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DYNAMIC WATER ROUTING USING A PREDICTOR-CORRECTOR METHOD WITH SEDIMENT ROUTING

by

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ABSTRACT

DYNAMIC WATER ROUTING UTILIZING A PREDICTOR-CORRECTOR
METHOD WITH SEDIMENT ROUTING

Numerical water routing models are often limited in their application because of either the underlying simplifications, the restrictions imposed by stability considerations or the complexity of the numerical scheme solving the governing equations.

Herein a stable and efficient dynamic water routing method is presented which overcomes the above difficulties by introducing physical concepts into the finite difference solution technique. Stability restrictions or complexity of the explicit and implicit schemes are overcome without reverting to simplifications of the complete St. Venant equations, but by controlling the flood wave movement in space and time with the nonlinear wave celerity. Simplicity and efficiency in the solution technique is attained by solving the governing equations in an uncoupled manner with a predictor-corrector method. The use of a predictor-corrector method inhibits the growth of error by reconsidering and readjusting the predicted values in the corrector step.

The application of the dynamic water routing model DYNWAR to a hypothetical case had previously shown the model to be independent of size of the space and time increments of the finite difference grid. Furthermore the results showed good convergence and stability properties. The model was successfully applied to a general case which included computation of bed elevation changes based on sediment routing by size fraction. The completeness and efficiency of the dynamic water routing model DYNWAR makes it particularly interesting for general studies of large river systems with mild and steep channel bed slopes,

for alternative studies of flood control structures and/or channel improvements where the backwater and dynamic effects are relevant and also for sediment routing to evaluate bed elevation changes.

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LIST OF SYMBOLS

Symbol	Description
A	flow area [ft^2]
A_s	change in cross-sectional area
a	coefficient in power function
B	channel width
BF	bulking factor
b	power in power function
C	Courant number
C_s	conversion factor
c	Chezy's friction coefficient
c_k	kinematic wave celerity corresponding to Chezy friction
c_e	expansion or contraction coefficient for gradually varying channels
c	flood wave celerity
D	flow depth
D_o	reference flow depth
d_s	bed material size
f_o	Darcy-Weisbach friction factor
$\vec{F}$	force vector
F_b	gravitatinal forces
F_e	pressure forces normal to the control boundaries
F_s	surface forces parallel to the control boundaries
F_r	Froude number
g	acceleration of gravity
H	total head
H_a	acceleration loss over channel increment Δx
H_E	difference between estimates and computed total head

Symbol	Description
H_f	friction loss over channel increment Δx
H_v	eddy losses over channel increment Δx
I_1 & I_2	Einstein Integrals
k	channel conveyance
L	wave length
L_o	reference wave length
$\vec{M}$	linear momentum vector
n	channel roughness coefficient
P_i	percentage of bed material in ith size fraction
R	hydraulic radius
Q	total channel discharge [cfs]
Q_s	total material transport rate
q	lateral inflow per unit channel length
q_b	bed load transport rate
q_{bi}	bed load transport rate in ith size
q_{si}	suspended bed material load in ith size
S_a	slope of acceleration line
S_{ed}	eddy loss slope
S_f	friction slope
S_o	channel bottom slope
t	time
t^*	total time
T	top width
u, v	average flow velocity along channel axis
U^*	shear velocity
V	control volume

Symbol	Description
V_s	sediment particle settling velocity
$\vec{v}$	fluid velocity vector
w	dimensionless parameter
x	distance along the channel
Z	elevation of channel bed above datum
α	energy correction coefficient and coefficient in discharge-area coefficient
α'	coefficient in area-discharge relation
β	momentum correction coefficient and power in discharge-area relation
β'	power in area-discharge coefficient
Δt	time increment
Δx	space increment
ΔV_s	change in sediment volume
ΔZ	mean bed elevation change
θ	weighting factor in Preissman four-point implicit scheme
μ	diffusion coefficient
ρ_w	specific mass of fluid
σ	wave number
τ_c	critical shear stress
τ_o	shear stress
γ	specific weight of water
γ_s	specific weight of sediment
K	Karmans constant
λ	porosity

Chapter I

I. INTRODUCTION

To predict water surface elevations and bed elevation changes as accurately and as economically as possible during the passage of a flood wave would help in engineering design and in general planning of man's activities with respect to river systems. Such a model must account for the important physical processes governing the movement of water and sediment through the system.

A mathematical model is an abstract representation of a river system and it can approximate the behavior of a flood wave by means of mathematical expressions. Tracing the movement of a flood wave and any related change in the form and height of the wave as it moves through the river system is called flood routing and can be evaluated quantitatively by use of a mathematical model. It is important to realize that the approximation will only be as reliable as the mathematical formulation describing the flood wave. Nevertheless, when applied properly, the mathematical model is a very convenient tool to route a flood wave through a river system and to predict quantitatively the rivers response in space and time to alternative channel improvements.

Most rivers must be considered alluvial systems because of the real possibility of changes in river morphology due to processes of erosion and sedimentation. In order for a mathematical model to accurately predict water surface elevation and other important hydraulic variables, the processes of erosion and sedimentation must be considered. Extending the water routing model to include sediment transport computations and changes in bed elevation due to aggradation or degradation completes the modeling goals.

STUDY OBJECTIVE

A multitude of mathematical models for flood routing in open channels exist, each having its advantages and disadvantages depending on the degree of simplification of the mathematical formulation, the complexity of the numerical scheme to solve the set of equations governing the motion of the flood wave (called St. Venant equations), and on the limitations of the model's applicability. Two major groups of models can be distinguished:

1. One group contains models based upon simplified St. Venant equations (concept of kinematic wave approximation). These models are limited in their application to steep slopes because of the assumption of equal friction and channel bed slope. Depending on the numerical scheme used to solve the equations, the models efficiency may be further restricted by mathematical stability conditions.
2. The second group contains models based upon the complete St. Venant equations (concept of dynamic wave approximation). These models are usually used on mild slopes where the acceleration forces cannot be neglected. The implicit schemes used to solve these equations are fairly efficient but complex and problems with computational stability may exist.

When confronted with the choice of a model the engineer often finds neither of the two groups satisfying. Because of the kinematic assumptions, the models of the first group are inapplicable when backwater and dynamic effects are dominant. The models of the second group are mathematically complex and require a large amount of computer time in their execution which makes them inefficient and inadequate for alternative studies for a large river system and/or over a long period of time.

The objective of this study is to develop a mathematical model based on the method of finite differences which considers the complete St. Venant equations but overcomes the mathematical restrictions and the complexity of the numerical schemes. The model could be applied to rivers having steep and mild slopes as well as backwater and dynamic effects. Due to the simplicity of the numerical scheme the model could find its application in the evaluation of the effectiveness of alternative flood control structures and channel improvements, and in the study of the behavior of various floods as they move through the river system. Furthermore, the relative importance of the different terms in the dynamic equation can be investigated and the results would indicate if a simplified version of the St. Venant equations could be used in any particular case. Sediment routing is then coupled to this model.

APPROACH

A model considering the complete St. Venant equations but still simple and effective in its execution can only be obtained if the limitations of the numerical scheme are overcome and if the solution of the complete equations are simplified. To overcome the limitations of the numerical scheme, the nonlinear flood wave celerity is introduced to control the movement of the flood wave in space and time. Since the restrictions on the finite difference increments in the numerical scheme are a function of the flood wave celerity, the removal of the control of the flood wave movement from the numerical scheme will free the latter from the restrictions on the finite difference increments.

Thus, for the finite difference scheme, the increments of space and time steps are independent and unrelated to the flood movement. Their size can be set by considering the physical configuration of the river system, the purpose of the study, and/or the desired accuracy. The introduction of the physical process into the routing procedure improves significantly the efficiency of the numerical scheme.

Simplification in the numerical scheme can be obtained by solving the complete St. Venant equations in an uncoupled manner. In the previous paragraph the uncoupling of the equations in their solution has already been introduced by removing the control of the flood wave movement from the numerical scheme. Flood wave movement is evaluated separately by the use of the flood wave celerity alone. A further simplification is attained by uncoupling the continuity and the dynamic equations. In doing so the complexity in the solution of the equations by implicit schemes is avoided. However, since the equations are solved consecutively, instead of simultaneously, a certain degree of approximation in the final results must be accepted.

Sediment routing is accomplished by computing total bed material transport on a reach by reach basis based on the computed hydraulic varibles and then by using sediment continuity to determine bed elevation changes. Sediment is routed by sizes so that the important physical processes of armoring is accounted for.

Chapter II

REVIEW OF RELATED LITERATURE

GENERAL

Ordinarily, the flow in a river system is gradually varied and unsteady. This type of flow can be described by the basic equations of mass conservation and momentum conservation, generally referred to as the St. Venant equations. Water routing procedures involve the solution of these partial differential equations and other equations describing the characteristics of the river system. This literature review describes these equations, presents several techniques to solve them, and a classification of mathematical models. The equations given in the first section of this literature review will be used in the model presented in this report. The solution techniques and the classification of mathematical models, given in the last two sections, will provide a frame of reference for later evaluation of the relative advantages and disadvantages of the proposed model. For clarity, this chapter is divided into the following sections: governing equations, solution techniques for channel routing, and classification of mathematical models.

GOVERNING EQUATIONS

In this section the mass and momentum conservation equations, the flood wave celerity, and the nonuniform flow computations are given for gradually varied unsteady flow conditions. These conditions essentially state that the vertical component of the acceleration of the water particles are negligible in comparison with the total acceleration, and the effect of channel friction is appreciable. A complete presentation of the gradually varied unsteady flow conditions and further assumptions is given in the beginning of Chaper III. The uniform flow will be described in this section by Manning's equations.

Continuity Equation

The continuity equation for incompressible and homogeneous fluids can be established by considering the conservation of mass in an infinitesimal space between two channel sections (Chow, 1959). Referring to Figure 2-1, the channel discharge Q changes with distance at a rate $\partial Q/\partial x$ and the flow area A changes with time at a rate $\partial A/\partial t$.

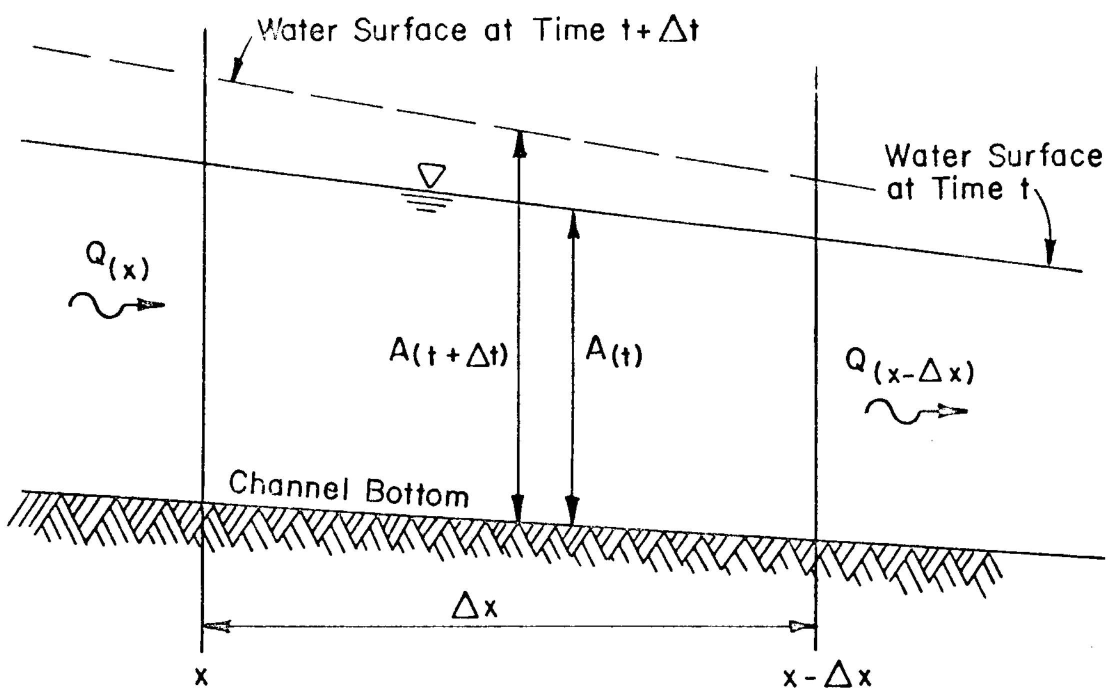

Figure 2-1. Schematic showing the continuity principle for a sample stream reach.

Change in volume through space in the time Δt is $(\partial Q/\partial x)\ \Delta x\ \Delta t$. The corresponding change in channel storage in space is $(\partial A/\partial t)\ \Delta x\ \Delta t$. For continuity the net change in volume plus the change in storage should be zero. After simplification the continuity equation becomes:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0 \qquad (2\text{-}1)$$

or if lateral inflow exists

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q \qquad (2\text{-}2)$$

where q is the lateral inflow per unit channel length.

Momentum Equation of Spatially and Temporarily Varied Flow

The momentum equation can be derived from Newton's second law, which states:

> The vector sum of all external forces acting on a fluid mass equals the time rate of change of the linear momentum vector of the fluid mass

$$\vec{F} = \frac{d\vec{M}}{dt} \qquad (2\text{-}3)$$

where $\vec{M} = m * \vec{v}$ is the linear momentum vector, m the fluid mass, $\vec{v}$ the fluid velocity vector, and $\vec{F}$ the vector representing the sum of the external forces. The external forces are of two types:

a) Boundary forces which include those acting normal to the control boundaries F_p, and those acting parallel to the control boundaries F_s.

b) Gravitational forces F_b.

Summing those forces and noting that the total rate of change of momentum will be the net flux across the control volume boundaries plus the rate of increase of momentum within the volume, Equation 2-3 yields (Daily and Harleman, 1966):

$$\vec{F}_p + \vec{F}_s + \vec{F}_b = - \int_{cs} \vec{v}\, \rho_w\, (\vec{v}\; d\vec{A}) + \frac{\partial}{\partial t} \int_{cv} \vec{v}\, \rho\; dV \qquad (2\text{-}4)$$

where $\vec{v}$ is local velocity vector, $\vec{A}$ is area (with outward normal positive), V is control volume, and ρ_w is specific mass of the fluid. Equation 2-4 is the general linear momentum equation and after transformation it yields the dynamic equation (Liggett, 1975):

$$S_o - S_f = \frac{dD}{dx} + \frac{1}{gA}\,\frac{d}{dx}\left(\frac{Q^2}{A}\right) + \frac{1}{gA}\,\frac{dQ}{dt} \qquad (2\text{-}5)$$

where S_o is channel bottom slope, S_f is friction slope, D is flow depth, and g is acceleration of gravity.

Physically, the first term on the left side of Equation 2-5 represents gravitational forces and the second term shear forces. On the right side of Equation 2-5, the first term represents pressure forces, the second is change of momentum across the control volume, and the third is time increase in momentum within the volume.

Equation 2-5 is valid for irregular cross sections and it states that the friction slope is equal to the channel bottom slope minus the sum of the pressure gradient and the convective and local acceleration gradients.

Manning's Equation

A uniform flow state is reached when the resistance forces are in balance with the gravity forces. For this condition, Manning's equation expresses the channel discharge Q as a function of the flow area A, hydraulic radius R, channel roughness n, and slope of the energy line S_f.

$$Q = \frac{1.486}{n} A R^{2/3} S_f^{1/2} \qquad (2\text{-}6)$$

Manning's equation is an empirical uniform flow formula and it is understood that its application to natural channels yields approximations, since the flow conditions are subject to more uncertain factors than are involved in an artificial prismatic channel. Despite the theoretical limitations of the flow formula which require uniform steady flow, the equation is used in flood routing techniques. The error caused by the nonuniform unsteady flow is believed to be small compared with those ordinarily occurring in the use of a uniform flow formula in natural channels (Chow, 1959).

The channel roughness coefficient n, for alluvial streams is not a constant but is a function of discharge and depth. Generally the channel roughness factor can be made a simple function of discharge:

$$n = a\ Q^b \qquad (2\text{-}7)$$

where a and b are empirically determined coefficients.

The channel conveyance K is defined by

$$K = \frac{1.486}{n} A R^{2/3} \qquad (2\text{-}8)$$

Combining Equations 2-6 and 2-8 yields:

$$Q = K\ S_f^{1/2} \qquad (2\text{-}9)$$

As seen from Equation 2-9, the conveyance K is directly proportional to the discharge Q and as such it can be interpreted as a measure of the carrying capacity of the channel section for uniform flow (Chow, 1959).

Flood Wave Celerity

A monoclinal rising wave can be observed in a prismatic channel when the discharge increases suddenly. This type of wave is suited to analyze the speed of a flood wave because it travels downstream with a constant celerity and its profile does not change shape. Thus the monoclinal rising wave can be artificially brought to rest by superimposing a velocity equal to the wave celerity c. Applying the continuity principle to the now stationary wave will yield an equation for the flood wave celerity.

$$c = \frac{dQ}{dA} \qquad (2\text{-}10)$$

where c is flood wave celerity, Q is channel discharge and A is flow area. The equation states that the flood wave celerity is equal to the ratio of the change in channel discharge to the change in flow area. This equation is also known as the Kleitz-Seddon principle. A graphical interpretation of the flood wave celerity c is given in Figure 2-2.

The discharge-flow area curve in Figure 2-2 is concave upward and as a result the flood wave celerity c (θ_w), which is a secant through p_1 and p_2, must be greater than either flow velocities v_1 (θ_1) or v_2 (θ_2) which are secants through the origin (Chow, 1959). For wide rectangular channels the ratio of maximum wave celerity to the water velocity is 1.57 or 1.50, depending if Manning's or Chezy's formula is used for the derivations. When applying Equation 2-10 to a flood wave other than the monoclinal rising wave, one must consider that the argument leading to Equation 2-10 is subject to the assumption that the wave motion may be reduced to steady flow by letting the observer move

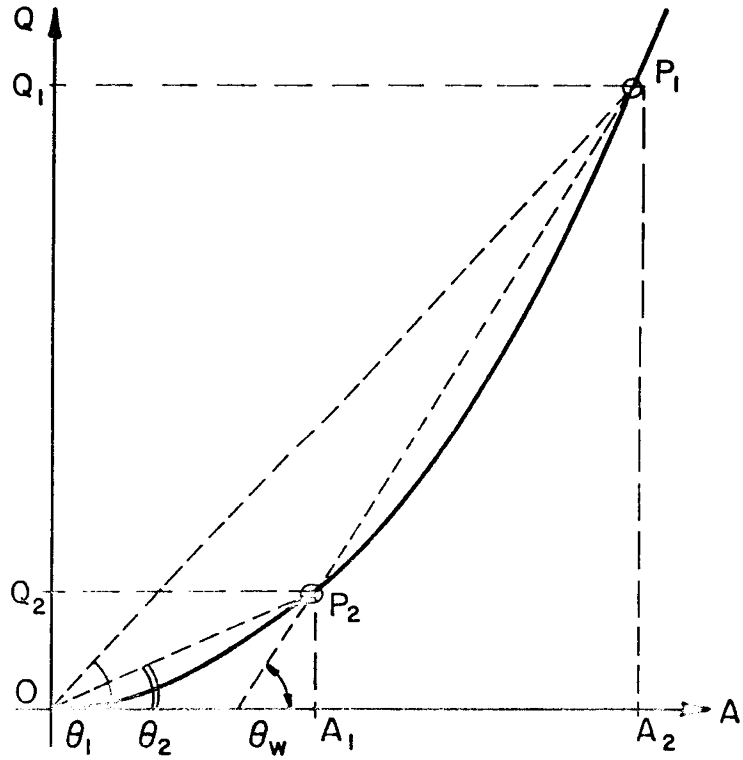

Figure 2-2. Graphical interpretation of the celerity equation for the monocline rising wave.

with a velocity equal to the wave celerity. This implies that the wave profile is permanent in form without dispersion or subsidence. This assumption is acceptable over a short time interval Δt for which the wave does not change its shape appreciably. Another limitation is given by the total derivative dQ/dA which has a unique meaning only if Q is a function of A alone which does not hold for unsteady flow (Henderson, 1966). Despite these limitations, measurements by Seddon and Wilkinson have shown that the flood wave celerity in natural channels can well be approximated by Equation 2-10 (Chow, 1959).

Unsteady Nonuniform Flow Computations

For a given discharge the unsteady nonuniform flow computations will determine the gradual variation of the flow depth along an irregular channel and it will allow the tracing of the longitudinal profile of the water surface. The computations are carried out step wise starting from a known water surface elevation at a downstream control and moving upstream cross section by cross section. Referring to Figure 2-3, the total head and head loss between two adjacent cross sections are equated as:

$$Z_2 + D_2 + \frac{\alpha u_2^2}{2g} = Z_1 + D_1 + \frac{\alpha u_1^2}{2g} + H_f + H_V + H_a \qquad (2\text{-}11)$$

where Z is elevation of the channel bed above datum, D is flow depth, $u = Q/A$ is average flow velocity, α is energy correction coefficient, and H_f is friction loss over the channel increment Δx and it may be written as:

$$H_f = S_f \ \Delta x \qquad (2\text{-}12)$$

where S_f is friction slope and Δx is horizontal distance between cross sections.

H_V represents eddy losses over the channel increment Δx. No rational method is available to evaluate eddy losses. They depend mainly on the velocity head and may be expressed as part of it:

$$H_V = C_e \left| (u_1^2 - u_2^2)/2g \right| \qquad (2\text{-}13)$$

where C_e is an empirical coefficient having values of 0.0 to 0.1 for gradually converging reaches and 0.2 for diverging reaches. For abrupt expansions and contractions, C_e is about 0.5 (Chow, 1959).

