0128, LABEL STATEMENTS 40-59)*************************************************
C READ BOUNDARY CONDITIONS
READ(5,10061) TRIB(IGT(N)),N=1,NTIB)
PXU=1.0
PTY=1.0
PVU=FL(SW(1,1)*FLDw(2,1))
PMU=J*FLOAT(J+JTS)
PTMU=0.0
PTMU=TY
PFU=0.0
IF(J.LT.7) WRITE(6,3000) (PXU,PTY,PVU,PMU,PTMU,PFU)
C SET D/S BOUNDARY (STATEMENTS 0129-0155, LABEL STATEMENTS 60-79)
C MX=NXSEC-1
0130 HDT=DT
0131 50 PDT=DX(MX)/J(MX)
0132 IF(PDT.LE.JT) GO TO 51
0133 HDT=J*PDT
0134 MX=MX-1
0135 GO TO 50
0136 XP=FLOAT(MX)+1.0-RDT/PDT
C FIND PARCEL U/S OF XP
C
C FIND DLU CONCENTRATION IF PARCEL WHICH WILL FALL OUT

C 52 IF(PX(LP).LT.XP) GO TO 63
0132
C 53 NS=LP+2
0133
C PX(NS)=FLOAT(N*SEC)
0134
C A FIND DLU CONCENTRATIDN IF PARCEL 0.1-1ICM MILL FALL OUT
0135
C MX=IFIX(X(K))
0136
C XP=X(K)*X(K)
0137
C X=MX=IFIX(PX(LP))
0138
C XL=X(K)*X(K)
0139
C MX=IFIX(PX(LP+1))
0140
C XR=X(K)*X(K)
0141
C COF=(XP-XL)/(XR-XL)
0142
C PT(NS)=(PT(LP)+(PT(LP)+DF(LP))*(1.0-COF)+(PT(LP+1)+DF(LP+1))*COF
0143
C PV(NS)= 10.0
0144
C PH(NS)= PH(LP)*(1.0-COF)+PH(LP+1)*COF
0145
C PTR(NS)=PTR(LP)*(1.0-COF)+PTR(LP+1)*COF
0146
C PDF(NS)=PDF(LP)*(1.0-COF)+PDF(LP+1)*COF
0147
C IF(JLT.7) WRITE(6,3000) 4DT.PJT,XP,XL,XR,COF,PT(NS),PV(NS)

C MOVE INTERIOR PARCELS (STATEMENTS 0156-0183, LABEL STATEMENTS 100-119)************************************************4

C LNS=NS-1
0156
C 0157 DU 103 I=1,N*SEC
0158 103 NPT(I)= 0
0159
C 0160 DU. 100 =K=2,LNS
0161 K=K-1
0162 XOLD=PX(K)
0163 MX=IFIX(XOLD)
0164
C PDT=PX*UX(MX)/J(MX)
0165
C IF(PDT.GE.RDT) GO TO 101
0167 102 PDT=PDT*D=M T+101
C PASSED 5=10
0168 5=10
0169 XOLD=PX(K)
0170 PDX=1.0
0171 NPT(MX)=NPT(MX)+1
0172 KPG(NPT(MX),MX)=K
0173 GO TO 102
0174
C 101 CONTINUE
C STOPPED IN 4DT.XREACH
C PX(K)=XOLD*J*P(J)(MX)/DX(MX)
0175
C PT(K)=PT(K)+DF(K)
0176
C PV(K)=PV(K)
0177
C PH(K)=PH(K)
0178
C PTH(K)=PT(K)
0179
C PTI(K)=PTI(K)
0180
C PDF(K)=PDF(K)
0181
C IF(JLT.7) WRITE(6,3001) K,K0,4XM,NPT(I),I=1,N*SEC)
0182 3001 FORMAT(' '912110)
0183