Similarly to the friction loss slope one may want to define an eddy loss slope S_{ed} by:

$$S_{ed} = \frac{H_v}{\Delta x} \tag{2-14}$$

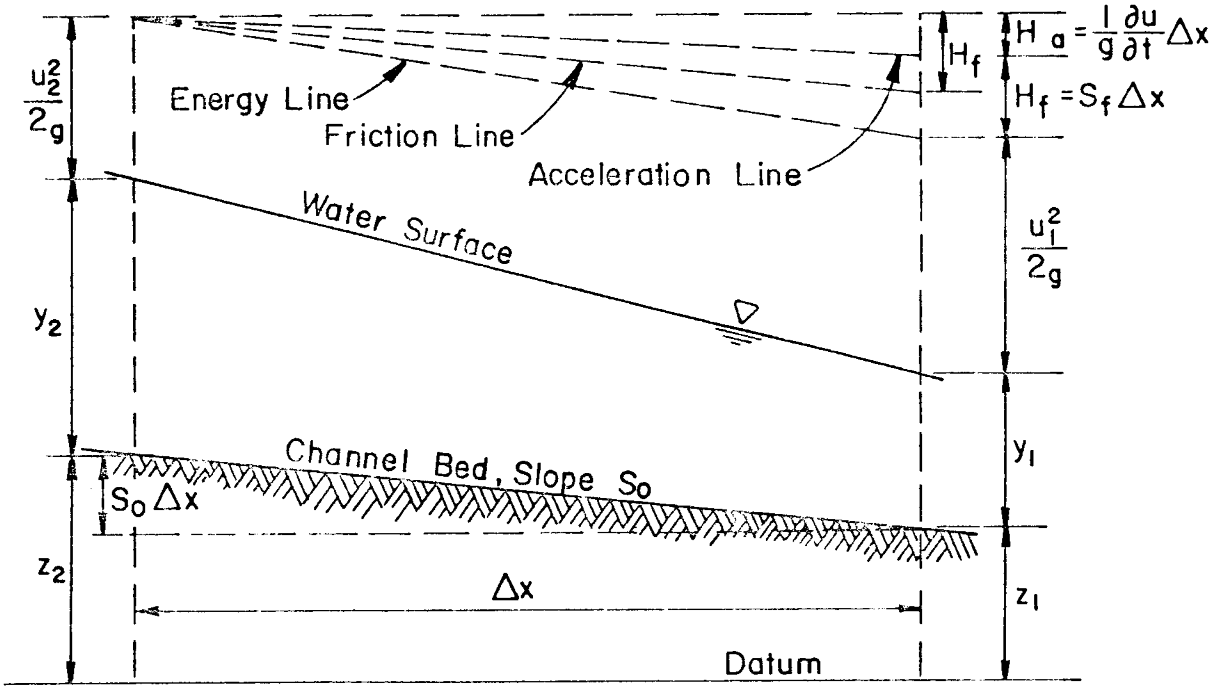

Figure 2-3. Example channel reach for the unsteady nonuniform flow computations.

H_a in Equation 2-11 is the loss due to the flow acceleration and it may be written as:

$$H_a = S_a \Delta x = \frac{1}{g} \frac{\partial u}{\partial t} dx \tag{2-15}$$

where S_a is slope of the acceleration line. Additional losses due to other factors may be introduced in a similar manner.

For subcritical flow, total head H_1 at the downstream cross section is known from the previous computational step or as initial boundary condition,

$$H_1 = Z_1 + D_1 + \frac{\alpha u_1^2}{2g} \tag{2-16}$$

and the continuity equation can be written as

$$Q = u \quad A \tag{2-17}$$

Combining Equations 2-11 through 2-17 yields

$$\left(\frac{Q_2}{A_2}\right)^2 \frac{1}{2g} + D_2 + Z_2 - \Delta x \frac{(S_{f_1} + S_{f_2})}{2}$$

$$- C_e \left| (u_1^2 - u_2^2) \; /2g \right| - \Delta x \frac{(S_{a_1} + S_{a_2})}{2} = H_1 \tag{2-18}$$

with the acceleration slope S_a given by

$$S_a = \frac{1}{g} \frac{\partial}{\partial t} \left(\frac{Q}{A}\right) \tag{2-19}$$

To solve Equation 2-18 a trial value of the stage $(Z_2 + D_2)$ is taken at the upstream cross section. Hydraulic properties and total head are computed for this stage. The test of the trial and error process is whether the estimated value of the total energy at the upstream cross section is equal to the calculated one. If not, a further trial value must be taken. The second trial will provide a better estimate, if results of the first trial are used as a guide to the second trial. Defining H_E as the difference between estimated and computed values of the total head at the upstream cross section, response of H_E to small changes of depth D_2 can be obtained by differentiating H_E with respect to D_2. Since Z_2, H_1, and S_{f_1} are constants, then

$$\frac{d}{dD_2} H_E = \frac{d}{dD_2} \left(D_2 + \frac{u_2^2}{2g} + 1/2 \quad \Delta x \; S_2\right) \tag{2-20}$$

$$\frac{d}{dD_2} H_E = 1 - F_{r_2}^{\;2} - \frac{1}{2} \Delta x \frac{d}{dD_2} S_2 \tag{2-21}$$

where S_2 is the slope of all the losses and F_r is the Froude number at the upstream section. Since S_2 varies approximately as the inverse cube of depth D_2 (uniform flow equation), one may write

$$\frac{d\,S_2}{dD_2} \cong \frac{3\,S_2}{D_2} \cong \frac{3\,S_2}{R_2} \tag{2-22}$$

where R_2 is the hydraulic radius which approximates the depth D_2. Equation 2-21 then yields

$$\Delta\,D_2 = \frac{H_E}{1-F_{r_2}^{\,2} + \dfrac{3S_{f_2}\,\Delta x}{2\,R_2}} \tag{2-23}$$

where $\Delta\,D_2$ is the amount by which the water level must be changed in order to make H_E neglibible (Henderson, 1966).

By starting at a known downstream water surface elevation and proceeding upstream one reach at a time, the water surface profile for the river segment can be computed.

It should be noted that at this point each and all terms of the dynamic equation (Equation 2-5) are contained in the unsteady non-uniform flow computations. This can be illustrated by dividing Equation 2-11 by Δx, combining it with the continuity equation, and rearranging terms as follows.

$$\frac{Z_2 - Z_1}{\Delta x} = S_o$$

$$\frac{D_2 - D_1}{\Delta x} = \frac{\partial D}{\partial x}$$

$$\frac{1}{\Delta x}\left(\frac{u_2^2}{2g} - \frac{u_1^2}{2g}\right) = \frac{1}{gA}\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) - \frac{1}{g}\frac{Q}{A^2}\frac{\partial Q}{\partial x}$$

$$\frac{H_a}{\Delta x} = \frac{1}{gA}\frac{\partial Q}{\partial t} - \frac{1}{g}\frac{Q}{A^2}\frac{\partial A}{\partial t}$$

$$\frac{H_\ell + H_v}{\Delta x} = S_f$$

which yields Equation 2-5

$$S_o - S_f = \frac{\partial D}{\partial x} + \frac{1}{gA}\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) + \frac{1}{gA}\frac{\partial Q}{\partial t} \tag{2-5}$$

Thus, the unsteady nonuniform flow computations essentially solve the dynamic equation.

Even though the momentum and energy approaches have much in common, the momentum approach is based on Newton's second law and it equates the change in momentum flux through the volume to the external forces acting on it, while the energy approach is based on first law of thermodynamics and equates the change in the energy flux through the volume to the internal energy losses. An important difference is that the momentum equation is a vector relationship while the energy equation is scalar. Furthermore energy and momentum correction coefficients, α and β respectively, are derived independently from different principles and are not equal.

The total head approach (used in the unsteady nonuniform flow computations) is based on the potential energy. It equates the change in hydraulic head which is a partial measure of energy, to the head loss in the system. Since the total head equation is based on potential energy it is similar to the energy equation, but the two approaches are only equal if no energy is added to the system. The total head equation cannot easily handle energy entering or leaving the system, while the energy equation can account for these other sources and sinks by adding additional terms.

However, a loose comparison can be made between the momentum, energy and total head approach because

a) the flow is assumed one-dimensional (see assumptions in Chapter III) which removes the vectorial character of the momentum equation,

b) the momentum and energy coefficients, α and β respectively, are assumed to equal one, $\beta \cong 1.0$, $\alpha \cong 1.0$ (see assumptions in Chapter III), and

c) no energy is entering or leaving the system (for the model the system is equivalent to the river reach between two cross sections).

A loose comparison can be made between the momentum, energy and total head equation, as done previously, under the given assumptions even though all three equations are derived from different principles and are generally not interchangeable.

CHANNEL ROUTING AND SOLUTION TECHNIQUES

Analytical and Numerical Solutions

Partial differential equations of mass and momentum conservation, describing gradually varied unsteady open channel flow, have two dependent variables, discharge Q and flow depth D (or the area A), and two independent variables, space x and time t. The equations are

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q \tag{2-24}$$

$$\frac{dZ}{dx} - \frac{Q^2}{K^2} = \frac{d}{dx} D + \frac{1}{gA} \frac{d}{dx} (\frac{Q^2}{A}) + \frac{1}{gA} \frac{dQ}{dt} \tag{2-25}$$

where Z is elevation of the channel bed, D is flow depth, and g acceleration of gravity. The term dZ/dx stands for the channel bed slope S_o and Q^2/K^2 for the friction slope S_f. These two partial differential equations are nonlinear because several coefficients of derivative terms involve a dependent variable and because the discharge Q, a dependent variable, appears to the second power in the resistance term.

Commonly used solution techniques for differential equations such as the separation of variables, the Laplace transformation, or the Fourier transformation are procedures which may be applied to linearized, thus simplified versions of the St. Venant equations (Miller, 1971). However, simplifications cause the solution of these equations to deviate from the actual physical behavior they are representing, which makes the exact solutions of little use to the engineer. One successful analytical solution technique to solve the St. Venant equations is the method of characteristics which will be briefly described in the next section.

Alternatively, numerical techniques may be used to solve the nonlinear partial differential equations, producing solutions which usually correspond more closely to the physical situation than their analytical counterpart for a simplified set of equations (Miller, 1971). Numerical techniques involve the replacement of the derivatives in the partial differential equations with finite difference approximations and some kind of numerical integration process proceeding step wise through time and space. The solution is usually accurate enough for engineering problems and often the only alternative to a simplification of the complete St. Venant equations. In the following section the method of finite differences will be briefly described.

Method of Characteristics and Finite Differences

The method of characteristics may be described as a technique in which two partial differential equations for mass and momentum conservation are replaced by four ordinary differential equations. These can be solved analytically for the simple case of kinematic wave approximation (Li, 1975a) and numerically on a characteristic grid for the full dynamic wave appoximation (Abbott, 1975). Characteristic lines, which form the characteristic grid, can be interpreted physically as the propagation path followed by some disturbance or wave in the space-time plane. Along characteristic lines, properties of the disturbance or wave are assumed constant for each step in the numerical solution. Starting with known initial conditions, the behavior of the disturbance or wave can be computed by solving the four partial differential equations point by point in the space-time plane. Even though the method is in most cases simple, accurate, and convergent, it has the disadvantages of having a irregular mesh spacing in the characteristic grid and difficulties in the treatment of kinematic shocks.

The method of finite differences avoids the drawbacks of the method of characteristics at the expense of a reduction in accuracy. The domain of the independent variables, space x and time t, is replaced by a finite set of points (called grid points or mesh points) defined by a rectangular grid. The dependent variables, the discharge Q and the area A, and their derivatives are then expressed in terms of their values on the rectangular grid. A solution for the dependent variables can then be found through application of a finite difference scheme. A finite difference scheme is a formula which stands for difference equations obtained by replacing the partial derivations by partial difference quotients. There are two types of finite difference schemes: explicit and implicit schemes.

Explicit and Implicit Schemes

Explicit schemes are those that advance the solution in time and space by solving for the unknown dependent variables one grid point at a time. Each equation in the explicit formulation solves for one of the known dependent variables at an advance point in time, in terms of known quantities (known from previous calculations or from initial or boundary conditions) or the preceeding time line. The unknown dependent variable is determined directly (explicitly) from the equation. Explicit schemes are relatively simple to formulate, but are usually limited to a small time step Δt by considerations for numerical stability. The limitation due to the Courant-Friedrich-Lewy stability condition

$$c \ \frac{\Delta t}{\Delta x} \leq 1 \tag{2-26}$$

where c is perturbation celerity and Δt and Δx are time and space increments respectively. Physically, this conditions states that during one time increment, the perturbation at a grid point cannot travel further than one space increment. Thus the size of the time increment Δt is limited to

$$\Delta t \leq \frac{\Delta x}{c} \tag{2-27}$$

As examples of explicit schemes one may cite the Diffusion scheme, the Leap-Frog scheme, and the Lax-Wendroff second-order scheme (Liggett and Cunge, 1975). These schemes differ only in the method of approximating the derivatives on the grid.

In an implicit scheme, all values of the dependent variables in two successive time rows are used simultaneously in one computational step in the solution procedure. There are as many finite difference equations as unknowns, provided that a boundary condition is known at either end of the reach, or two boundary conditions at one end of the reach. Simultaneous solution of the set of difference equations for each time step is accomplished by an iterative procedure or by the inversion of a matrix, so that the unknowns are solved implicitly (not independently). The implicit scheme has the advantage of not being subjected to the strict stability criterion of explicit schemes; it however is not unconditionally stable. Furthermore, implicit schemes are more efficient than explicit schemes in their use of computational resources. As examples one may cite the Preissman implicit scheme and Abbott's implicit scheme (Liggett and Cunge, 1975).

CLASSIFICATION OF MATHEMATICAL MODELS

The dynamic equation (Equation 2-28) can be simplified by neglecting certain terms according to the relative magnitude of the various forces responsible for the motion. The different terms of Equation 2-28 are

i) the body forces given by the channel botton slope S_o,

ii) the surface forces given by the friction slope S_f and the pressure gradient dD/dx, and

iii) the inertia forces given by the local acceleration $\frac{1}{gA}\frac{\partial}{\partial t} Q$ and the convective acceleration $\frac{1}{gA}\frac{\partial}{\partial x}(\frac{Q^2}{A})$.

The various simplifications have lead to such models as the kinematic wave model, the diffusion wave model, and to the dynamic wave model if no simplifications are made. An overview of the different approximations is given as follows

$$\frac{1}{gA}\frac{\partial}{\partial t}(Q) + \frac{1}{gA}\frac{\partial}{\partial x}(\frac{Q^2}{A}) + \frac{\partial}{\partial x}(D) - S_o + S_f = 0 \qquad (2\text{-}28)$$

Steady uniform flow / Kinematic wave approximation

Steady nonuniform flow / Diffusion wave approximation

Steady nonuniform flow / Quasi-steady dynamic wave approximation

Unsteady nonuniform flow / Dynamic wave approximation

Kinematic Wave Approximation

The kinematic wave model assumes that inertia and pressure gradient terms in Equation 2-28 are negligible compared to the friction and gravity terms. Thus the dynamic equation reduces to

$$S_f = S_o \qquad (2\text{-}29)$$

One may interpret this as a statement of uniform flow. However, the wave-like features of the kinematic wave are introduced by the mass conservation equation which contains information on the nonuniformity and unsteady nature of the flow (Ponce, 1980a). Combining Equation 2-29, the mass conservation equation and Manning's uniform flow equation, one obtaines, after transformation, the kinematic wave equation

$$\frac{\partial Q}{\partial t} + \left(\frac{\partial Q}{\partial A}\right) \frac{\partial Q}{\partial x} = 0 \qquad (2\text{-}30)$$

where Q is channel discharge, A is flow area, x is space, and t is time. The term in parenthesis is the Kleitz-Seddon wave celerity. Physically, Equation 2-30 states that the variation of the discharge Q with time is proportional to the variation of the discharge Q in space with the wave celerity as the proportionality factor.

The following important properties characterize the kinematic wave: the kinematic wave propagates only in the downstream direction with the Kleitz-Seddon celerity and the wave may deform (wave skewness) but does not dissipate or attenuate (Ponce, 1977).

Because of its simplicity the kinematic wave model is of great interest to the engineer and it has been studied thoroughly. A few publications are presented in the following. One of the mile stones in the analysis of the kinematic wave has been set by Lighthill and Whitham with their publication on kinematic waves (Lighthill and Whitham, 1955). In this paper properties of the kinematic wave and formation of kinematic shock due to the nonlinearity of the wave celerity are described. Furthermore, Lighthill and Whitham mentioned the diffusive character of the wave as the kinematic shock forms and derived the proper fomulation for the diffusion wave. The paper provides a strong background in the understanding of the flood waves and their movements.

Li et al. (1976) treated the kinematic wave problem in depth and proposed an analytical and numerical solution for flood routing. The analytical solution is said to be restricted in practical applications because of the kinematic shock fomation, whereas the numerical solutions provide artificial dampening and smoothing effects and there is no kinematic shock formation. A modified kinematic wave solution has been proposed. It first solves the kinematic wave equation with an assumed friction slope and then refines the value of the friction slope using the complete momentum equation.

In another publication Li et al. (1975b) presented a second-order nonlinear kinematic wave approximation for overland and channel routing with time variant inflows and varying roughness. A linear scheme is employed to obtain a good first approximation for the flow conditions which are then refined by a second-order nonlinear scheme to ensure convergence. The model also includes the effects of rainfall on flow resistance due to raindrop impact. Applicability of the model has been tested for various cases. Simulated hydrographs agree well with analytical solutions for some simple cases and with measured overland flow hydrographs and natural channel hydrographs for general cases.

A fully analytical solution to the kinematic wave approximation for unsteady overland flow was developed by the same authors (Li et al. (1975a). The method of characteristics was used and characteristics were solved analytically. Thus, the solution is independent of time and space increments selected in the computations (due to discretization of the boundary conditions) and problems with stability and convergence were avoided. This analytical kinematic wave solution has a great advantage over the numerical solutions which require a proper discretization to convergence.

Kibler et al. (1970) developed a hydrologic model to study the dynamic behavior of surface runoff. The model is essentially operating as a succession of planes for which the kinematic wave approximations are applied. Formation of the kinematic shock as one moves from one plane to another with milder slope has been discussed in depth. Furthermore, the solution of the kinematic equations in the presence of shocks were analyzed for several finite difference schemes. The smoothing effect of all rectangular methods in the shock-affected region of the hydrograph was visible and, in general, the hydrograph peak was reduced and delayed by as much as 20 percent for the first-order schemes. The applications of the kinematic cascade model to complex watersheds accurately simulated overland flow.

The references above represent only a few of the many publications available, but demonstrate the importance of kinematic wave approximation and its applications. In the model presented in this thesis, kinematic wave approximation has been given a major role because of its versatility and its simplicity. However, it should be remembered that the kinematic wave model by itself cannot be applied when the backwater and/or dynamics effects are dominant.

Diffusion Wave Approximation

The diffusive wave model assumes the inertia (local and convective) terms in Equation 2-28 are negligible when compared to the pressure gradient, friction and gravity terms. The dynamic equation can then be written as

$$S_f = S_o - \frac{\partial D}{\partial x} \tag{2-31}$$

Combining Equation 2-31 with Chezy's uniform flow equation yields

$$Q = C\ B\ D^{3/2}\ \left(S_o - \frac{\partial D}{\partial x}\right)^{1/2} \tag{2-32}$$

where C is Chezy's friction coefficient and B is channel width. Differentiating Equation 2-32 with respect to x and substituting $\partial Q/\partial x$ into the mass conservation equation yield the diffusion wave equation

$$\frac{\partial D}{\partial t} + c_k \frac{\partial D}{\partial x} = \mu \frac{\partial^2 D}{\partial x^2} \tag{2-33}$$

where c_k is kinematic wave celerity corresponding to a wide channel with Chezy friction and $\mu = Q/A \;\; D/2S_f$ is the diffusion coefficient. In Equation 2-33 the term on the right side is the diffusion term and the second term on the left side is the convection term. Thus the diffusion wave equation accounts for the convection, diffusion and deformation of the hydrograph. Steepening of the rising limb of the hydrograph cannot proceed uncontrolled as for the kinematic wave, because the diffusive behavior of the wave counteracts the steepening tendency of the wave (Ponce, 1980). As can be seen from Equation 2-33, the diffusion equation can only be solved for one dependent variable (the flow depth D); thus the remaining dependent variable (here the discharge Q) must be calculated from a single-valued rating curve, which indicates that the dynamic effects of the wave are not taken into account. Under some additional assumptions, a convection-diffusion equation in terms of discharge can be derived (Cunge, 1969).

The Muskingum-Cunge method (Cunge, 1969) is essentially a diffusion wave approximation even though it is based on the kinematic wave assumptions. It is the numerical scheme of the Muskingum method that introduced an error into the analytical solution of the original equation in the form of an artificial alternation of the rate of flow and by modifying the celerity of the resulting wave. The key to the model is the determination of the artificial dampening coefficient, which should be such that the dampening effects resulting from the numerical scheme correspond to the real dampening effect. Cunge proposed a formula which is related to the physical river characteristics to calculate the proper coefficients so as to reproduce the real dampening effect. However, as Cunge mentions, the Muskingum method cannot be used on a river with dams or other structures to evaluate the flood wave behavior without changing the values of the coefficients accordingly. Thus the method is not suited for the evaluation of wave behavior of planned flood control structures or major channel improvements for which the empirical coefficients are not available.

A variation of this model, the Muskingum-Cunge method with variable parameters (Ponce, 1980) will be used to verify the results obtained by the proposed model for the hypothetical test cases.

Because of the additional consideration of the pressure gradient in the momentum equation, the range of application of the diffusion wave is larger than for the kinematic wave (Ponce, 1977). However, the dynamic (inertial) effects of the flood wave have still not been taken into account.

Dynamic Wave Approximation

Dynamic wave is defined as that wave in which the inertia, surface and body forces interact without restrictions. The solution is based on the complete St. Venant equations which represent a set of quasilinear (no derivatives to a power over one) partial differential equations for which no complete analytical solution is available. However with the use of linear analysis, Ponce (1977) has provided detailed information on the properties of the dynamic wave. Most significantly, the dynamic wave approximation accounts for convection, diffusion and deformation of the wave. Celerity and diffusion of the dynamic wave are functions of the reference flow Froude Number ($F_o = \sigma_o/\sqrt{gD_o}$) and the dimensionless wave number ($\sigma = 2\pi/L \;\; L_o$), where L is wave length and L_o is defined as D_o/S_o; D_o is reference flow depth and S_o is channel bottom slope. The attenuation of the dynamic wave can be markedly strong depending on the wave characteristics. The dynamic wave travels faster than the kinematic wave, since its celerity lies between the kinematic and inertial wave celerity values.

Even though there is no analytical solution to the complete St. Venant equations, numerical solution techniques have been developed and applied to various practical problems.

Chen (1973) has compared several numerical solution techniques to solve the St. Venant equation and has applied his water and sediment routing model to natural channels. The numerical solution methods Chen analyzed were the explicit scheme, the characteristic method with characteristic grid and implicit formulation, and with rectangular grid and explicit formulation, the nonlinear-implicit method and the linear implicit method. Chen concluded that the nonlinear implicit scheme results in small errors, but that it also requires a tremendous amount of computation, which makes this solution technique extremely inefficient for long-term flow computations. Chen rated the linear implicit method as best for solving the basic differential equations and used it in his model. He also concluded that the size of the time and space increments for the numerical methods significantly affects the calculated results and that they must be chosen carefully to simulate the unsteady flow phenomena efficiently and accurately.

Ponce (1980c) has developed an unsteady flow model based on the complete St. Venant equations. The numerical model relies on a finite difference formulation using a Preissman four-point implicit scheme which includes a weighting factor θ to control the stability and convergence properties of the model. The linearization of the St. Venant equations by a series expansion allows one to solve the equations directly using a double sweep solution technique. This unsteady water routing model will be used to verify results obtained by the proposed model for hypothetical test cases.

The range of application of models based on the complete St. Venant equations encompasses all situations of gradually varied flow. The models evaluate the diffusion and the dynamic effects of the wave under consideration of backwater effects. The main advantage of the dynamic wave models is their completeness in the analysis of flood wave behavior, but they require complex and involved solution techniques which are the main drawback.

In summary, this review of mathematical models illustrates the simplicity, efficiency, and limitations of the kinematic wave models, as well as the completeness, the wide range of applicability, and the complexity of the dynamic wave model. It also provides a frame of reference from which the evaluation of the proposed model can be performed.

CONCLUSIONS

In the previous sections an outline of mathematical water routing models and of numerical solution techniques has been presented. An overview of the kinematic and dynamic wave approximation, and a list of advantages and disadvantages of the explicit and implicit finite difference solution schemes are given in Table 2-1.

Clearly the kinematic wave approximation is strongly restricted in its applications by the assumption of equal channel bed and energy slope value. On the other hand the dynamic wave approximation is widely applicable, however its solution scheme is complex and often too involved for engineering purposes. A water routing procedure combining the advantages of the finite difference solution schemes yet solving the complete St. Venant equations would present an interesting alternative to the existing water routing models.

The dynamic model presented in this study will fill this gap by retaining the completeness of the dynamic wave approximation and utilizing a solution technique that avoids the disadvantages of the explicit and implicit finite difference solution schemes.

Table 2-1. Summary of kinematic and dynamic wave approximation and finite difference solution techniques.

Mathematical Water Routing Models

Kinematic Wave Approximation	Dynamic Wave Approximation
- Simplified St. Venant equations	- Complete St. Venant equations
- Cannot consider backwater or dynamic effects	- Considers backwater and dynamic effects
- For river with steep slopes only	- Mainly used for rivers with mild slopes
- Usually solved by explicit finite difference schemes	- Usually solved by implicit finite difference schemes

Finite Difference Solution Techniques

	Advantage	Disadvantage
Explicit Schemes	Simple	Inefficient because time increment restricted by stability criterion
Implicit Schemes	Efficient	Complex (matrix inversion) and involved May have stability problems

Chapter III

OUTLINE OF THE UNSTEADY FLOW MODEL

INTRODUCTION

Gradually varied unsteady flow conditions are generally encountered when studying flood wave movement in natural rivers. The proposed model is restricted to these flow conditions which essentially require that the change in space and time of flow depth and discharge take place in a gradual manner. A complete description of all flow conditions and all underlying assumptions of the model is given in the first section of this chapter.

The proper combination of the equations given in Chapter II with the equations describing the configuration of the river system and their solution to given boundary conditions will ultimately result in the correct routing of a flood hydrograph along a river. This routing problem will be solved on a finite difference space-time plane by a predictor-corrector method. In the first step, the nonlinear flood wave celerity is used to locate the position of the flood wave in space according to the distance it traveled during one time period. This first step is called the predictor because it predicts the expected location and properties of the flood wave. In the second step, the flood wave will be adjusted by requiring mass conservation which also will introduce the attenuation and dissipation of the flood wave. The final flood wave profile can then be calculated. This second step will be called the corrector, since it corrects the predicted flood wave properties. Both the prediction and correction step are presented in the section covering the solution technique.

ASSUMPTIONS FOR THE UNSTEADY FLOW MODEL

Prescribing flow conditions and certain channel characteristics often results in a great simplification of the basic equations and their solution. However, with each additional assumption the range of applicability of the model is further restricted. For the unsteady flow model, assumptions are made in such a way as not to reduce the models applicability to special cases, but to simplify the equations and their solutions by eliminating the special cases (for example surges, hydraulic jumps, pulsating flow, etc.). The following assumptions are made with respect to the flow.

1. The flow is one-dimensional and can be modeled as a function of the dimension along the longitudinal axis of the channel and time.
2. The flow is gradually varied, thus the pressure distribution in the vertical direction is hydrostatic.
3. The flood wave celerity given by the Kleitz-Seddon law applies.
4. The flow resistance of the unsteady flow can be described by a steady flow resistance equation.
5. The momentum and energy coefficients are assumed to each equal one; $\beta \cong 1.0$ and $\alpha \cong 1.0$.

Assumptions made with respect to channel characteristics are:

1. The channel bed slope α is small enough so $\cos \alpha \cong 1.0$.
2. The cross-sectional shape of the channel is sufficiently uniform so that the flow variables can be described by values that are averaged over the cross section.

Some of these assumptions, such as gradually varied flow conditions, are essential for the proper operation of the model, whereas others, such as the restriction on the momentum coefficient, are minor and may be modified if necessary. Most of the above assumptions are generally encountered in natural rivers and do not restrict the applicability of the model.

Use of the finite difference method in the solution technique requires proper discretization of the equations. Certain limitations with respect to discretization are necessary to assure accuracy in the solution. They do not affect the applicability of the model, but restrict the size of the finite difference increments to values compatible with the given configuration of the river system and its boundary conditions. The limitations are that the space and time increments of the finite difference grid should be small enough to allow for

1. proper discretization of the inflow hydrographs and other boundary conditions, and
2. assumption of constant flood wave celerity over any time and space increment.

These limitations hold for all applications of the model and assure accuracy in the solution.

SOLUTION TECHNIQUE

General

Correct combination and application of the equations governing the flood wave movement will result in a solution technique to solve the water routing problem. In this model, the solution technique is based on a predictor-corrector method. In the predictor part the translation of the flood wave during one time increment is predicted and an estimation of the flow characteristics is obtained. In the corrector part these flow characteristics are adjusted with consideration given to the dynamic and backwater effects which have been estimated in the the predictor part. In the following sections, both steps are described in detail.

Prediction of the Flood Wave Translation

In the predictor part, the location of the flood wave after one time increment is determined by translating each point of the wave separately with its celerity as shown schematically and in an exaggerated form in Figure 3-1.

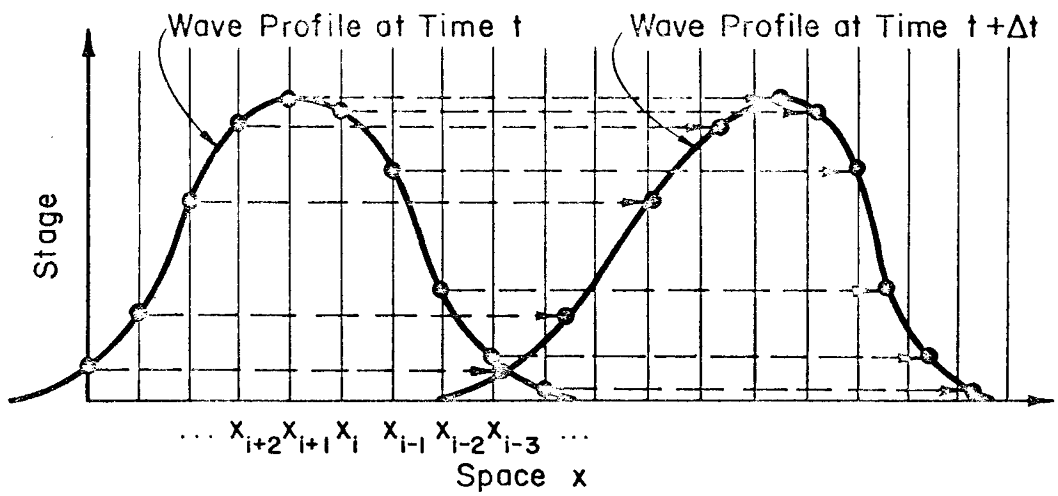

Figure 3-1. Wave translation during a time increment Δt.

To establish the distance of travel of any wave point for a given time increment, the Kleitz-Seddon wave celerity is applied.

$$c = \frac{dQ}{dA} \tag{3-1}$$

where c is flood wave celerity, Q is channel discharge and A is flow area. Rewriting the uniform flow equation (Equation 2-6) as a power function, yields:

$$Q = \alpha A^{\beta} \tag{3-2}$$

in which α and β are coefficients whose values depend on the channel shape, the roughness of the wetted perimeter, and the friction slope. Both coefficients may vary in space and time depending on the flow conditions. Taking the derivative of Equation 3-2 and replacing it into Equation 3-1 yields

$$\frac{dQ}{dA} = \alpha \beta A^{\beta-1} \tag{3-3}$$

$$c = \alpha \beta A^{\beta-1} = \beta \frac{\alpha A^{\beta}}{A} \tag{3-4}$$

and

$$c = \beta \frac{Q}{A} \tag{3-5}$$

In Appendix A a relation expressing the coefficient β as a function of channel slope and roughness is derived. With Equation 3-5 describing the flood wave celerity in terms of flow and channel characteristics one can proceed with the translation of the wave.

During one time increment a point on the wave may travel through several space increments. For accuracy purposes, the wave celerity is reassessed at the beginning of each space increment through which the point travels, depending on the change in channel characteristics and the additional lateral inflow. Referring to the finite difference grid in Figure 3-2, the wave point 1 at section x_{i+2} is translated with a celerity c_1 equal to the flow velocity Q_1/A_1 times the coefficient β_1. In Figure 3-2 the slope of the path line of the wave point is an indication of its celerity. The time required to reach section x_{i+1} is then computed by

$$t_1 = \frac{\Delta x_{i+2}}{c_1} \tag{3-6}$$

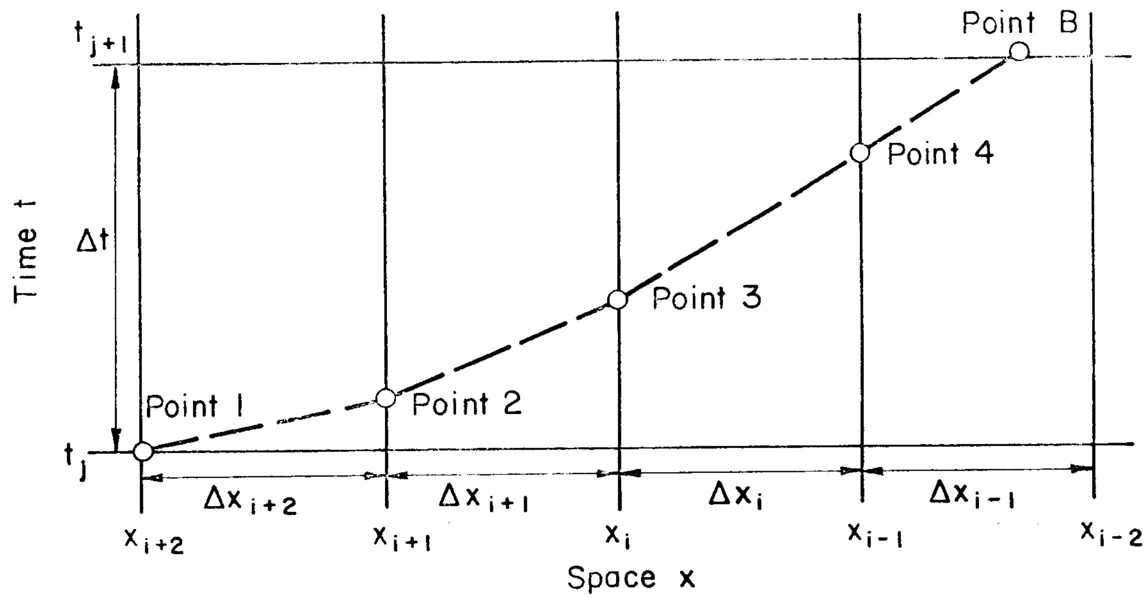

Figure 3-2: Translation of a wave point.

If the time t obtained by Equation 3-6 is smaller than the time increment Δt, as shown in Figure 3-2, the wave celerity at point 2 is reassessed by

$$c_2 = \beta_2 \frac{Q_2}{A_2} \tag{3-7}$$

where discharge Q_2 equals discharge Q_1 plus the lateral inflow q_2 at point 2, flow area A_2 is obtained from the uniform flow equation with discharge Q_2 and friction slope $S_{f_{i+1,j}}$, and the coefficient β_2 is equal to $\beta_{i+1,j}$. The lateral inflow q_2 is obtained by linear interpolation of the lateral inflows q^j_{i+1} and q^{j+1}_{i+1}

$$q_2 = q^j_{i+1} + \frac{(q^{j+1}_{i+1} - q^j_{i+1})\ t^*}{\Delta t_j} \qquad (3\text{-}8)$$

where t^* is the total time elapsed since the beginning of translation of wave point 1. This procedure is repeated until the total time that the particular wave point has been translated equals the time increment Δt, and point B, its location and discharge, is obtained.

By translating all points of the wave in a similar manner (Figure 3-1), the shape and location of the flood wave for the time level t_{j+1} is calculated. The calculated wave points however no longer correspond to the intersections of the finite difference grid lines and a linear interpolation must be used to compute the discharge values at these intersections.

To proceed to step two in the solution technique, the friction slope S_f of the newly located wave must first be calculated at each cross section. This can be done with the unsteady nonuniform flow computations if a downstream boundary condition is given to start the computations. The downstream boundary condition may be a rating curve, the uniform flow condition, or a operation rule of a control structure. From this boundary condition, the computations will proceed upstream, one reach at a time, and will solve the dynamic equation to yield the flow characteristics at each cross section. For practical purposes, the different loss slopes calculated by the unsteady nonuniform flow computations (the friction slope S_f, the acceleration slope S_a, and the eddy slope S_{ed} (Chapter II)), are lumped together into the friction slope S_f, thus from here on the latter will include dynamic effects of the wave and backwater effects.

In summary, the application of the nonlinear wave celerity to locate the flood wave in space does provide for the deformation of the wave (due to larger celerities at higher flows) but it does not provide for its attenuation (Figure 3-1), which will be introduced in the corrector step.

Correction of the Flow Characteristics

With the flood wave located in space for the time level t_{j+1}, the attenuation and the corresponding change in the shape of the wave is introduced by application of the continuity principle. The finite difference form of the equation of continuity (Equation 2-2) can be expressed as (see Figure 3-3)

$$\left[\frac{(Q_{i-1}^{j+1}+Q_{i-1}^{j})-(Q_{i}^{j+1}+Q_{i}^{j})}{2}\right]\frac{1}{\Delta x}+\left[\frac{(A_{i-1}^{j+1}+A_{i}^{j+1})-(A_{i-1}^{j}+A_{i}^{j})}{2}\right]\frac{1}{\Delta t}$$

$$=\frac{q_{i-1}^{j+1}+q_{i-1}^{j}}{2} \tag{3-9}$$

in which Q_i^j is discharge at grid point (x_i, t_j), and Δx and Δt are space and time increments respectively.

Known values in Equation 3-9 are discharge, flow area, and friction slope at the grid points (i, j), (i, j+1) and i-1, j). Unknowns are discharge Q_{i-1}^{j+1} and flow area A_{i-1}^{j+1} which are related according to the uniform flow equation (Equation 2-2) with the value of the friction slope S_f having been obtained in the predictor step. With these two equations the two unknowns can be calculated. Li et al. (1975b) have shown that Q is the better choice as independent variable in the numerical solution of the above equations. The

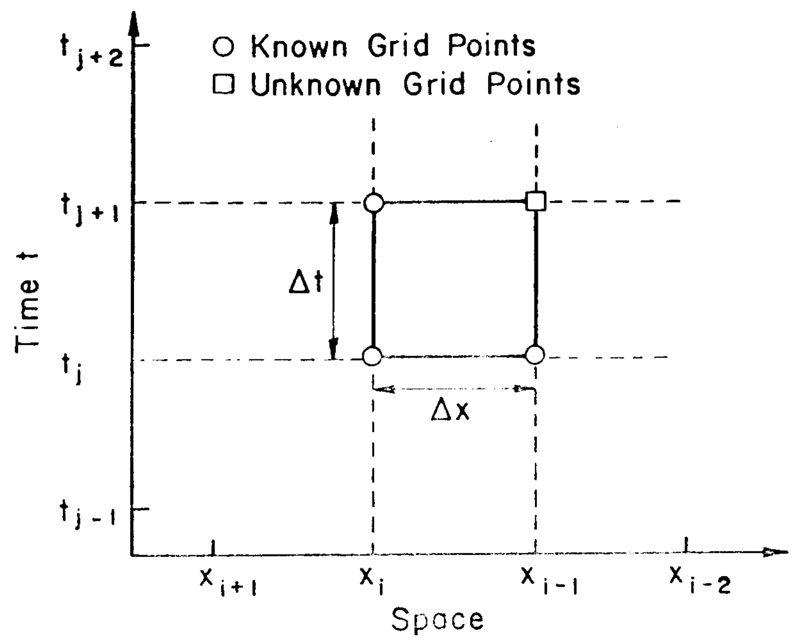

Figure 3-3. Space-time plane for the discretization of the continuity equation.

argument leading to this conclusion is that the relative error in flow area is smaller than the relative error in discharge because the power coefficient β' (defined below) of the discharge is usually less than one. Equation 3-2 is then rewritten in the form

$$A = (\frac{1}{\alpha}\ Q)^{1/\beta} \tag{3-10}$$

or

$$A = \alpha'\ Q^{\ \beta'} \tag{3-11}$$

with $\alpha' = (\frac{1}{\alpha})^{1/\beta}$ and $\beta' = 1/\beta$

Substituting Equation 3-11 into Equation 3-9, a nonlinear equation in Q_{i-1}^{j+1} is obtained. An approximate solution for the discharge Q_{i-1}^{j+1} is found with the Newton-Raphson iteration technique for which the first value of Q_{i-1}^{j+1} is the estimated value obtained in the predictor step. Starting at the upstream cross section, where the value of the discharge

Q is given as a boundary condition and the value of the flow area A has been calculated previously in the predictor step, the adjustment of the discharge Q and the flow area A, according to the continuity principle, is performed successively for all reaches. This assures mass conservation over the entire river. The final flood wave characteristics are then obtained by executing the unsteady nonuniform flow computations with the adjusted discharge Q.

Hereby, the corrector step or the adjustment of the flow characteristics for the current time level are obtained.

The following remarks should be made:

- All computations of mass conservation in the corrector step are made with a fixed friction slope S_f which incorporates an estimate of the current dynamic and backwater effects.
- The application of the mass conservation principle in the corrector step provides only for the mass conservation at the current time level. During the wave translation, as one moves from one time level to the other, there is no control of mass conservation. However, because of the continual adjustment of the flow characteristics, the error involved is small.
- Due to the consecutive application of the continuity and dynamic equation in the corrector step, the final flow characteristics will not rigorously satisfy the continuity equation. However the application of the dynamic equation in the corrector step can be considered as a second iteration step since it was already applied once in the predictor step. This improves the accuracy of the final results and the flow characteristics do not change significantly.

In the last two sections the predictor-corrector method has been described for one time increment. Repeating these steps for all times will result in the routing of the flood wave.

Convergence and Stability

O'Brien, Hyman, and Kaplan (1950) explained convergence and stability with the following words:

> "... let D represent the exact solution of the partial differential equation, Δ represent the exact solution of the partial difference equation, and N represent the numerical solution of the partial difference equation. We call (D-Δ) the truncation error; it arises because of the finite distance between points of the difference mesh. To find the conditions under which $\Delta \rightarrow D$ is the problem of convergence. We call (Δ-N) the numerical error. If a faultless computer working to an infinite number of decimal places were employed, the numerical error would be zero. To find the conditions under which (Δ-N) is small throughout the entire region of integration is the problem of stability."