161
0182   IF(J= T+7) WRITE(6*,3600) XULJ*RT+PJ*PX(K),PT(K),PV(K),PT(K),PT(K),PT(K)
0183   CONTINUE
0184   TRANSFER BOUNDARY CONDITIONS TO PARCEL CHARACTERISTICS (STATEMENTS 0185-0191)
0186   PX(1)=PU
0187   PT(1)=TU
0188   PV(1)=PV
0189   PH(1)=PHU
0190   PT(1)=PTU
0191   DIFFERENT INFLOW (STATEMENTS 0192-0227, LABEL STATEMENTS 120-129)***************************
0192   IF(NTRI6•EQ•0) 30 TO 123
0193   K=0
0194   VOL=123  K=1•NTRI6
0195   I= IOT(N)
0196   IF(J•T•(I) WRITE(6,3001)K,N=NTRI6+I,N,1.1
0197   VOL=0.0
0198   M=NPT(I)
0199   VOL=VOL+PV(KK)
0200   X(I)=X(K)+PV(KK)
0201   COF=PV(KK)/VOL
0202   IF(QT(I)•LE•0.0) DEL=0.0
0203   PT(KK)=PT(KK)+UEL
0204   PTR(KK)=PTR(KK)+UEL
0205   IF(NTRI6•EQ•0) 30 TO 123
0206   121 CONTINUE
0207   GO TO 123
0208   120 CONTINUE
0209   FIND NEAREST PARCEL
0210   124 K=K+1
0211   MX=IFIX(PX(K))
0212   XR=X(MX)+(PX(K)-FLOAT(MX))•DX(MX)-X(I)
0213   IF(PX(K)•LT•FLOAT(I)) GO TO 124
0214   MX=IFIX(PX(K))
0215   XR=X(MX)+(PX(K)-FLOAT(MX))•DX(MX)-X(I)
0216   K=K+1
0217   123 CONTINUE
IF (J + L.T.10) WRITE (6, 3000) XR, XL, PT(K), PV(K), 0 TR(K), DEL
K = K - 1
CONTINUE

FIND CONCENTRATIONS AT IGO (STATEMENTS 0226-0241, LABEL STATEMENTS 130-139)***************************************

K = K + 1
IF (PX(K) * LE. * FLOAT(IGO)) GO TO 130
IX = FIX(PX(K))
XR = X(IX) + OX(IX) * (PX(K) - FLOAT(IX)) - X(IGO)
IX = FIX(PX(K - 1))
XL = X(IGO) - X(IX) + OX(IX) * (PX(K - 1) - FLOAT(IX))
COF = XL / (XL + XR)
CIGO = PT(K - 1) + COF * (PT(K) - PT(K - 1))
CIIGO = PTI(K - 1) + COF * (PTI(K) - PTI(K - 1))
CDIGO = PDF(K - 1) + COF * (PDF(K) - PDF(K - 1))
CTIGO = PTR(K - 1) + COF * (PTR(K) - PTR(K - 1))
TTIGO = TIME - JH(K - 0) - COF * (PH(K) - P1(K - 1))

WRITE RESULTS (STATEMENTS 0242-0253, LABEL STATEMENTS 140-149)

IF (J .EQ. 1) WRITE (6, 2000) IGO, NXSEC
IF (MOD(J, 10) .EQ. 0) GO TO 140
GO TO 2

IDAY = (TIME / 24.0) + 1
HR = TIME - FLOAT(IDAY - 1) * 24.0
TT = TIME - PM(NS)
WRITE (6, 2001) IDAY, HR, CI30, T300, CIIGO, CIIGO, CIIGO, CTIGO, PT(NS) + PDF(NS), PT(NS) + PDF(NS) + PM(NS)

2 CONTINUE
Output of

Conservative Transport in Unsteady Flow
The initial upstream discharge is constant at 12,000 cubic meters per second.

The river is discretized by 8,040 points.

The simulation will be run for 40 time steps each 1.00 hours long. The river is discretized by 8,040 points.

### Initial Conditions

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### Model Documentation for a Conservative Substance in Unsteady Flow

The time step is 0.05 hours, and the river is discretized by 8,040 points.