In other words a difference scheme is convergent if the solution of the difference equations approaches the solution of the partial differential equations as the mesh size is made smaller and smaller. A difference scheme is stable if errors introduced at any stage of the computation process do not grow with time and distance. The effects of instability often show up as oscillations in the computed values of the dependent variables.

The classical approach to analyze the stability and convergence properties of a model cannot be applied to the proposed model because the solution technique is not based on a numerical scheme that solves a set of equations, but on a successive application of a physical concept and mathematical equations. However, if one analyzes separately the convergence and stability properties of each step of the solution technique, the following observations can be made.

The physical concept, the translation of the wave, is precisely what makes it possible to overcome the restrictions (mostly stability restrictions) of a numerical scheme. There is no partial differential equation that describes the wave translation and thus there is no analytical solution to which the numerical results of the translation can converge if the mesh size was made smaller and smaller. Or stated differently, the computation of the flood wave celerity does not involve neighboring points on the finite difference grid, thus there are no discretization errors.

The mathematical equations involved in the solution technique are the unsteady nonuniform flow computations and the continuity equation. The unsteady nonuniform flow computations are convergent and stable. If the computations are started at an assumed elevation that is incorrect for the given discharge, the resulting flow profile will become more nearly correct after every step (Chow, 1959). Thus the unsteady nonuniform flow computations, which are applied twice in the solution technique, converge and do not become unstable if an error is introduced at any location.

The numerical scheme solving the continuity equation is essentially the same as the nonlinear scheme presented by Li et al.

(1975b) which was shown to be stable and convergent and consequentially, similar stability and convergence properties can be expected from the scheme use in the dynamic model.

However the question of stability of the solution techniques is not so much dependent on whether or not a particular scheme is unstable, but on whether the interaction of all schemes provides a stable solution. Tracing an initial error as it moves from one scheme to another would be unrealistic in the frame of this study, but intuitively one may accept that the successive application of stable schemes is also stable.

Nevertheless, stability and convergence properties of the numerical schemes may be tested qualitatively by applying the model to hypothetical situations for which the solutions are known and then comparing the results. Stability and convergence were tested and verified by this process by Garbrecht (1981).

LIMITATIONS AND APPLICABILITY

The unsteady flow model is not expected to reproduce all flow situations. The governing equations presented in Chapter II have been derived under the assumption of gradually varied flow conditions and as such the models applicability is limited to these cases. These limitations, however, do not restrict the usefulness of the model for most cases encountered in natural and improved channels. Further restrictions in the applicability of the model are set by the assumptions made at the beginning of this chapter.

Due to the one-dimensionality of the model, care must be taken when applying it to improved channels with pronounced curvature in their alignment. The model makes no allowance for secondary flow effect upon the water surface elevation. There are no definite criteria on how "straight" a channel must be in order to be represented accurately by the one-dimensional model. For a naturally meandering river increasing channel roughness usually compensates for additional resistance due to the meanders. However, the secondary flow effects certainly cannot be reproduced.

Generally, the model cannot reproduce flow situations created by discontinuities in the river, if these disturb the flow pattern to a point where the governing equations are no longer applicable. However, overall effect of discontinuities such as weirs, lakes, dams or any control structure on the behavior of a flood wave can very well be evaluated by breaking the river system into two segments separated by the discontinuity and then by applying the model to each segment individually. By doing so, the discontinuity is isolated and enters the model as a downstream boundary conditions for the upper river segment.

The Kleitz-Seddon principle for wave celerity is restricted to situations where channel flow prevails. This results in another limitation of the unsteady flow model because in reaches where the backwater effects are strong enough to force the flow to depart appreciably from normal flow conditions, the wave celerity is no longer controlled by the channel resistance but by gravity. The celerity of the gravity wave is $c = v + \sqrt{gD}$ where D is flow depth and it is larger than the wave celerity given by the Kleitz-Seddon law. Thus for rivers with dominant backwater effects, the Kleitz-Seddon principle is not a good approximation of the flood wave celerity. Certain adjustments can be made by introducing a discharge dependent correction factor in reaches where the backwater effect are dominant.

In the following are given some situations which can be modeled by the unsteady flow model: distributed lateral inflows, inflow of major tributaries, backwater effects, additional losses due to the non-uniformity of the channel, irregular channel bed slope, dynamic effects, and discharge dependent channel roughness.

Furthermore, it should be mentioned that the model requires a downstream control of some form. This may be a rating curve, a rule of operation for a control structure, the uniform flow condition, or a prescribed water surface elevation.

The simplicity, efficiency and completeness of the dynamic water routing model make it especially interesting for the following applications:

- alternative studies for flood control structures and/or channel improvements where the backwater and dynamic effects are relevant
- general studies of large river systems with mild and steep channel bed slopes
- evaluation of the relative importance of the different terms in the dynamic equation for a particular river reach; this would indicate which terms, if any, may be neglected in the St. Venant equations and what approximation can be made for further investigations of the same river reach.

CHAPTER IV

SEDIMENT ROUTING

GENERAL

The amount of material transported or deposited in a channel reach is the result of the interaction of two processes. The first is the transport capacity of the reach. This is determined in part by the hydraulic conditions which are a direct result of the water discharge, channel configuration, and channel resistance and the sediment sizes present. Smaller particles can be transported at larger rates than larger particles under the same flow conditions. The second process is the supply of sediment entering the reach. This is determined by the nature of the channel and watershed above the study reach and development that it may be subjected to.

When sediment supply is less than sediment transport, the flow will remove additional sediment from the channel bed and banks to reduce the difference. This results in degradation of the channel and possible failure of the banks. If the supply entering the reach is greater than the capacity, the excess supply will be deposited, causing aggradation.

SEDIMENT TRANSPORT CAPACITY

Transport of the bed material load of a channel is divided into two zones. The sediment moving in a layer close to the bed is referred to as the bed load. The sediment which is carried in the remaining upper region of the flow is referred to as suspended load. The total bed material load is the sum of the two quantities. The turbulent mixing process and the action of gravity on the sediment particles cause a continual transfer between the two zones. Although there is no distinct line between the zones, the definitions are made in order to aid in the mathematical description of the process. A third type of load, the wash load, is also defined. It consists of fine particles that are not present in the bed in appreciable quantities, and will not easily settle out. Wash load is not considered in this model because it does not significantly affect aggradation or degradation.

Sediments of different sizes will experience different rates of transport. Therefore, the transport capacities for a range of sediment sizes are determined and totaled to produce an acceptable determination of total transport capacity. The total transport capacity for a channel section is

$$Q_s = T \Sigma P_i \, (q_{bi} + q_{si}) \qquad (4.1)$$

In Equation (4.1), T is the top width of the channel, P_i is the fraction of one sediment size, q_{bi} is the bed load transport rate per unit width for the ith size, and q_{si} is the suspended load transport rate for the ith size.

BED LOAD TRANSPORT CAPACITY

The Meyer-Peter, Muller formula gives good results for bed load transport over a wide range of sediment sizes. It was adopted for this study because of the wide range of sediment sizes present in the study system. The Meyer-Peter, Muller formula is well suited to model the dynamics of channel armoring processes as well as transport of sand sizes with little armoring potential. The formula is

$$q_{bi} = \frac{12.85}{\sqrt{\rho}\, \gamma_s} \, (\tau_o - \tau_c)^{1.5} \qquad (4.2)$$

in which

$$\tau_c = 0.047 \, (\gamma_s - \gamma) d_s \qquad (4.3)$$

In Equations (4.2 and 4.3), q_{bi} is the bed load transport rate in volume per unit width for a specific size of sediment, τ_c is the critical tractive force necessary to initiate particle motion, ρ is the density of water, γ_s is the specific weight of sediment, γ is the specific weight of water, and d_s is the size of sediment.

The boundary shear stress acting on the grain is

$$\tau_o = \frac{f_o}{8} \rho V^2 \tag{4.4}$$

where ρ is the density of flowing water and f_o is the Darcy-Weisbach friction factor, and V is the mean velocity of the flow.

SUSPENDED TRANSPORT CAPACITY

The suspended sediment transport capacity is determined by using a solution developed by Einstein. This method relies upon an integration of the sediment concentration profile as a function of depth. The nature of the profile is determined using turbulent transport theory. The sediment profile is assumed to be in equilibrium, and therefore the rate at which sediment is transported upward due to turbulence and the concentration gradient is exactly equal to the rate at which gravity is transporting sediment downward. If the sediment concentration is known at one point, then the entire concentration is determined. The point of known concentration is assumed to be the upper limit of the bed load layer. The results equation is

$$q_s = \frac{q_b}{11.6} \frac{G^{w-1}}{(1-G)^w} [(\frac{V}{U_*} + 2.5)I_1 + 2.5\ I_2] \tag{4.5}$$

in which q_s is the suspended load, q_b is the bed load, G is the relative depth of the bed layer, U_* is the shear velocity, V is the mean velocity of flow, I_1 and I_2 are the Einstein integrals and w is the dimensionless parameter given by

$$w = \frac{V_s}{\kappa U_*} \qquad (4.6)$$

In Equation (4.6), V_s is the fall velocity of the sediment particles and κ is the Karman constant (assumed 0.4).

I_1 and I_2 are integrals which cannot be evaluated directly. One must either use tables or numerical techniques. In the computer routing used to determine transport capacity, these integrals are evaluated using a numerical technique developed by Simons, Li & Associates, Inc.

AGGRADATION AND DEGRADATION

Sediment aggradation or degradation within a subreach for a given time interval is ΔV_s = (sediment supply - sediment transport) $\cdot$ C_s $\cdot$ BF, where ΔV_s is the change in sediment volume in the reach, C_s is a conversion factor, and BF is a bulking factor given as BF $1/(1-\lambda)$, where λ is the porosity of the bed material. The change in cross-sectional area is assumed to be uniform for the subreach. The change in elevation for a point within the main channel is

$$\Delta Z = \frac{A_S}{T}$$

where A_S is the change in cross-sectional area and equals the change in volume divided by the reach length and T is the width of the main channel. The changes in elevation are used to generate new cross-section data for the next time interval. Power functions describing the new geometric properties are recomputed for each time step.

CHAPTER V

APPLICATION EXAMPLE

GENERAL

To demonstrate how the model works a test case is chosen. For this example a 100 year flood is routed down the Salt River through Pheonix, Arizona. The Salt River is an ephemeral stream but it drains enough area to experience some rather large floods.

HYDROLOGY

For example, the peak of the 100 year flood in Phoenix is about 176,000 cfs. Table 5-1 gives the discretization of the 100 year flood by using 6 hour time increments. The duration of the flood is about 10 days. Figure 5-1 shows the normalized hydrograph.

BED MATERIAL

The Salt River has a sand, gravel, cobble and boulder bed. Sizes of bed material range from sand sizes on up to particles 1 foot in diameter. A size distribution of the bed material was obtained and is tabulated below in Table 5-2.

SPATIAL DESIGN

Cross-section data was obtained in HEC-2 format. Forty one cross-sections were available (a listing of these cross sections is given in the input data section). Figure 5-2 shows a schematic of the cross sections with respect to various physical features encountered in the river including the 48th Street bridge, dikes, the Hohokam expressway, the Instrumental Landing System (ILS) for Sky Harbor Airport, channelization, the Aerial Surveilance Radar (ASR) encroachment, dikes, and I-10 channelization and bridge. These 41 cross sections are grouped into 12

Table 5-1. 100 year flood discharge hydrograph at 6 hour time increments.

Time (hours)	Q (cfs)	Time (hours)	Q (cfs)
6	2500	150	36000
12	2500	156	32000
18	7000	162	28000
24	9680	168	26400
30	14000	174	23000
36	19000	180	20500
42	26000	186	18000
48	34320	192	15840
54	46000	198	14000
60	66880	204	12500
66	95040	210	11000
72	117040	216	9680
78	141680	222	8400
84	165440	228	7000
90	166320	234	6000
96	146080	240	4400
102	124080		
108	102080		
114	84000		
120	71280		
126	62000		
132	55000		
138	48000		
144	41360		

Table 5-2. Salt River bed material size distribution.

Percentage in Size Class	Geometric Mean Diameter (mm)
10	0.51
10	2.3
10	8.2
10	26
10	49
10	76
10	120
10	167
10	215
10	250

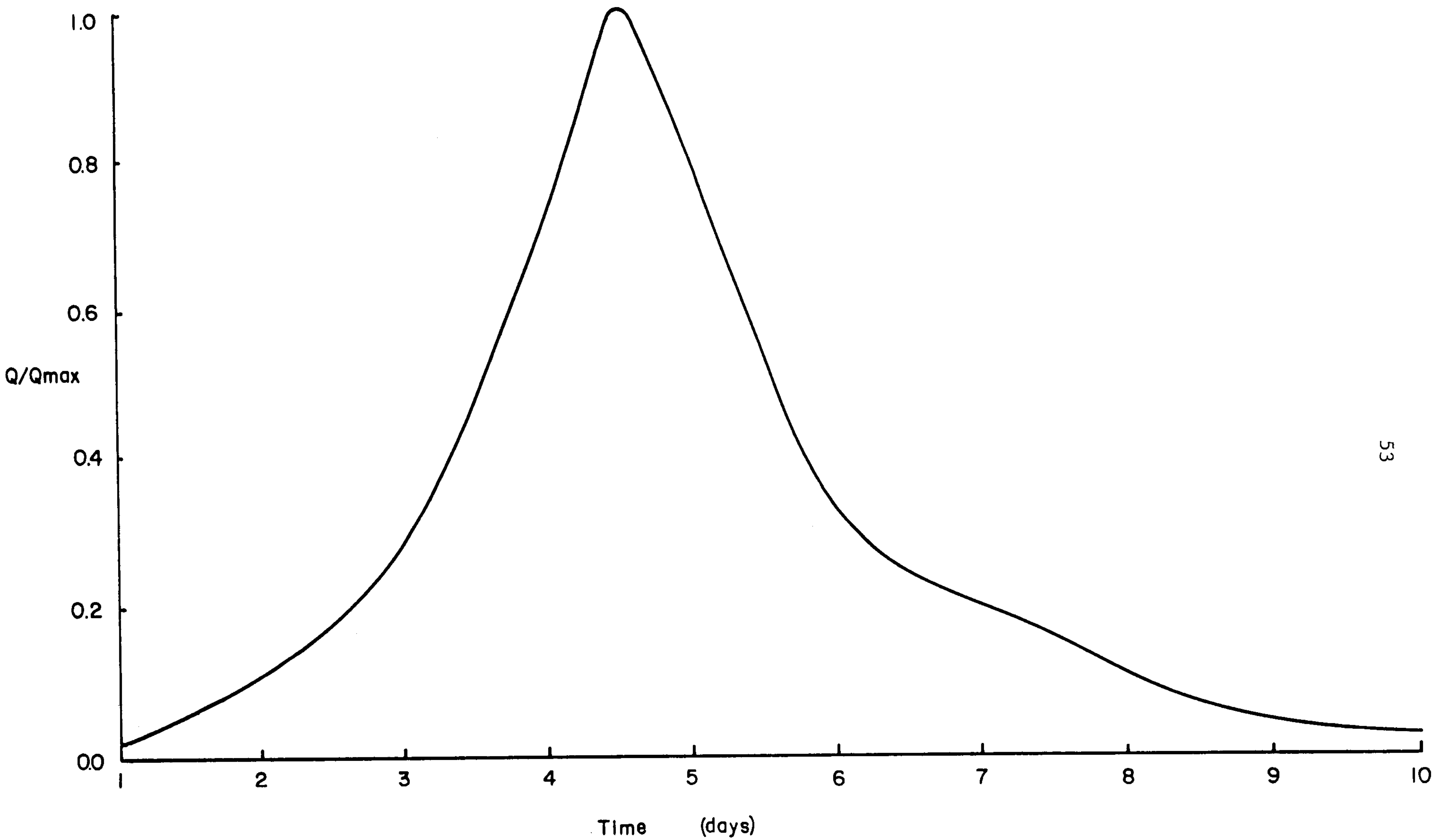

Figure 5-1. Normalized hydrograph.

River Distance (feet above I-10 grade control structure	Cross Section Identification	Location	Reach Definition
22,920	(41) 21,180	Upstream boundary	12
21,820	(40) 20,080		
20,820	(39) 19,070		11
19,520	(38) 17,920		
17,880	(37) 16,760		
16,620	(36) 15,580		10
15,500	(35) 14,420	48th Street	
14,440	(34) 14,120	Initial dikes	
13,640	(33) 13,520	Hohokam Expressway	
12,990	(32) 12,920		
12,570	(31) 12,520		9
12,150	(30) 12.120		
11,730	(29) 11,720	ILS	
11,520	(28) 11,520	ILS	
11,320	(27) 11,320	ILS	8
11,120	(26) 11,120	ILS	
10,720	(25) 10,720		
10,320	(24) 10,320		
10,120	(23) 10,120	1000' wide channel begins	
9,520	(22) 9,520		
8,920	(21) 8,920		7
8,260	(20) 8,260		
7,860	(19) 7,860	ASR	
7,660	(18) 7,660	ASR	
7,510	(17) 7,510	ASR	6
7,310	(16) 7,310	ASR	
6,910	(15) 6,910		
6,040	(14) 6,040	End of dikes on south side	5
5,440	(13) 5,440		
4,840	(12) 4,840		
4,240	(11) 4,240		4
3,520	(10) 3,520	End of dikes on north side	
3,120	(9) 3,120		
2,520	(8) 2,520		3
1,920	(7) 1,920		
1,520	(6) 1,520	I-10 channelization begins	
910	(5) 910	I-10 Bridge	2
800	(4) 800	I-10 Bridge	
450	(3) 450		
150	(2) 150		1
0	(1) 0	Grade control structure	

Figure 5-2. Schematic of reach definition.

reaches of similar hydraulic conditions for sediment routing computations. Water routing computations utilize all 41 cross sections. The purpose of the reach definition is given in Table 5-3.

RESULTS

In the output section the hydraulic variables, sediment transport variables and bed elevation changes are printed out and shown for the flood peak and also for the end of the flood. Final cross sections are also given. The results show a small amount of degradation just downstream of the upstream supply reach then a condition of general degradation from there on downstream. This is what one would expect considering the constrictions caused by various encroachments in the river. General degradation averages 1.5 to 2 feet. Table 5-4 gives the final mean bed elevation changes. This is a mean bed elevation change across the total width of the main channel. Actual degradation would be more for example where the flow concentrates in higher conveyance stream tubes such along the thalweg. The model does not consider 2-dimensional effects. Also, local scour at bridge piers etc., needs to be added to get an actual picture of potential degradation. The purpose and extent of this and most other sediment routing models is to give a general scour and mean bed elevation changes.

Table 5-3. Purpose for reach subdivision.

Reach Number	Purpose
1	Isolation of I-10 grade control structure and establishment of hydraulic control
2	Isolation of I-10 bridge and channelization
3	Isolation of region between I-10 channelization and Sky Harbor channelization
4	Isolation of area of channelization with dike on north side only
5	Isolation of area with dikes on both side
6	Representation of contraction in vicinity of ASR
7	Isolation of channelized region between ILS and ASR
8	Representation of contraction in vicinity of ILS and contraction of 1000-foot channel
9	Isolation of initial channelization and Hohokam Expressway
10	Isolation of wide braided section above channelization
11	Isolation of wide braided and flat section above channelization
12	Determination of supply to study areas

Table 5-4. Final mean bed elevation changes after 100 year flood.

Section	Final mean bed elevation change (ft)
41	0.00
40	0.00
39	.89
38	1.60
37	.39
36	.89
35	.65
34	-.68
33	-1.98
32	-2.10
31	-2.11
30	-2.11
29	-1.78
28	-1.78
27	-1.77
26	-1.76
25	-1.71
24	-1.78
23	-1.66
22	-1.72
21	-1.73
20	-1.73
19	-1.90
18	-1.90
17	-1.90
16	-1.90
15	-1.75
14	-1.75
13	-1.36
12	-1.36
11	-1.36
10	-1.37
9	-.31
8	-.60
7	-.31
6	-.79
5	-.74
4	-.73
3	-.65
2	-.67
1	-.65

Chapter VI

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to develop a mathematical water routing model in nonuniform channels which could overcome the limitations of commonly used finite difference schemes. The introduction of the Kleitz-Seddon wave celerity to control the movement of the flood wave resulted in a simple and efficient technique to route a flood through a river system.

The main application of the model is to evaluate the effect of control structure and/or channel improvement alternatives by reflecting the change in flood wave behavior and to perform general flood routing studies in large river systems with mild and steep slopes. With this water routing model sediment routing was added to make a more general and useful model.

SUMMARY AND CONCLUSIONS

The basic equations used in this model are the mass and momentum conservation equations for gradually varied flow, Manning's uniform flow equation, and the Kleitz-Seddon equation for the flood wave celerity. Furthermore, it was shown that the unsteady nonuniform flow computations, presented in Chapter II, can be regarded as an iterative solution to the complete dynamic equation. A proper combination and uncoupled application of these equations on a finite difference grid resulted in a simple predictor-corrector solution technique based on explicit schemes.

In the first step, the nonlinear wave celerity was applied over one time increment to translate the flood wave along the river and the flow characteristics were estimated by the unsteady nonuniform flow computations. To obtain an accurate movement of the flood wave, its celerity was continuously reevaluated according to the changes in discharge and channel characteristics. This step was called the predictor step because it located the flood wave in space for the next time level and predicted the flow characteristics.

In the second step, the attenuation of the flood wave was introduced by correcting the flow characterisitcs to meet the mass conservation principle, and the final flood wave profile was calculated by reapplying the unsteady nonuniform flow computations. This step was called the corrector step because it corrected the flow characteristics that were estimated in the first step.

Briefly, the predictor-corrector solution method is an application of the kinematic wave principles to the movement of the flood wave and a correction of the flow characteristics by the continuity equation and the full dynamic equation.

Successive application of the basic equations as described above by the predictor-corrector method results in the routing of a flood wave.

By controlling the flood wave movement on the finite difference grid with the Kleitz-Seddon wave celerity, the limitations usually encountered in solving the flood routing problem with the method of finite differences were overcome. These limitations are stability restrictions for explicit schemes and complexity of the implicit schemes.

Prior to this study the model was tested for various finite difference discretizations of a long unit width channel and a sinusoidal inflow hydrograph. Results of all test applications compared astonishingly well to the known solution and the model proved to be stable, convergent and independent of the size of the finite difference increments. Stability restrictions of explicit schemes were overcome by a factor of 10 and more (up to 30) and, because of the large time and space increments, the proposed solution technique was at least twice (or more) as efficient at solution techniques based on implicit schemes (see Garbrecht, 1981).

The applicability of the unsteady flow model is limited to gradually varied unsteady flow conditions, to flows which can be described as a function of one dimension (usually along the channel axis) and of time, and to main channel flows. Effect of discontinuities in the river (such as weirs or dams) on the behavior of the flood wave can be analyzed by proper application of the unsteady flow model.

The simplicity and efficiency of the unsteady flow model makes it interesting for evaluation of alternative flood control structures and/or channel improvements, and for the analysis of the flood wave behavior in large river systems with varying channel characteristics. Furthermore, the model can be used to evaluate the relative importance of the various terms of the dynamic equation and the results may indicate what approximations could be made for future investigations of the same river reach.

A sediment routing example of a 100 year flood on the Salt River in Phoenix, Arizona was given. Model results showed degradation in the higher velocity constricted reaches which agree with qualitative analysis of potential bed elevation changes.

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APPENDIX A

PROGRAM THEORY

General

The proper application of the dynamic model requires a basic knowledge of the program operation. In this appendix the determination of the hydraulic properties of a cross section from digitized channel data and the computation of the hydraulic property relationships are described. In a later section an overview of the computational sequence is given. This allows the user to understand the operation of the dynamic model and to upgrade or modify certain sections according to specific needs. The input requirements and the program output are then described.

Computation of the Hydraulic Properties

At numerous locations in the dynamic model the channel hydraulic properties such as flow area, total conveyance, wetted perimeter and hydraulic radius are needed for various depths. Only two hydraulic properties, the flow area and the wetted perimeter, need to be computed from digitized channel cross section data. All other hydraulic properties which are necessary in the program can then be derived algebraically from these two.

Coordinate points

Channel cross sections are defined by a set of (x,z) coordinates. Figure A-1 depicts a typical cross section. The lower of the two banks defines the overbank elevation (for overbank flow) and its value must be given for each cross section.

Flow area

The flow area for a given water surface elevation is computed by summing incremental areas between consecutive coordinates of the cross

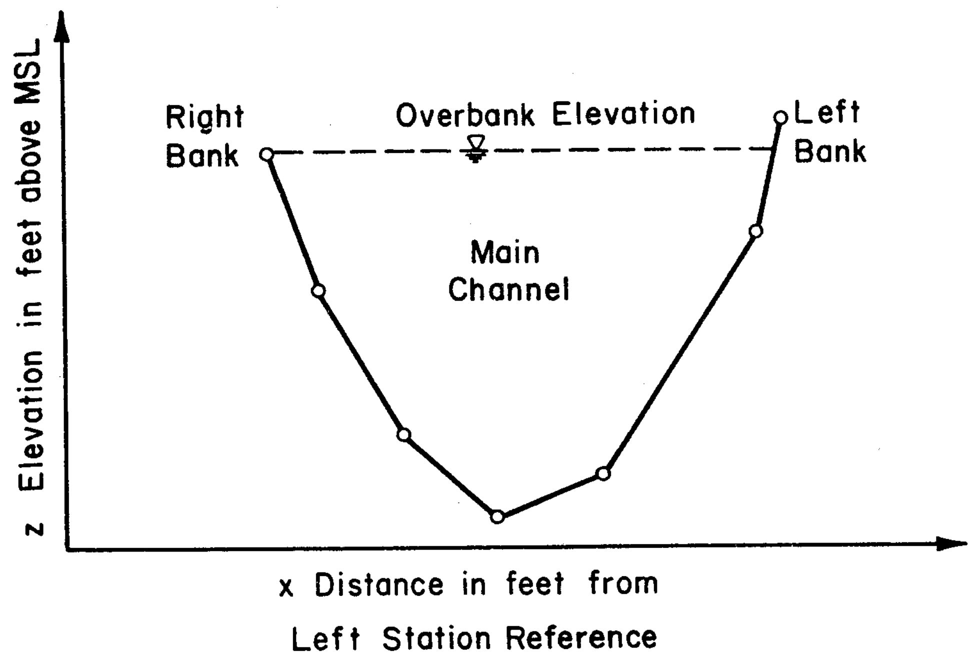

Figure A-1. Typical channel cross section.

section. Figure A-2 illustrates this technique. The total area of flow is then the summation of the incremental areas, a_i:

$$A = \sum_{i=1}^{N} a_i \tag{A-1}$$

where N is the total number of cross section incremental areas. Incremental areas are computed by:

$$a_i = x_b D_a \tag{A-2}$$

where x_b is the width of the increment and D_a is defined as:

$$D_a = 1/2 \ (D_1 + D_2) \tag{A-3}$$

where D_1 and D_2, as well as x_b are defined in Figure A-2.

If the water surface intercepts the cross section between coordinate points as shown by increment 1 and 5 in Figure A-2, straight line interpolation between points is used to compute the triangular area.

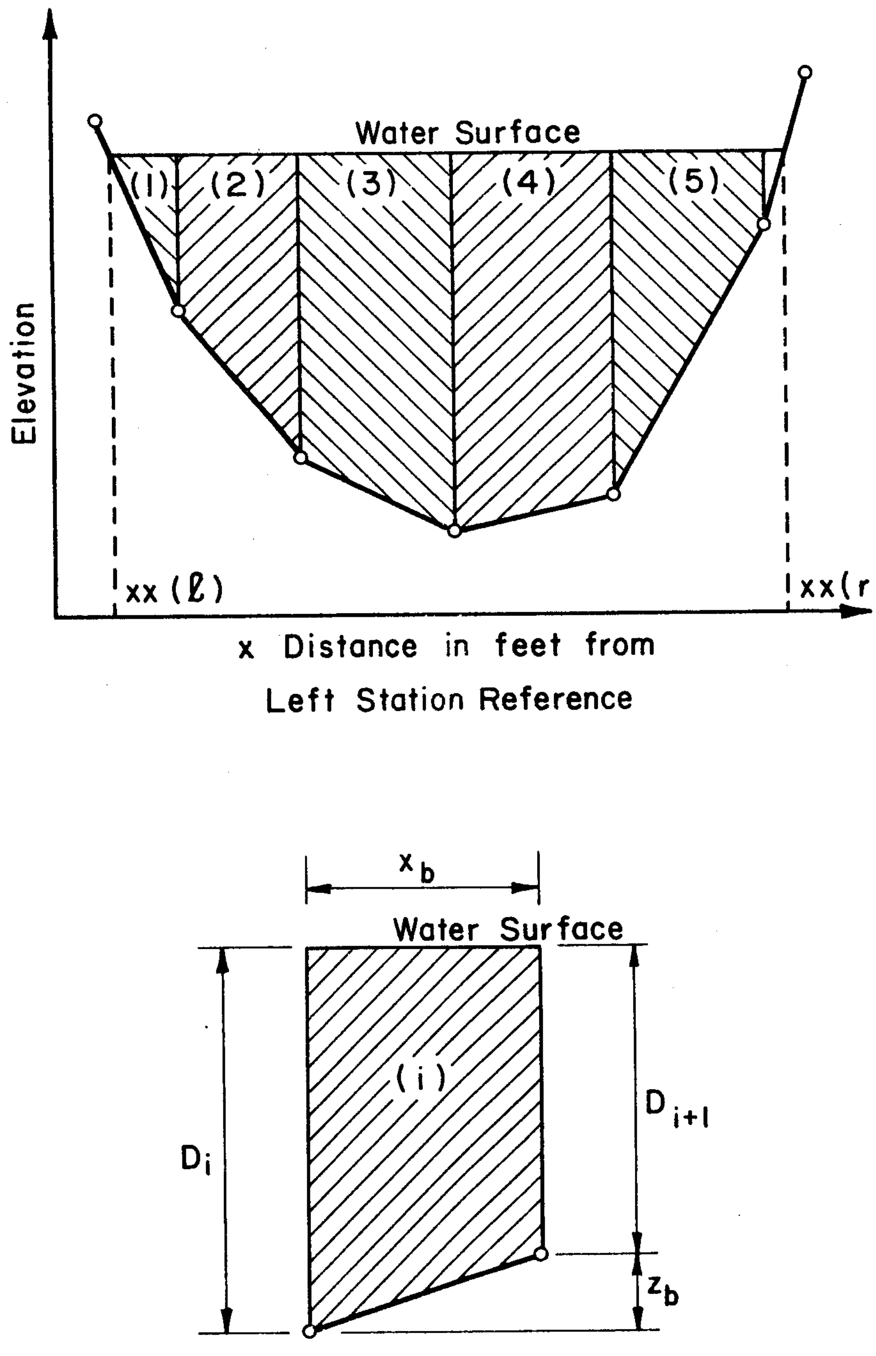

Figure A-2. Incremental areas in a cross section.

Wetted perimeter

The wetted perimeter p_i is the length of the cross section below the water surface and is computed in increments by:

$$p_i = \sqrt{{x_b}^2 + {z_b}^2} \qquad \text{(A-4)}$$

where z_b is defined in Figure A-2. The summation of all incremental wetted perimeters p_i yields the total wetted perimeter P.

From these two channel hydraulic properties all other necessary properties can be computed as described in the following section.

Channel Hydraulic Property Relationships

In the dynamic model the hydraulic properties are needed for numerous purposes. Calculation of these values each time they are needed would require a large amount of computations. A more efficient way uses power functions for the hydraulic properties. A power funtion is a simple relation which allows an effective evaluation of the hydraulic properties using the thalweg depth and two coefficients. The general form of a power function is:

$$HP = a\ D^b \qquad \text{(A-5)}$$

where HP is the hydraulic property, a and b are the computed coefficient and exponent respectively, and D is the thalweg depth.

The hydraulic properties are calculated for a certain number of evenly spaced incremental depths of flow. The logarithm of these values are then used to compute the coefficient and exponent of the power function by a least square regression. Figure A-3 illustrates the procedure. The obtained power function is only valid for the cross section for which it has been computed.

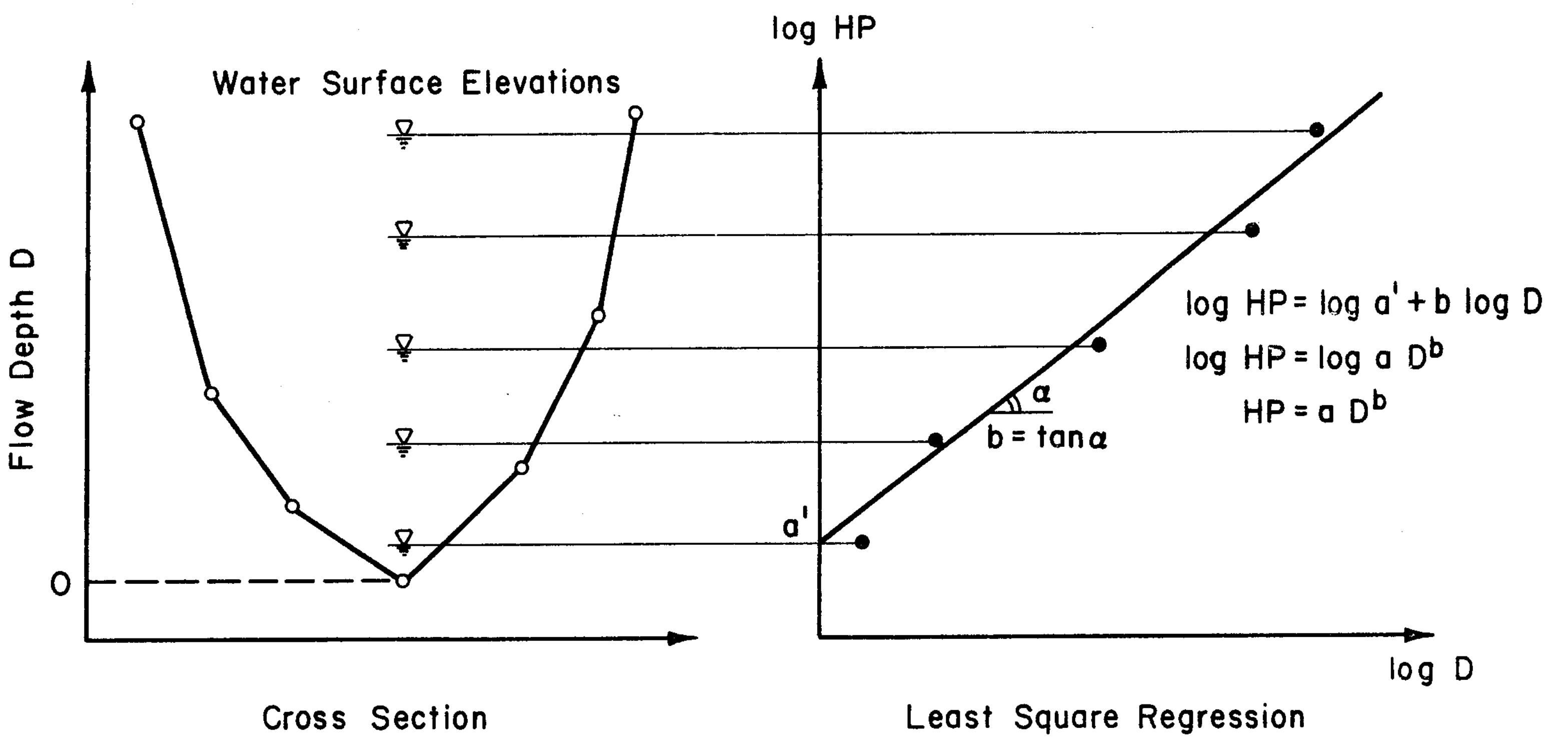

Figure A-3. Computation of the coefficients and powers of the power functions.

The power functions computed by the program are

1 - Total flow area $$TA = a_1 D^{b_1} \quad \text{(A-6)}$$

2 - Wetter perimeter $$TP = a_2 D^{b_2} \quad \text{(A-7)}$$

where a_1, a_2 and b_1, b_2 are the computed coefficients and exponents respectively. The power functions for the hydraulic radius and the total conveyance are derived algebraically from Equations A-6 and A-7 as follows:

Hydraulic radius: $$R = \frac{TA}{TP} = \frac{a_1 D^{b_1}}{a_2 D^{b_2}} = a_4 D^{b_4} \quad \text{(A-8)}$$

with $$a_4 = a_1/a_2 \quad \text{(A-9)}$$

$$b_4 = b_1 - b_2 \quad \text{(A-10)}$$

Total conveyance: $$TK = \frac{1.486}{n(Q)} AR^{2/3} = a_3 D^{b_3} \quad \text{(A-11)}$$

with $$a_3 = \frac{1.486}{n(Q)} * a_1 * a_4^{2/3} \quad \text{(A-12)}$$

$$b_3 = b_1 + 2/3\ b_4 \quad \text{(A-13)}$$

Derivation of β

The coefficient β used to evaluate the flood wave celerity is obtained from Manning's equation as follows

$$Q = \frac{1.486}{n} A R^{2/3} S_f^{1/2} \quad \text{(A-14)}$$

Substituting

$$n = a_5 Q^{b_5} \quad \text{(A-15)}$$

$$P = a_2 D^{b_2} \qquad \text{(A-16)}$$

$$A = a_1 D^{b_1} \qquad \text{(A-17)}$$

where n is Manning's channel roughness, P is wetted perimeter, D is flow depth, A is flow area and a_1, a_2, a_5, b_1, b_2, and b_5 are empirically determined coefficients. Substituting Equations A-15, A-16 and A-17 into A-14 and rearranging yields

$$Q = \left[\frac{1.48^6 \; a_1^{\frac{2 b_2}{3 b_1}}}{a_5 \; a_2^{2/3}} \; S_f^{1/2} \right]^{\frac{1}{1+b}} A^{\frac{5b_1 - 2b_2}{3 b_1(1+b_5)}} \qquad \text{(A-18)}$$

or $$Q = \alpha A^{\beta}$$

Thus,

$$\beta = \frac{5 - 2 b_{2/b_1}}{3 (1+b_5)} \qquad \text{(A-19)}$$

Equation A-19 is used in the present model, where the coefficient b_5 is discharge dependent and calculated for each cross section at every time step.

<u>Computational Sequence</u>

Two distinct parts may be recognized in the computational sequence of the program.

A) The necessary information for the dynamic model computations is read or calculated and the initial conditions are computed.

B) For each subsequent time level the flood wave movement is estimated and the flood wave profile and flow characteristics are computed.

Figure A-4 at the end of this section gives a flow chart for the computational sequence.

Part A

- Data input [INPUT]

First the river system characteristics and the channel characteristics are read and stored in appropriate arrays. (This information will initialize and control the program execution.) Then the inflows at each cross section for the initial time level are read from [FLOW]. The inflow for the subsequent time levels will be read as they are needed. No further data is needed for the program execution.

The detailed input requirements (formats and examples) will be outlined in the next section.

- Hydraulic properties [CHANGEO]

For the given cross section geometry the flow area and the wetted perimeter are computed for various depths at each cross section [GEOM]. A power function is then developed by fitting a least square regression curve through the log values of the hydraulic properties and depth [LSQ]. The power function for the hydraulic radius and the total conveyance are computed analytically from the flow area and wetted perimeter relations. The coefficient of the power function for the total conveyance depends on the channel roughness which varies with discharge, so that its value is recalculated for each time level [NVAL].

The power functions for the hydraulic properties can conveniently be recalled as needed during the program execution.

- Initial conditions [INITIAL]

Assuming steady-state flow conditions, the discharges at each cross section are obtained by summing all the inflow upstream of the cross section. Knowing the discharge at all cross sections, the water surface profile and the flow characteristics at each cross section are calculated by the nonuniform flow computations [BACKWA]. These are the initial conditions.

Part B

- Estimation of the flood wave translation [NEWDIS]

The first operation at a new time level is to estimate the discharge by translating the flood wave from the last time level according to its celerity. The celerity is a function of channel shape, channel roughness and discharge, so that each point of the flood wave is translated with its corresponding celerity. During the translation process the wave celerity is continuously adjusted according to the change in discharge and in channel shape encountered as the wave is translated downstream [NEWFLOW]. The first cross sections at the beginning of the reach are not covered by the above procedure and the discharges will be computed by summing all inflows upstream of the particular cross sections. With the discharge known at all cross sections, the flow characteristics can be estimated by the nonuniform flow computations [BACKWA].

- Correction of the flow characteristics [CORDA]

The discharge, the flow area and the total friction slope computed previously in the flood wave translation step do not satisfy the continuity principle. Starting at the upstream cross section where the estimated values of discharge, flow area and friction slope are assumed to be correct, the continuity principle is applied to the downstream space increment over one time increment. Considering the estimated friction slope as correct, the discharge and flow area values at the downstream cross section are relaxed to meet the continuity principle and the uniform flow equation simultaneously. The same procedure is then applied to the next space increment downstream and so forth, with the flow characteristics of the upstream cross section being the ones calculated previously. The application of the continuity principle introduces the attenuation of the flood wave.

- Computation of the flow characteristics [BACKWA]

With the adjusted discharges from the corrector step the nonuniform flow computations yield the total energy slope, the flow area, the flow depth and the water surface elevation for each cross section. These flow characteristics with the power functions are sufficient to derive any other hydraulic properties of interest.

- Output [OUTPUT]

For the current time level, for which the computations are completed, discharge, flow area, total energy slope, water surface elevation, flow depth and lateral inflow at each cross section are printed out.

- Sediment transport cpapcity computation [QS, TRANSP, POWER]
  Using the current hydraulic conditions the total bed material load capacity is computed for each reach.
- Sediment routing [SROUT]
  Based on the sediment transport capacity and current size distribution of the bed the amount of aggradation or degradation is computed and distributed to each cross section in each

reach. The geometry relations are recomputed [CHANGEO, GEOM, LSQ]

- Time level shift [TIMCHA]

Since at most the two previous time levels are needed to evaluate the temporal variation of the flow variables, the time levels prior to the last two are not needed and are purged to reduce computer storage requirements. Thus the program works only with three time levels. This however requires a shift in time level for all flow variables at the end of each time step. This is done by placing all flow values of the current time level into the previous time level, and those of the previous time level into the second previous. The current time level will then be empty and ready for the next computational step.

The program then returns to the beginning of part B and performs the same steps as many times as the number of time periods given by the input data.

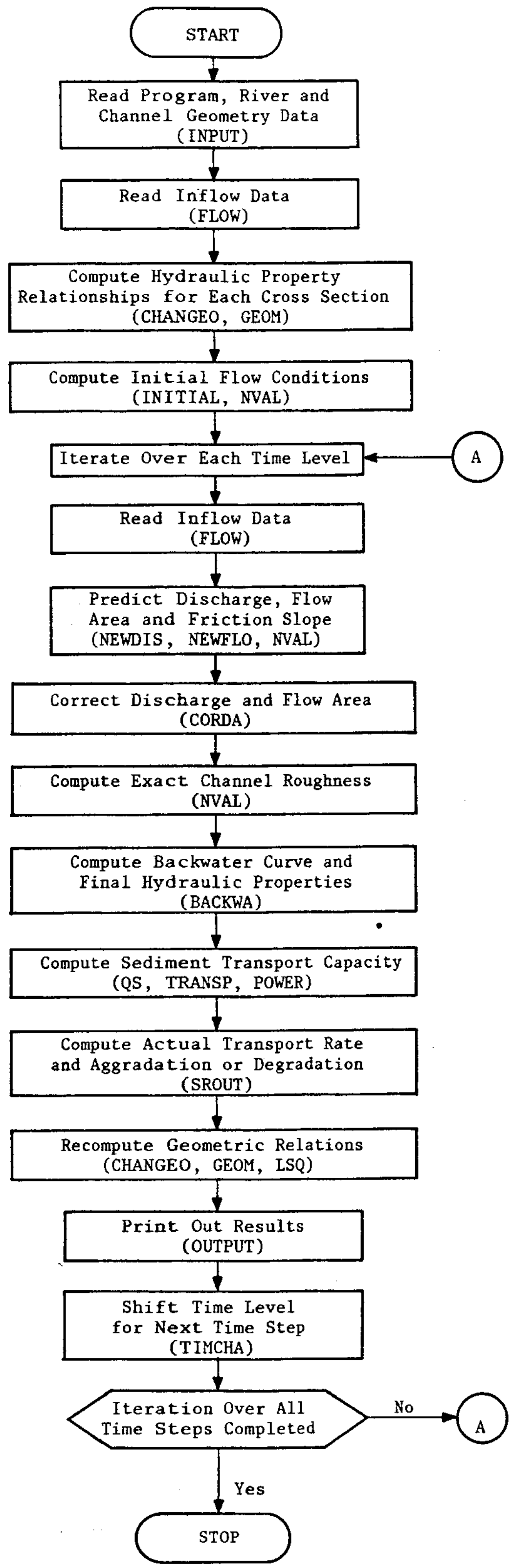

Figure A-4. Flow chart of program DYNWAR.

APPENDIX B

INPUT AND OUTPUT DATA FOR THE EXAMPLE APPLICATION

Input Requirements and Output Data

The program operates in the English unit system and the input variables are in pounds, feet, seconds, except for the time increment length is in hours and the sediment sizes are in millimeters. This section defines the structure and the format of the input files. For example data for a 100 year flood event on the Salt River in Phoenix, Arizona is given.

Input Data

All data is read into the program from subroutines INPUT and FLOW. The input data are divided into three files to ease the task of assembling the debugging. The three files are:

TAPE 10 - General Data

TAPE 9 - Discharge Data

TAPE 8 - Cross Section Data

TAPE 10 General Data

The following cards give the general information for the program execution.

Card Number	Format	Description
1	2I5, F5.2	NCS, NTP, DT Number of cross sections (NCS); number of time periods (NTP); time period length (DT) in hours.
2	6F10.7	FA1, FB1 Coefficient (FA1) and power (FB1) for the channel roughness-discharge power function.
3	3F5.2	ALPHA, CC, CE Energy correction coefficient (ALPHA); channel contraction loss coefficient (CC); channel expansion loss coefficient (CE).

Example:

NCS	Number of cross section:	41	First card
NTP	Number of time periods:	40	
DT	Time increment length:	6	
FA1	Coefficients and powers	0.030	Second card
FB1	for the channel roughness-discharge power function	0.000	
ALPHA	Energy correction coefficient	1.0	Third card
CC	Channel contraction loss coefficient	0.15	
CE	Channel expansion loss coefficient	0.25	

Card Number	Format	Description
4	I10	NR
		Number of reaches(NR)
5 - 5 + NR	2I10	NRL, NRU
		Downstream cross-section number of reach (NRL)
		Upstream cross-section number of reach (NRU)
		(a pair of numbers on each card from 1 to the number of reaches)
6 + NR	I2, 2F10.3, F10.8	NS, PORB, F, SNU
		Number of sediment sizes (NS) (usually $\leq$ 10)
		Bed porosity (PORB)
		Darcy-Weisbach Friction factor (F)
		Kinematic viscosity (SNU)
7 + NR	10F10.3	DMB
		Sediment sizes (DMB)
8 + NR	10F10.3	PBO
		Decimal percentages in each size fraction (PBO)
9 + NR	I2	NT
		Number of tributaries (NT)
10 + NR	10f10.4	RDT
		River mile of tributary (RDT)
11 + NR	10f10.3	PTRIB
		Size distribution of Tributaries (PTRIB)

GENERAL DATA FILE FOR SALT RIVER

```
     41    406.0
 .030        0.          .030        0.          .030        0.
 1.0   .15  .25
          12
           1             3
           4             6
           7             9
          10            13
          14            15
          16            19
          20            23
          24            29
          30            34
          35            37
          38            39
          40            41
 10.4        .066        .0000105
 0.51       2.3         8.2         26.         49.         76.         120.        167.        215.        250.
 .10        .10         .10         .10         .10         .10         .10         .10         .10         .10
  .0
 /
```

TAPE 9 Discharge Data

Care Number	Format	Description
1→depends on # of x-sections and time steps	10F8.2	(QIN (I,IT), I = 1, NCS) Inflow at each cross section. Flow values for the upstream inflow.
varies	8F10.2	(GLATN (J), J = 1, NT) Tributary sediment inflow (cfs)

Note: if NT = 0 no tributary sediment inflow is read.

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2500.									
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2500.									
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
7000.									
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0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
9680.									
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0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
14000.									
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0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
19000.									
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0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
26000.									
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0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
34320.									
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0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
46000.									
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0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
66880.									
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0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
95040.									
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0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
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141680.									
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0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
165440.									
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0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
166320.									
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0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

DISCHARGE DATA FOR EXAMPLE

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0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
102080.									
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0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
84000.									
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71280.									
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62000.									
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55000.									
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41360.									
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36000.									
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0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
32000.									
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0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
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28000.									
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0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
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0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
26400.									
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0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
20500.									
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18000.									
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0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
15840.									
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14000.									
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0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
12500.									
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0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
11000.									
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
9680.									
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
8400.									
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0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
7000.									
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
6000.									
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
4400.									

TAPE 8 Cross-Section Data

The cross-section cards are in standard HEC-2 format. Only the X1 and GR cards are actually read. Refer to a HEC-2 users manual for data description.

```
T1        SALT RIVER-SKY HARBOR
T2        100 YEAR FLOOD
T3        PROPOSED CHANNEL  JULY 80
J1              0       0       0      -1                         176000 1094.0
J2      1       0      -1      0.      0.
NC                             .1      .3
NH     3.    .035     85.     .03    985.    .035   1065.
X1     0.     4.0      0.   1065.
GR  1107.     0.0  1079.2     85.  1079.2    985.   1107.   1065.
NH     3.    .035     85.     .03    955.    .035   1040.
X1    150     4.0      0.   1040.    150.    150.    150.
GR  1107.      0.  1079.3     85.  1079.3    955.   1107.   1040.
NH      3    .035    110.     .03    890.    .035   1280.
X1    450       6     12.    955.    300.    300.    300.
GR  1107.     12.  1079.6    110.  1079.6    890.   1100.    955.   1100.   1250.
GR  1107.   1280.
NH      3    .035    120.     .03    820.    .035   1560.
X1    800       9     60.    880.    350.    350.    350.
X3     10       0       0       0       0       0       0  1118.8  1118.8
GR1122.8       0.  1118.8      0.   1100.     60.   1080.    120.   1080.    820.
GR  1100.    880.   1100.   1520.  1118.8   1560.  1122.8   1560.
SB   1.25     1.5     2.5       0     700      20   31040       3
NH     3.    .035    120.     .03    820.    .035   1560.
X1    910       9     60.    880.    110.    110.    110.
X2      0       0      1.  1118.8  1122.8
X3     10       0       0       0       0       0       0  1122.8  1122.8
GR1122.8        0  1118.8      0.   1100.     60.   1080.    120.   1080.    820.
GR  1100.    880.   1100.   1520.  1118.8   1560.  1122.8   1560.
NH      3    .035   9735.    .030  10435.    .035  10781.
X1   1520      10   9695.  10500.    590.    640.    610.
GR1110.4    9256.  1104.1   9315.  1103.1   9366.  1106.4   9391.  1098.6   9624.
GR1100.4    9695.  1080.7   9735.  1080.7  10435.  1101.5  10500.  1107.9  10781.
NH      3 .035     9708.0  .03     10886.0 .035    10969.0
X1   1920      15 9935.00 10886.0     400     400     400
GR1111.5 9366.0 1107.8  9445.0  1108.6  9573.0  1100.8  9598.0  1101.0  9674.0
GR1088.3 9708.0 1084.0  9769.0  1084.0  9890.0  1085.9  9935.0  1081.1  9945.0
GR1081.1 10345.0 1083.6 10350.0 1083.6  10825.0 1105.5  10886.0 1106.1  10969.0
NH      3 .035     9560.0  .03     10770.  .035    11000.0
X1   2520      14 9910.00 10400.0     600     600     600
GR1111.2 9380.0 1109.6  9560.0  1102.1  9580.0  1087.9  9760.0  1087.3  9910.0
GR1081.7 9930.0 1081.7  10330.0 1091.1  10340.0 1088.8  10400.0 1084.5  10540.0
GR1084.5 10650.0 1086.4 10700.0 1085.9  10770.0 1112.2  11000.0
NH      3 .035     9440.0  .03     10650.0 .035    10930.0
X1   3120      16  9750.0 10650.0     600     600     600
GR1117.0 9370.0 1090.2  9440.0  1090.2  9630.0  1093.1  9750.0  1092.3  9890.0
GR1084.5 9910.0 1084.5  10310.0 1088.8  10320.0 1086.3  10350.0 1086.3  10600.0
GR1096.4 10650.0 1092.6 10690.0 1093.0  10760.0 1096.7  10780.0 1110.8  10810.0
GR1114.6 10930.0
NH      3 .035     9500.0  .03     10500.0 .035    10547.3
X1   3520      10  9883.3 10306.0  400.00  400.00  400.00
GR1116.0   9250.0  1091.1  9320.0  1091.1  9500.0  1091.1  9883.3  1085.5  9894.5
GR1085.5  10294.7  1091.1 10306.0  1091.1 10500.0  1114.3 10546.3  1114.8 10547.3
NH      3 .035     9500.0  .03     10500.  .035   10544.6
X1   4240      10  9860.6 10284.5  720.00  720.00  720.00
GR1115.0   9225.0  1097.0  9270.0  1093.2  9500.0  1093.2  9860.6  1087.3  9872.5
GR1087.3  10272.6  1093.2 10284.5  1093.2 10500.0  1115.0 10543.6  1115.5 10544.6
NH      3 .035     9592.0  .03    10500.0 .035     10542.6
X1   4840      11  9842.0 10266.2  600.00  600.00  600.00
GR1117.0   9220.0  1094.8  9265.0  1094.8  9592.0  1094.8  9692.0  1094.8  9842.0
GR1088.8   9854.0  1088.8 10254.2  1094.8 10266.2  1094.8 10500.0  1115.6 10541.6
GR1116.1 10542.6
NH      3 .035    9500.0   .03    10500.0  .035     10540.7
X1   5440      10  9826.1 10250.1  580.00  620.00  600.00
GR1119.0   9300.0  1096.4  9350.0  1096.4  9500.0  1096.4  9826.1  1090.4  9838.1
GR1090.4  10238.1  1096.4 10250.1  1096.4 10500.0  1116.2 10539.7  1116.7 10540.7
NH      3 .035     9500.0  .03    10500.0  .035    10538.8
X1   6040      11  9817.0 10241.1  540.00  660.00  600.00
GR1117.3   9461.2  1098.0  9500.0  1098.0  9715.0  1098.0  9755.0  1098.0  9817.0
GR1092.0   9829.0  1092.0 10229.1  1098.0 10241.1  1098.0 10500.0  1116.8 10537.8
GR1117.3 10538.8
NH      3  .035     9500.0  .03   10500.0 .035     10538.1
X1   6910      10  9803.4 10227.4  780.00  950.00  870.00
GR1119.2   9461.9  1118.7  9462.9  1100.2  9500.0  1100.2  9803.4  1094.2  9815.4
GR1094.2  10215.4  1100.2 10227.4  1100.2 10500.0  1118.7 10537.1  1119.2 10538.1
NH      3  .035    9500.0  .03     10489.0 .035     10527.9
X1   7310      10  9797.0 10221.0  360.00  440.00  400.00
GR1120.7   9461.1  1120.2  9462.1  1101.3  9500.0  1101.3  9797.0  1095.3  9809.0
GR1095.3  10209.0  1101.3 10221.0  1101.3 10489.0  1120.2 10526.9  1120.7 10527.9
NH      3 .035     9500.0  .03    10313.0  .035    10352.4
```

CROSS SECTION DATA FOR GIVEN EXAMPLE

```
GR1095.8  10205.8   1101.8 10217.8   1101.8 10313.0   1120.5 10351.4   1121.0 10352.4
NH      3   .035    9500.0     .03  10326.0    .035   10364.2
X1   7660        10  9791.3 10215.4   140.00   160.00   150.00
GR1121.6   9461.8   1120.8  9462.8   1102.2   9500.0   1102.2  9791.3   1096.2  9803.3
GR1096.2  10203.4   1102.2 10215.4   1102.2  10326.0   1120.8 10363.2   1121.3 10364.2
NH      3   .035    9500.0     .03  10436.9    .035   10474.8
X1   7860        10  9788.3 10212.3   180.00   220.00   200.00
GR1121.6   9462.2   1121.1  9463.2   1102.7   9500.0   1102.7  9788.3   1096.7  9800.3
GR1096.7  10200.3   1102.7 10212.3   1102.7  10436.9   1121.1 10473.8   1121.6 10474.8
NH      3   .035    9500.0     .03  10500.0    .035   10537.0
X1   8260        10  9788.0 10212.0   390.00   410.00   400.00
GR1122.2   9463.0   1121.7  9464.0   1103.7   9500.0   1103.7  9788.0   1097.7  9800.0
GR1097.7  10200.0   1103.7 10212.0   1103.7  10500.0   1121.7 10536.0   1122.2 10537.0
NH      3   .035    9500.0     .03  10500.0    .035   10535.7
X1   8920        10  9783.5 10207.5   685.00   635.00   660.00
GR1123.3   9464.3   1122.8  9465.3   1105.4   9500.0   1105.4  9783.5   1099.4  9795.5
GR1099.4  10195.5   1105.4 10207.5   1105.4  10500.0   1122.8 10534.7   1123.3 10535.7
NH      3   .035    9500.0     .03  10500.0    .035   10534.6
X1   9520        10  9821.3 10249.6   660.00   540.00   600.00
GR1124.3   9465.4   1123.8  9466.4   1107.0   9500.0   1107.0  9821.3   1101.0  9833.3
GR1101.0  10237.6   1107.0 10249.6   1107.0  10500.0   1123.8 10533.6   1124.3 10534.6
NH      3   .035    9500.0     .03  10500.0   .035   10533.0
X1  10120        10  9949.3 10392.8   660.00   540.00   600.00
GR1125.3   9466.6   1124.8  9467.6   1108.6   9500.0   1108.6  9949.3   1102.6  9961.3
GR1102.6  10380.8   1108.6 10392.8   1108.6  10500.0   1124.8 10532.4   1125.3 10533.0
NH      3   .035    9500.0     .03  10500.0    .035   10533.0
X1  10320        1010012.2 10463.7   220.00   180.00   200.00
GR1125.6   9467.0   1125.1  9468.0   1109.1   9500.0   1109.1 10012.2   1103.1 10024.2
GR1103.1  10451.7   1109.1 10463.7   1109.1  10500.0   1125.1 10532.0   1125.6 10533.0
NH      3   .035    9500.0     .03  10638.6    .035   10670.3
X1  10720        1110168.2 10637.7   400.00   400.00   400.00
GR1126.7   9468.2   1110.8  9500.0   1110.8  10140.0   1110.8 10165.0   1110.8 10168.2
GR1104.6  10180.7   1104.6 10625.2   1110.8  10637.7   1110.8 10638.6   1126.2 10669.3
GR1126.7  10670.3
NH      3   .035    9486.9     .03  10979.6    .035   11011.0
X1  11120        1110337.0 10795.4   400.00   400.00   400.00
GR1128.3   9455.4   1112.6  9486.9   1112.6  10130.0   1112.6 10320.0   1112.6 10337.0
GR1106.0  10350.6   1106.0 10782.3   1112.6  10795.4   1112.6 10979.6   1127.8 11010.0
GR1128.3  11011.0
NH      5   .035    9446.7     .03  10090.0    .035   10235.0     .03  11132.8    .035
NH11164.
X1  11320        13 10409.3 10861.9      200      190      200
GR1129.1   9415.4   1113.4  9446.7   1113.4  10090.0   1133.0 10120.0   1133.0 10185.0
GR1113.4  10235.0   1113.4 10390.0   1113.4  10409.3   1106.8 10422.6   1106.8 10848.6
GR1113.4  10861.9   1113.4 11132.8   1129.1  11164.
NH      5   .035   9382.5     .03   10073.0    .035   10490.6     .03  11293.0    .035
NH11324.
X1  11520        1210477.0 10927.7   200.00   190.00   200.00
GR1129.9   9351.3   1114.3  9382.5   1114.3  10073.0   1125.0 10160.0   1132.0 10250.0
GR1132.0  10440.0   1114.3 10477.0   1107.5  10490.6   1107.5 10914.1   1114.3 10927.7
GR1114.3  11293.0   1129.9 11324.
NH      3   .035    9300.9     .03  11468.5    .035   11499.6
X1  11720        13 10546.4 10997.6      200      200      210
GR1130.7   9269.9   1115.2  9300.9   1115.2  10180.0   1117.4 10250.0   1118.0 10300.0
GR1117.4  10350.0   1115.2 10420.0   1115.2  10546.4   1108.3 10560.2   1108.3 10983.7
GR1115.2  10997.6   1115.2 11468.5   1130.7  11499.6
NH      3   .035    9113.3     .03  11694.7    .035   11724.3
X1  12120        1010685.1 11137.4   400.00   400.00   420.00
GR1131.7   9083.7   1131.2  9084.7   1116.9   9113.3   1116.9 10685.1   1109.7 10699.5
GR1109.7  11123.0   1116.9 11137.4   1116.9  11694.7   1131.2 11723.3   1131.7 11724.3
NH      3   .035    8925.5     .03  11840.8    .035   11867.9
X1  12520        1010823.8 11277.2   400.00   400.00   420.00
GR1132.2   8898.5   1131.7  8899.5   1118.6   8925.5   1118.6 10823.8   1111.2 10838.7
GR1111.2  11262.3   1118.6 11277.2   1118.6  11840.8   1131.7 11866.9   1132.2 11867.9
NH      3   .035    8737.8     .03  11980.6    .035   12005.1
X1  12920        1010962.6 11416.6   400.00   400.00   420.00
GR1132.6   8713.3   1132.1  8714.3   1120.4   8737.8   1120.4 10962.6   1112.7 10978.0
GR1112.7  11401.1   1120.4 11416.6   1120.4  11980.6   1132.1 12004.1   1132.6 12005.1
NH      3   .035    9220.0     .03  12230.0    .035   12240.0
X1  13520        14 11180.0 11680.0      680      625      650
GR1136.0   7100.0   1130.0  9220.0   1121.0   9320.0   1121.1  9350.0   1125.1  9402.0
GR1126.5   9530.0   1126.5 11180.0   1117.7  11340.0   1117.7 11610.0   1124.0 11680.0
GR1125.2  11940.0   1122.5 12120.0   1126.1  12230.0   1133.3 12240.0
NH      9   .035    8260.0     .03   8420.0    .035    8990.0     .03   9215.0   .035
NH9850.0    .03    10960.0    .035  11120.0     .03   12535.0    .035  12550.0
X1  14120        23 11120.0 12535.0      750      810      800
GR1138.0  8225.0 1126.0   8260.0   1126.0   8355.0   1134.0  8420.0   1136.0  8520.0
GR1136.0  8760.0 1132.0   8990.0   1126.0   9025.0   1126.0  9055.0   1128.5  9215.0
GR1134.5   9230.0   1134.5  9820.0   1124.5   9850.0   1127.0  9960.0   1124.2 10650.0
GR1127.0  10945.0   1131.2 10960.0   1134.5  11120.0   1117.8 11570.0   1117.8 11680.
GR1122.7  11860.0   1128.2 12535.0   1134.8  12550.0
NH      7   .035    1140.0     .03   3580.0    .035    4080.0     .03   5420.0   .035
NH6210.0    .03     6670.0    .035   7920.0
X1  14420        17  5770.0  6670.0      580     1150     1060
GR1137.1       0.   1130.0  1140.0   1129.6   1560.0   1129.3  2240.0   1130.6  2580.0
GR1127.9   2640.0   1129.5  3580.0   1132.7   3610.0   1134.0  4080.0   1126.8  4410.0
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NH      7  .035    2227.0  .03      2791.0  .035      3740.0  .03      5188.0  .035
NH5594.0 .03     6741.0  .035     6782.0
X1 15580       26  5965.0  6619.0     1120     1100     1120
GR1139.7  1500.0  1131.7  2227.0  1133.1  2578.0  1131.5  2700.0  1124.4  2733.0
GR1125.0  2791.0  1139.1  2966.0  1138.3  3610.0  1134.3  3740.0  1126.2  3821.0
GR1126.8  3874.0  1135.0  3909.0  1136.0  4040.0  1128.3  4192.0  1129.2  5188.0
GR1137.5  5308.0  1137.1  5560.0  1130.4  5594.0  1135.4  5965.0  1126.6  6033.0
GR1126.6  6298.0  1121.3  6379.0  1129.4  6609.0  1133.7  6619.0  1135.6  6741.0
GR1144.0  6782.0
NH      7  .035    2882.0  .03      3176.0  .035      3880.0  .03      4090.0  .035
NH4660.0 .03     6769.0  .035     6970.0
X1 16760       25  5372.0  6769.0     1200     1240     1260
GR1143.7  1432.0  1136.8  2882.0  1134.7  2992.0  1129.4  3004.0  1128.0  3049.0
GR1132.6  3176.0  1139.6  3237.0  1138.7  3858.0  1132.5  3880.0  1132.5  4090.0
GR1141.0  4144.0  1141.0  4634.0  1134.0  4660.0  1134.0  5320.0  1138.4  5372.0
GR1137.5  5835.0  1132.1  6137.0  1126.3  6314.0  1126.3  6391.0  1131.0  6500.0
GR1129.2  6612.0  1126.8  6664.0  1126.8  6748.0  1142.9  6769.0  1146.6  6970.0
NH      5  .035    3309.0  .03      3840.0  .035      4723.0  .03      7018.0  .035
NH7030.0
X1 17920       16  4705.0  5580.0     1180     1640     1640
GR1144.9  1364.0  1138.9  3309.0  1133.0  3340.0  1133.0  3840.0  1143.6  4074.0
GR1144.4  4705.0  1131.3  4723.0  1131.3  5141.0  1139.5  5580.0  1138.4  6625.0
GR1134.9  6642.0  1132.0  6802.0  1132.0  6898.0  1141.9  6921.0  1141.9  7018.0
GR1151.5  7030.0
NH      5  .035    2380.0  .03      5160.0  .035      5280.0  .03      6196.0  .035
NH6423.0
X1 19070       14  3604.0  5160.0     1200     1240     1300
GR1149.4  1588.0  1143.8  2380.0  1141.2  3604.0  1129.7  3662.0  1136.7  4099.0(
GR1134.3  4268.0  1131.5  4641.0  1141.0  5160.0  1140.0  5280.0  1136.4  5342.0
GR1137.0  5990.0  1132.0  6113.0  1132.0  6196.0  1152.0  6423.0
NH      5  .035    3570.0  .03      4055.0  .035      4189.0  .03      6297.0  .035
NH6333.0
X1 20080       16  4055.0  5059.0     1000     1050     1000
GR1150.0  2141.0  1146.5  2307.0  1143.5  3570.0  1134.0  3652.0  1134.0  3814.0
GR1145.9  4055.0  1145.3  4189.0  1132.0  4250.0  1131.2  4669.0  1134.7  4925.0
GR1142.2  5059.0  1142.1  5290.0  1136.5  5490.0  1142.7  5564.0  1142.2  6297.0
GR1153.5  6333.0
NH      5  .035    3030.0  .03      3419.0  .035      3766.0  .03      6053.0  .035
NH6103.0
X1 21180       13  3848.0  4681.0     1100     1100     1100
GR1152.2  2282.0  1147.4  3030.0  1140.6  3284.0  1149.3  3419.0  1152.4  3766.0
GR1151.8  3848.0  1129.0  4130.0  1132.1  4630.0  1140.9  4681.0  1144.5  4800.
GR1147.5  5620.0  1145.4  6053.0  1152.0  6103.0
EJ


ER
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Output

During the program execution all output is written on TAPE 6 and it is printed after the simulation is totally completed. First the general information concerning the temporal and spatial design of the river reach is given. This includes the number of cross sections (NCS), the number of time periods (NTP), the time increment length (DT) in seconds and for each cross section the river mile (RD(I)), the reach length to the downstream cross section (CX(I)) and the thalweg elevation (ZMIN(I)).

The coefficients and exponents of the various power functions are then printed out. A1(I) and B1(I) are respectively the coefficient and the power of the flow area versus flow depth relation, A2(I) and B2(I) of the wetted perimeter relation, A3(I) and B3(I) of the total conveyance relation, A4(I) and B4(I) of the hydraulic radius relation and B5(I) is the power of the channel roughness versus discharge relation (used to evaluate the flood wave celerity). All coefficients and exponents may change in time because of bed elevation changes. These are only given for the initial conditions.

The output of the above coefficients are followed by the correlation coefficients (RCK(I)) and the standard deviations (SD(I)) for those power functions which have been computed by a least squares regression curve fitting technique.

Next the coefficient (FA) and exponent (FB) of the channel roughness-discharge relations is printed.

The results of the model simulation are then printed for each time level. These include for each cross section of the total discharge velocity, the flow area, the total energy slope, the water surface elevation, the flow depth, the instantaneous bed elevation change, the new thalweg elevation and the cumulative bed elevation change. Following this table the total sediment transport, the sediment transport by sizes and the adjusted percentages of bed material in each size fraction is printed for each reach. To conclude each time step the cross-sectional area change for each reach is printed. An example of time steps 15 and 40 are given representing the flood peak and the final time step.

After the water and sediment routing is completed the final cross-sections are printed showing how each cross-section has responded to the changing bed elevation.

**** GENERAL INFORMATION ****

NUMBER OF CROSS SECTIONS = 41
NUMBER OF TIME PERIODS = 40
TIME INCREMENT = 21600.00

CROSS SECTION NUMBER	RIVER MILE	REACH LENGTH	THALWEG ELEVATION
1	0.	0.	.1079E+04
2	.2841E-01	.1500E+03	.1079E+04
3	.8523E-01	.3000E+03	.1080E+04
4	.1515E+00	.3500E+03	.1080E+04
5	.1723E+00	.1100E+03	.1080E+04
6	.2879E+00	.6100E+03	.1081E+04
7	.3636E+00	.4000E+03	.1081E+04
8	.4773E+00	.6000E+03	.1082E+04
9	.5909E+00	.6000E+03	.1084E+04
10	.6667E+00	.4000E+03	.1086E+04
11	.8030E+00	.7200E+03	.1087E+04
12	.9167E+00	.6000E+03	.1089E+04
13	.1030E+01	.6000E+03	.1090E+04
14	.1144E+01	.6000E+03	.1092E+04
15	.1309E+01	.8700E+03	.1094E+04
16	.1384E+01	.4000E+03	.1095E+04
17	.1422E+01	.2000E+03	.1096E+04
18	.1451E+01	.1500E+03	.1096E+04
19	.1489E+01	.2000E+03	.1097E+04
20	.1564E+01	.4000E+03	.1098E+04
21	.1689E+01	.6600E+03	.1099E+04
22	.1803E+01	.6000E+03	.1101E+04
23	.1917E+01	.6000E+03	.1103E+04
24	.1955E+01	.2000E+03	.1103E+04
25	.2030E+01	.4000E+03	.1105E+04
26	.2106E+01	.4000E+03	.1106E+04
27	.2144E+01	.2000E+03	.1107E+04
28	.2182E+01	.2000E+03	.1108E+04
29	.2220E+01	.2000E+03	.1108E+04
30	.2295E+01	.4000E+03	.1110E+04
31	.2371E+01	.4000E+03	.1111E+04
32	.2447E+01	.4000E+03	.1113E+04
33	.2561E+01	.6000E+03	.1118E+04
34	.2674E+01	.6000E+03	.1118E+04
35	.2731E+01	.3000E+03	.1118E+04
36	.2951E+01	.1160E+04	.1121E+04
37	.3174E+01	.1180E+04	.1126E+04
38	.3394E+01	.1160E+04	.1131E+04
39	.3612E+01	.1150E+04	.1130E+04
40	.3803E+01	.1010E+04	.1131E+04
41	.4011E+01	.1100E+04	.1129E+04

COEFFICIENTS OF THE POWER RELATIONS

CROSS SECTION	A1	B1	A2	B2	A3	B3	A4	B4	B5
1	.8662E+03	.1034E+01	.8345E+03	.6928E-01	.4399E+05	.1678E+01	.1038E+01	.9651E+00	0.
2	.8354E+03	.1037E+01	.8036E+03	.7319E-01	.4247E+05	.1679E+01	.1040E+01	.9634E+00	0.
3	.7102E+03	.1069E+01	.5771E+03	.2021E+00	.4040E+05	.1646E+01	.1231E+01	.8666E+00	0.
4	.4445E+03	.1232E+01	.3212E+03	.4338E+00	.2735E+05	.1765E+01	.1384E+01	.7987E+00	0.
5	.4445E+03	.1232E+01	.3212E+03	.4338E+00	.2735E+05	.1765E+01	.1384E+01	.7987E+00	0.
6	.5995E+03	.1097E+01	.4080E+03	.3199E+00	.3838E+05	.1614E+01	.1469E+01	.7767E+00	0.
7	.3951E+03	.1330E+01	.7993E+03	.1685E+00	.1225E+05	.2104E+01	.4943E+00	.1161E+01	0.
8	.2578E+03	.1441E+01	.3922E+03	.4115E+00	.9654E+04	.2127E+01	.6572E+00	.1029E+01	0.
9	.3306E+03	.1390E+01	.5296E+03	.3264E+00	.1197E+05	.2099E+01	.6243E+00	.1064E+01	0.
10	.2395E+03	.1464E+01	.4179E+03	.3747E+00	.8180E+04	.2191E+01	.5731E+00	.1090E+01	0.
11	.2193E+03	.1492E+01	.2440E+03	.5616E+00	.1011E+05	.2112E+01	.8985E+00	.9305E+00	0.
12	.2213E+03	.1498E+01	.2489E+03	.5585E+00	.1013E+05	.2125E+01	.8891E+00	.9400E+00	0.
13	.2280E+03	.1468E+01	.2531E+03	.5283E+00	.1054E+05	.2095E+01	.9010E+00	.9398E+00	0.
14	.2526E+03	.1399E+01	.2830E+03	.4619E+00	.1160E+05	.2024E+01	.8927E+00	.9371E+00	0.
15	.2532E+03	.1398E+01	.2845E+03	.4615E+00	.1159E+05	.2023E+01	.8898E+00	.9369E+00	0.
16	.2536E+03	.1394E+01	.2834E+03	.4571E+00	.1167E+05	.2019E+01	.8951E+00	.9372E+00	0.
17	.2797E+03	.1309E+01	.3022E+03	.3711E+00	.1315E+05	.1934E+01	.9254E+00	.9377E+00	0.
18	.2779E+03	.1315E+01	.3015E+03	.3772E+00	.1304E+05	.1940E+01	.9217E+00	.9377E+00	0.
19	.2615E+03	.1369E+01	.2909E+03	.4325E+00	.1207E+05	.1994E+01	.8991E+00	.9369E+00	0.
20	.2542E+03	.1397E+01	.2873E+03	.4609E+00	.1160E+05	.2022E+01	.8847E+00	.9364E+00	0.
21	.2553E+03	.1396E+01	.2907E+03	.4601E+00	.1160E+05	.2020E+01	.8784E+00	.9359E+00	0.
22	.2605E+03	.1390E+01	.2982E+03	.4544E+00	.1179E+05	.2014E+01	.8735E+00	.9355E+00	0.
23	.2762E+03	.1372E+01	.3164E+03	.4365E+00	.1249E+05	.1996E+01	.8729E+00	.9356E+00	0.
24	.2845E+03	.1363E+01	.3255E+03	.4274E+00	.1287E+05	.1987E+01	.8742E+00	.9357E+00	0.
25	.2809E+03	.1401E+01	.3330E+03	.4669E+00	.1241E+05	.2024E+01	.8435E+00	.9344E+00	0.
26	.2264E+03	.1540E+01	.2964E+03	.6039E+00	.9347E+04	.2163E+01	.7638E+00	.9356E+00	0.
27	.2123E+03	.1574E+01	.2529E+03	.6493E+00	.9344E+04	.2190E+01	.8396E+00	.9244E+00	0.
28	.2076E+03	.1577E+01	.2508E+03	.6734E+00	.9048E+04	.2180E+01	.8279E+00	.9038E+00	0.
29	.1749E+03	.1720E+01	.1613E+03	.9202E+00	.9141E+04	.2253E+01	.1084E+01	.7999E+00	0.
30	.1591E+03	.1800E+01	.1487E+03	.1015E+01	.8258E+04	.2323E+01	.1070E+01	.7846E+00	0.
31	.1530E+03	.1842E+01	.1455E+03	.1083E+01	.7855E+04	.2348E+01	.1052E+01	.7589E+00	0.
32	.1464E+03	.1868E+01	.1451E+03	.1143E+01	.7325E+04	.2352E+01	.1009E+01	.7254E+00	0.
33	.1029E+03	.1971E+01	.9184E+02	.1379E+01	.5500E+04	.2365E+01	.1120E+01	.5921E+00	0.
34	.5203E+02	.2201E+01	.7078E+02	.1403E+01	.2099E+04	.2733E+01	.7351E+00	.7982E+00	0.
35	.3705E+02	.2413E+01	.6672E+02	.1461E+01	.1240E+04	.3048E+01	.5554E+00	.9526E+00	0.
36	.9074E+01	.2853E+01	.2179E+02	.1873E+01	.2511E+03	.3506E+01	.4165E+00	.9797E+00	0.
37	.7188E+02	.2150E+01	.1009E+03	.1356E+01	.2841E+04	.2679E+01	.7121E+00	.7936E+00	0.
38	.3305E+03	.1767E+01	.5472E+03	.8112E+00	.1172E+05	.2405E+01	.6041E+00	.9562E+00	0.
39	.3396E+02	.2474E+01	.1137E+03	.1291E+01	.7518E+03	.3263E+01	.2986E+00	.1183E+01	0.
40	.1956E+03	.1755E+01	.2170E+03	.9735E+00	.9044E+04	.2275E+01	.9016E+00	.7811E+00	0.
41	.1102E+03	.1693E+01	.1195E+03	.9388E+00	.5167E+04	.2195E+01	.9216E+00	.7538E+00	0.

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CORRELATION COEFFICIENT AND STANDARD DEVIATION FOR THE COEFFICIENTS OF THE POWER RELATIONS

CROSS SECTION	RCK1	SD1	RCK2	SD2
1	.9999E+00	.8335E-02	.9578E+00	.1617E-01
2	.9999E+00	.8838E-02	.9581E+00	.1701E-01
3	.9991E+00	.3480E-01	.7866E+00	.1234E+00
4	.9949E+00	.9711E-01	.8860E+00	.1765E+00
5	.9949E+00	.9711E-01	.8860E+00	.1765E+00
6	.9974E+00	.6215E-01	.7764E+00	.2019E+00
7	.9972E+00	.7695E-01	.8689E+00	.7462E-01
8	.9997E+00	.2961E-01	.9689E+00	.8173E-01
9	.9994E+00	.3767E-01	.9428E+00	.8969E-01
10	.9975E+00	.8017E-01	.7837E+00	.2309E+00
11	.9965E+00	.9740E-01	.8754E+00	.2411E+00
12	.9959E+00	.1053E+00	.8610E+00	.2565E+00
13	.9963E+00	.9800E-01	.8647E+00	.2386F+00
14	.9976E+00	.7603E-01	.8685E+00	.2050E+00
15	.9976E+00	.7614E-01	.8681E+00	.2052E+00
16	.9976E+00	.7499E-01	.8691E+00	.2022E+00
17	.9984E+00	.5703E-01	.8834E+00	.1530F+00
18	.9984E+00	.5846E-01	.8815E+00	.1571E+00
19	.9978E+00	.7009E-01	.8719E+00	.1889E+00
20	.9975E+00	.7662E-01	.8675F+00	.2055E+00
21	.9974E+00	.7785E-01	.8668E+00	.2058E+00
22	.9973E+00	.7895E-01	.8665E+00	.2036E+00
23	.9973E+00	.7851E-01	.8668E+00	.1952E+00
24	.9973E+00	.7772E-01	.8671E+00	.1909E+00
25	.9961E+00	.9614E-01	.8612E+00	.2142E+00
26	.9921E+00	.1514E+00	.8521E+00	.2884E+00
27	.9956E+00	.1150E+00	.8643E+00	.2937E+00
28	.9942E+00	.1332E+00	.8815E+00	.2805E+00
29	.9873E+00	.2152E+00	.8730E+00	.3996E+00
30	.9855E+00	.2410E+00	.8667E+00	.4544E+00
31	.9836E+00	.2625E+00	.8657E+00	.4868E+00
32	.9763E+00	.3221E+00	.8649E+00	.5157E+00
33	.9812E+00	.3011E+00	.9571E+00	.3244E+00
34	.9914E+00	.2260E+00	.9745E+00	.2509E+00
35	.9902E+00	.2642E+00	.9431E+00	.4002E+00
36	.9978E+00	.1487E+00	.9862E+00	.2447E+00
37	.9953E+00	.1630E+00	.9866E+00	.1746E+00
38	.9973E+00	.1014E+00	.9614E+00	.1804E+00
39	.9962E+00	.1676E+00	.9814E+00	.1961E+00
40	.9942E+00	.1473E+00	.9668E+00	.2001E+00
41	[illegible]	[illegible]	[illegible]	[illegible]

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COEFFICIENTS OF THE CHANNEL ROUGHNESS - DISCHARGE RELATION

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FA1 =      .030000000
FB1 =     0.000000000
FA2 =      .030000000
FB2 =     0.000000000
FA3 =      .030000000
FB3 =     0.000000000
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*** RESULTS FOR EACH TIME PERIOD ***

TIME PERIOD = 15

SECTION	DISCHARGE	VELOCITY	AREA	SLOPE	WS ELEV	DEPTH	INST DZ	THALWEG	CUM DZ
41	166320.	10.36	16054.	.002751	1147.98	18.98	.00	1129.00	0.00
40	166368.	6.75	24665.	.001222	1146.95	15.75	.00	1131.20	0.00
39	166354.	6.43	25890.	.001364	1145.71	13.28	.49	1132.92	3.22
38	166213.	7.15	23235.	.002059	1143.44	7.28	.87	1137.03	5.74
37	166107.	8.56	19399.	.003129	1140.11	12.88	.15	1127.39	1.09
36	166345.	7.55	22044.	.002353	1136.99	13.67	.33	1123.65	2.36
35	167036.	5.02	33277.	.000716	1135.74	15.77	.24	1120.21	1.72
34	167221.	5.80	28832.	.001786	1135.38	17.92	-.04	1117.42	-.37
33	167355.	15.65	10695.	.012564	1127.98	11.31	-.13	1116.54	-1.09
32	167287.	8.98	18635.	.002248	1125.90	14.24	-.14	1111.52	-1.14
31	167212.	8.28	20195.	.001873	1125.23	15.08	-.14	1110.02	-1.14
30	167142.	7.98	20935.	.001468	1124.48	15.83	-.14	1108.51	-1.14
29	167107.	8.64	19351.	.002048	1123.41	16.35	-.18	1106.88	-1.44
28	167091.	11.12	15022.	.002492	1122.18	15.93	-.18	1106.07	-1.45
27	167072.	10.61	15742.	.002191	1121.83	16.28	-.18	1105.38	-1.44
26	167070.	10.13	16497.	.001951	1121.90	17.13	-.18	1104.59	-1.43
25	167067.	12.10	13810.	.002245	1120.37	16.97	-.17	1103.22	-1.39
24	167063.	12.53	13335.	.002245	1119.22	17.37	-.18	1101.67	-1.45
23	167067.	12.62	13234.	.002258	1118.52	17.32	-.18	1101.02	-1.58
22	167107.	12.59	13268.	.002271	1117.03	17.47	-.19	1099.37	-1.64
21	167179.	12.35	13541.	.002101	1115.71	17.77	-.19	1097.75	-1.66
20	167275.	12.22	13686.	.002113	1114.15	17.91	-.19	1096.05	-1.66
19	167362.	13.00	12870.	.003501	1112.68	17.85	-.24	1094.59	-2.11
18	167423.	16.71	10020.	.004375	1110.11	15.79	-.24	1094.09	-2.11
17	167465.	16.39	10218.	.005646	1110.08	16.15	-.24	1093.69	-2.11
16	167501.	13.20	12692.	.002442	1110.62	17.19	-.24	1093.19	-2.11
15	167529.	13.39	12515.	.002659	1109.46	16.87	-.23	1092.36	-1.85
14	167519.	14.59	11481.	.003555	1106.43	16.04	-.23	1090.16	-1.85
13	167529.	13.18	12712.	.002836	1105.25	15.85	-.11	1089.29	-1.11
12	167571.	11.77	14239.	.002047	1104.41	16.61	-.11	1087.70	-1.11
11	167626.	12.06	13897.	.002170	1102.86	16.56	-.11	1086.19	-1.11
10	167748.	11.88	14121.	.002172	1101.15	16.66	-.11	1084.39	-1.11
9	167797.	11.26	14902.	.002061	1100.17	15.38	-.10	1084.69	.19
8	167822.	10.80	15534.	.001832	1099.09	16.88	-.19	1082.02	.32
7	167884.	9.71	17288.	.001635	1098.42	17.06	-.10	1081.26	.16
6	167934.	12.93	12985.	.002264	1096.46	16.60	-.13	1079.72	-.99
5	168045.	13.51	12436.	.002899	1094.23	15.05	-.13	1079.06	-.95
4	168072.	13.87	12119.	.002966	1093.92	14.73	-.13	1079.06	-.95
3	168147.	13.65	12314.	.002757	1093.29	14.48	-.01	1078.80	-.79
2	168181.	13.26	12685.	.002404	1092.33	13.81	-.01	1078.51	-.79
1	168188.	13.15	12787.	.002351	1091.86	13.51	-.01	1078.43	-.77

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 1 G(IR),GS(IR,M) :   .366E+03   .314E+03   .138E+02   .114E+02   .975E+01   .101E+02   .612E+01   .136E+01   .455E+00 0.          0.
SEDIMENT PERCENTAGES :           .057       .069       .087       .089       .103       .095       .072       .133       .147       .147
 2 G(IR),GS(IR,M) :   .366E+03   .314E+03   .138E+02   .113E+02   .957E+01   .101E+02   .635E+01   .933E+00   .602E+00 0.          0.
SEDIMENT PERCENTAGES :           .058       .070       .088       .088       .102       .096       .065       .136       .149       .149
 3 G(IR),GS(IR,M) :   .363E+03   .313E+03   .135E+02   .110E+02   .897E+01   .960E+01   .638E+01 0.          0.          0.          0.
SEDIMENT PERCENTAGES :           .036       .068       .071       .075       .127       .193       .158       .090       .090       .090
 4 G(IR),GS(IR,M) :   .359E+03   .313E+03   .126E+02   .101E+02   .681E+01   .725E+01   .576E+01   .303E+01 0.          0.          0.
SEDIMENT PERCENTAGES :           .045       .061       .074       .066       .082       .096       .164       .153       .130       .130
 5 G(IR),GS(IR,M) :   .356E+03   .313E+03   .121E+02   .985E+01   .574E+01   .582E+01   .406E+01   .311E+01   .197E+01 0.          0.
SEDIMENT PERCENTAGES :           .061       .068       .083       .074       .080       .079       .092       .153       .156       .154
 6 G(IR),GS(IR,M) :   .352E+03   .313E+03   .118E+02   .966E+01   .537E+01   .522E+01   .349E+01   .194E+01   .126E+01   .165E+00 0.
SEDIMENT PERCENTAGES :           .071       .076       .092       .083       .087       .084       .083       .095       .162       .166
 7 G(IR),GS(IR,M) :   .349E+03   .313E+03   .117E+02   .955E+01   .520E+01   .490E+01   .326E+01   .168E+01 0.          0.          0.
SEDIMENT PERCENTAGES :           .059       .074       .087       .073       .080       .082       .107       .146       .146       .146
 8 G(IR),GS(IR,M) :   .345E+03   .313E+03   .113E+02   .937E+01   .470E+01   .377E+01   .239E+01 0.          0.          0.          0.
SEDIMENT PERCENTAGES :           .062       .080       .084       .067       .074       .087       .137       .137       .137       .137
 9 G(IR),GS(IR,M) :   .341E+03   .313E+03   .109E+02   .920E+01   .434E+01   .232E+01   .114E+01 0.          0.          0.          0.
SEDIMENT PERCENTAGES :           .076       .076       .074       .060       .063       .121       .132       .132       .132       .132
10 G(IR),GS(IR,M) :   .337E+03   .313E+03   .105E+02   .897E+01   .414E+01   .341E-01 0.          0.          0.          0.          0.
SEDIMENT PERCENTAGES :           .294       .072       .074       .077       .080       .081       .081       .081       .081       .081
11 G(IR),GS(IR,M) :   .355E+03   .330E+03   .114E+02   .969E+01   .411E+01 0.          0.          0.          0.          0.          0.
SEDIMENT PERCENTAGES :           .400       .082       .084       .090       .071       .054       .054       .054       .054       .054
12 G(IR),GS(IR,M) :   .402E+03   .357E+03   .171E+02   .151E+02   .973E+01   .363E+01 0.          0.          0.          0.          0.
SEDIMENT PERCENTAGES :           .100       .100       .100       .100       .100       .100       .100       .100       .100       .100
   AREA CHANGES (SQ FT) :  -14.   -107.   -92.   -45.   -98.   -101.   -81.   -82.   -63.   217.
   AREA CHANGES (SQ FT) :  762.     0.
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?

TIME PERIOD = 40

SECTION	DISCHARGE	VELOCITY	AREA	SLOPE	WS ELEV	DEPTH	INST DZ	THALWEG	CUM DZ
41	4400.	1.02	4326.	.000054	1137.75	8.75	.00	1129.00	0.00
40	4430.	.86	5128.	.000051	1137.63	6.43	.00	1131.20	0.00
39	4681.	1.19	3941.	.000188	1137.09	6.49	-.00	1130.59	.89
38	5008.	4.36	1149.	.004760	1134.32	1.42	-.01	1132.89	1.60
37	4939.	2.78	1777.	.001124	1131.05	4.36	-.00	1126.69	.39
36	3949.	5.17	764.	.005354	1126.74	4.55	-.00	1122.19	.89
35	2776.	2.12	1307.	.000664	1123.46	4.30	-.00	1119.15	.65
34	2887.	.89	3247.	.000439	1123.80	6.69	.00	1117.11	-.68
33	3432.	9.91	346.	.015844	1117.63	1.98	.00	1115.66	-1.98
32	3847.	4.87	789.	.002826	1113.17	2.62	.00	1110.55	-2.10
31	4132.	6.04	684.	.005748	1111.46	2.41	.00	1109.05	-2.11
30	4354.	4.27	1020.	.002284	1110.51	2.98	.00	1107.54	-2.11
29	4533.	5.69	797.	.004608	1109.09	2.53	-.01	1106.55	-1.78
28	4614.	4.78	966.	.002880	1108.55	2.80	-.01	1105.74	-1.78
27	4685.	5.30	883.	.004838	1107.71	2.66	-.01	1105.05	-1.77
26	4757.	6.01	791.	.005475	1106.62	2.35	-.01	1104.26	-1.76
25	4903.	4.52	1084.	.002491	1105.66	2.74	-.01	1102.91	-1.71
24	5006.	3.28	1528.	.001098	1104.90	3.55	-.01	1101.34	-1.78
23	5072.	3.91	1296.	.001769	1104.13	3.18	-.00	1100.95	-1.66
22	5319.	5.04	1056.	.003422	1102.12	2.83	-.00	1099.29	-1.72
21	5506.	4.29	1282.	.002086	1100.96	3.28	-.00	1097.67	-1.73
20	5667.	5.20	1090.	.003499	1098.90	2.93	-.00	1095.97	-1.73
19	5724.	4.72	1212.	.002549	1097.96	3.16	.00	1094.80	-1.90
18	5712.	4.57	1249.	.002272	1097.52	3.22	.00	1094.30	-1.90
17	5696.	4.36	1307.	.001974	1097.23	3.33	.00	1093.90	-1.90
16	5679.	4.06	1399.	.001667	1096.92	3.52	.00	1093.40	-1.90
15	5655.	4.51	1254.	.002295	1095.69	3.24	.01	1092.46	-1.75
14	5648.	3.85	1467.	.001458	1093.92	3.67	.01	1090.26	-1.75
13	5712.	4.45	1284.	.002098	1092.38	3.34	.00	1089.04	-1.36
12	5823.	4.40	1324.	.002059	1090.86	3.42	.00	1087.44	-1.36
11	5883.	4.60	1278.	.002299	1089.29	3.35	.00	1085.94	-1.36
10	5842.	3.20	1827.	.001033	1088.34	4.20	.00	1084.14	-1.37
9	5775.	4.66	1239.	.004369	1086.79	2.60	-.00	1084.19	-.31
8	5615.	3.20	1754.	.001004	1084.99	3.89	-.00	1081.10	-.60
7	5364.	4.22	1272.	.004313	1083.22	2.43	-.00	1080.79	-.31
6	5213.	3.06	1706.	.000859	1082.51	2.60	-.00	1079.92	-.79
5	5094.	3.76	1353.	.001538	1081.74	2.47	-.00	1079.27	-.74
4	5076.	4.48	1132.	.002436	1081.42	2.14	-.00	1079.28	-.73
3	5050.	3.37	1500.	.001574	1080.95	2.01	.01	1078.95	-.65
2	5074.	3.08	1648.	.001612	1080.55	1.93	.01	1078.63	-.67
1	5087.	3.44	1479.	.002351	1080.08	1.68	.01	1078.55	-.65

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 1 G(IR),GS(IR,M) :  .333E+00  .162E+00  .145E+00  .260E-01 0.        0.        0.        0.        0.        0.        0.
SEDIMENT PERCENTAGES :         .091      .101      .101      .073      .084      .096      .050      .124      .139      .139
 2 G(IR),GS(IR,M) :  .446E+00  .192E+00  .188E+00  .656E-01 0.        0.        0.        0.        0.        0.        0.
SEDIMENT PERCENTAGES :         .098      .116      .112      .073      .076      .086      .043      .123      .137      .137
 3 G(IR),GS(IR,M) :  .444E+00  .166E+00  .197E+00  .806E-01 0.        0.        0.        0.        0.        0.        0.
SEDIMENT PERCENTAGES :         .040      .057      .053      .036      .064      .179      .236      .112      .112      .112
 4 G(IR),GS(IR,M) :  .426E+00  .154E+00  .194E+00  .784E-01 0.        0.        0.        0.        0.        0.        0.
SEDIMENT PERCENTAGES :         .069      .091      .081      .053      .054      .069      .152      .161      .134      .134
 5 G(IR),GS(IR,M) :  .427E+00  .153E+00  .197E+00  .769E-01 0.        0.        0.        0.        0.        0.        0.
SEDIMENT PERCENTAGES :         .083      .108      .096      .064      .061      .067      .074      .146      .152      .149
 6 G(IR),GS(IR,M) :  .626E+00  .244E+00  .266E+00  .116E+00 0.        0.        0.        0.        0.        0.        0.
SEDIMENT PERCENTAGES :         .099      .124      .111      .072      .068      .070      .067      .078      .153      .157
 7 G(IR),GS(IR,M) :  .651E+00  .260E+00  .267E+00  .124E+00 0.        0.        0.        0.        0.        0.        0.
SEDIMENT PERCENTAGES :         .081      .104      .092      .059      .061      .071      .093      .146      .146      .146
 8 G(IR),GS(IR,M) :  .625E+00  .259E+00  .246E+00  .120E+00 0.        0.        0.        0.        0.        0.        0.
SEDIMENT PERCENTAGES :         .070      .090      .080      .051      .055      .078      .144      .144      .144      .144
 9 G(IR),GS(IR,M) :  .445E+00  .196E+00  .173E+00  .754E-01  .111E-03 0.        0.        0.        0.        0.        0.
SEDIMENT PERCENTAGES :         .060      .073      .063      .047      .052      .121      .146      .146      .146      .146
10 G(IR),GS(IR,M) :  .473E+00  .286E+00  .152E+00  .340E-01 0.        0.        0.        0.        0.        0.        0.
SEDIMENT PERCENTAGES :         .120      .084      .088      .096      .102      .102      .102      .102      .102      .102
11 G(IR),GS(IR,M) :  .306E+00  .196E+00  .110E+00 0.        0.        0.        0.        0.        0.        0.        0.
SEDIMENT PERCENTAGES :         .080      .069      .093      .163      .125      .094      .094      .094      .094      .094
12 G(IR),GS(IR,M) :  .294E-02  .294E-02 0.        0.        0.        0.        0.        0.        0.        0.        0.
SEDIMENT PERCENTAGES :         .100      .100      .100      .100      .100      .100      .100      .100      .100      .100
     AREA CHANGES (SQ FT) :    6.   -0.   -0.    0.    5.    1.   -0.   -4.    0.   -2.
     AREA CHANGES (SQ FT) :   -5.    0.
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FINAL CROSS SECTIONS

	1	0.	0.	1065.						
	0.	1107.00	85.	1078.55	985.	1078.55	1065.	1107.00		
	2	150.	0.	1040.						
	0.	1107.00	85.	1078.63	955.	1078.63	1040.	1107.00		
	3	450.	12.	955.						
	12.	1107.00	110.	1078.95	890.	1078.95	955.	1100.00	1250.	1100.00
1280.	1107.00									
	4	800.	60.	880.						
	0.	1122.80	0.	1118.80	60.	1100.00	120.	1079.28	820.	1079.28
880.	1100.00	1520.	1100.00	1560.	1118.80	1560.	1122.80			
	5	910.	60.	880.						
	0.	1122.80	0.	1118.80	60.	1100.00	120.	1079.27	820.	1079.27
880.	1100.00	1520.	1100.00	1560.	1118.80	1560.	1122.80			
	6	1520.	9695.	10500.						
	9256.	1110.40	9315.	1104.10	9366.	1103.10	9391.	1106.40	9624.	1098.60
9695.	1100.40	9735.	1079.92	10435.	1079.92	10500.	1101.50	10781.	1107.90	
	7	1920.	9935.	10886.						
	9366.	1111.50	9445.	1107.80	9573.	1108.60	9598.	1100.80	9674.	1101.00
9708.	1088.30	9769.	1084.00	9890.	1084.00	9935.	1085.49	9945.	1080.79	
10345.	1080.79	10350.	1083.29	10825.	1083.29	10886.	1105.50	10969.	1106.10	
	8	2520.	9910.	10400.						
	9380.	1111.20	9560.	1109.60	9580.	1102.10	9760.	1087.90	9910.	1086.54
9930.	1081.10	10330.	1081.10	10340.	1090.32	10400.	1087.94	10540.	1084.50	
10650.	1084.50	10700.	1086.40	10770.	1085.90	11000.	1112.20			
	9	3120.	9750.	10650.						
	9370.	1117.00	9440.	1090.20	9630.	1090.20	9750.	1092.68	9890.	1091.88
9910.	1084.19	10310.	1084.19	10320.	1088.39	10350.	1085.99	10600.	1085.99	
10650.	1095.91	10690.	1092.60	10760.	1093.00	10780.	1096.70	10810.	1110.80	
10930.	1114.60									
	10	3520.	9883.	10306.						
	9250.	1116.00	9320.	1091.10	9500.	1091.10	9883.	1089.76	9895.	1084.14
10295.	1084.14	10306.	1089.76	10500.	1091.10	10546.	1114.30	10547.	1114.80	
	11	4240.	9861.	10285.						
	9225.	1115.00	9270.	1097.00	9500.	1093.20	9861.	1091.86	9873.	1085.94
10273.	1085.94	10285.	1091.86	10500.	1093.20	10544.	1115.00	10545.	1115.50	
	12	4840.	9842.	10266.						
	9220.	1117.00	9265.	1094.80	9592.	1094.80	9692.	1094.80	9842.	1093.46
9854.	1087.44	10254.	1087.44	10266.	1093.46	10500.	1094.80	10542.	1115.60	
10543.	1116.10									
	13	5440.	9826.	10250.						
	9300.	1119.00	9350.	1096.40	9500.	1096.40	9826.	1095.06	9838.	1089.04
10238.	1089.04	10250.	1095.06	10500.	1096.40	10540.	1116.20	10541.	1116.70	
	14	6040.	9817.	10241.						
	9461.	1117.30	9500.	1098.00	9715.	1098.00	9755.	1098.00	9817.	1096.33
9829.	1090.26	10229.	1090.26	10241.	1096.33	10500.	1098.00	10538.	1116.80	
10539.	1117.30									
	15	6910.	9803.	10227.						
	9462.	1119.20	9463.	1118.70	9500.	1100.20	9803.	1098.51	9815.	1092.46
10215.	1092.46	10227.	1098.51	10500.	1100.20	10537.	1118.70	10538.	1119.20	
	16	7310.	9797.	10221.						
	9461.	1120.70	9462.	1120.20	9500.	1101.30	9797.	1099.37	9809.	1093.40
10209.	1093.40	10221.	1099.37	10489.	1101.30	10527.	1120.20	10528.	1120.70	
	17	7510.	9794.	10218.						
	9462.	1121.00	9463.	1120.50	9500.	1101.80	9794.	1099.85	9806.	1093.90
10206.	1093.90	10218.	1099.85	10313.	1101.80	10351.	1120.50	10352.	1121.00	
	18	7660.	9791.	10215.						
	9462.	1121.30	9463.	1120.80	9500.	1102.20	9791.	1100.24	9803.	1094.30
10203.	1094.30	10215.	1100.24	10326.	1102.20	10363.	1120.80	10364.	1121.30	
	19	7860.	9788.	10212.						
	9462.	1121.60	9463.	1121.10	9500.	1102.70	9788.	1100.74	9800.	1094.80

10559.	1117.30	[illegible]	[illegible]	10241.	1096.33	[illegible] 10500.	[illegible] 1098.00	1098.00 10538.	9817. 1116.80	1096.33
10215.	15 9462. 1092.46	6910. 1119.20 10227.	9803. 9463. 1098.51	10227. 1118.70 10500.	9500. 1100.20	1100.20 10537.	9803. 1118.70	1098.51 10538.	9815. 1119.20	1092.46
10209.	16 9461. 1093.40	7310. 1120.70 10221.	9797. 9462. 1099.37	10221. 1120.20 10489.	9500. 1101.30	1101.30 10527.	9797. 1120.20	1099.37 10528.	9809. 1120.70	1093.40
10206.	17 9462. 1093.90	7510. 1121.00 10218.	9794. 9463. 1099.85	10218. 1120.50 10313.	9500. 1101.80	1101.80 10351.	9794. 1120.50	1099.85 10352.	9806. 1121.00	1093.90
10203.	18 9462. 1094.30	7660. 1121.30 10215.	9791. 9463. 1100.24	10215. 1120.80 10326.	9500. 1102.20	1102.20 10363.	9791. 1120.80	1100.24 10364.	9803. 1121.30	1094.30
10200.	19 9462. 1094.80	7860. 1121.60 10212.	9788. 9463. 1100.74	10212. 1121.10 10437.	9500. 1102.70	1102.70 10474.	9788. 1121.10	1100.74 10475.	9800. 1121.60	1094.80
10200.	20 9463. 1095.97	8260. 1122.20 10212.	9788. 9464. 1102.00	10212. 1121.70 10500.	9500. 1103.70	1103.70 10536.	9788. 1121.70	1102.00 10537.	9800. 1122.20	1095.97
10196.	21 9464. 1097.67	8920. 1123.30 10208.	9783. 9465. 1103.70	10208. 1122.80 10500.	9500. 1105.40	1105.40 10535.	9783. 1122.80	1103.70 10536.	9795. 1123.30	1097.67
10238.	22 9465. 1099.29	9520. 1124.30 10250.	9821. 9466. 1105.32	10250. 1123.80 10500.	9500. 1107.00	1107.00 10534.	9821. 1123.80	1105.32 10535.	9833. 1124.30	1099.29
10381.	23 9467. 1100.95	10120. 1125.30 10393.	9949. 9468. 1106.98	10393. 1124.80 10500.	9500. 1108.60	1108.60 10532.	9949. 1124.80	1106.98 10533.	9961. 1125.30	1100.95
10452.	24 9467. 1101.34	10320. 1125.60 10464.	10012. 9468. 1107.55	10464. 1125.10 10500.	9500. 1109.10	1109.10 10532.	10012. 1125.10	1107.55 10533.	10024. 1125.60	1101.34
10181. 10670.	25 9468. 1102.91 1126.70	10720. 1126.70 10625.	10168. 9500. 1102.91	10638. 1110.80 10638.	10140. 1109.43	1110.80 10639.	10165. 1110.80	1110.80 10669.	10168. 1126.20	1109.43
10351. 11011.	26 9455. 1104.26 1128.30	11120. 1128.30 10782.	10337. 9487. 1104.26	10795. 1112.60 10795.	10130. 1111.19	1112.60 10980.	10320. 1112.60	1112.60 11010.	10337. 1127.80	1111.19
10235. 10862.	27 9415. 1113.40 1112.03	11320. 1129.10 10390. 11133.	10409. 9447. 1113.40 1113.40	10862. 1113.40 10409. 11164.	10090. 1112.03 1129.10	1113.40 10423.	10120. 1105.05	1133.00 10849.	10185. 1105.05	1133.00
10440. 11293.	28 9351. 1132.00 1114.30	11520. 1129.90 10477. 11324.	10477. 9382. 1112.93 1129.90	10928. 1114.30 10491.	10073. 1105.74	1114.30 10914.	10160. 1105.74	1125.00 10928.	10250. 1112.93	1132.00
10350. 10998.	29 9270. 1117.40 1113.83	11720. 1130.70 10420. 11469.	10546. 9301. 1115.20 1115.20	10998. 1115.20 10546. 11500.	10180. 1113.83 1130.70	1115.20 10560.	10250. 1106.55	1117.40 10984.	10300. 1106.55	1118.00
11123.	30 9084. 1107.54	12120. 1131.70 11137.	10685. 9085. 1115.64	11137. 1131.20 11695.	9113. 1116.90	1116.90 11723.	10685. 1131.20	1115.64 11724.	10700. 1131.70	1107.54
11262.	31 8899. 1109.05	12520. 1132.20 11277.	10824. 8900. 1117.52	11277. 1131.70 11841.	8926. 1118.60	1118.60 11867.	10824. 1131.70	1117.52 11868.	10839. 1132.20	1109.05
11401.	32 8713. 1110.55	12920. 1132.60 11417.	10963. 8714. 1119.32	11417. 1132.10 11981.	8738. 1120.40	1120.40 12004.	10963. 1132.10	1119.32 12005.	10978. 1132.60	1110.55
9530. 11940.	33 7100. 1126.50 1125.20	13520. 1136.00 11180. 12120.	11180. 9220. 1126.15 1122.50	11680. 1130.00 11340. 12230.	9320. 1115.66 1126.10	1121.00 11610. 12240.	9350. 1115.66 1133.30	1121.10 11680.	9402. 1123.17	1125.10
8760. 9230. 10945. [illegible]	34 8225. 1136.00 1134.50 1127.00	14120. 1138.00 8990. 9820. 10960.	11120. 8260. 1132.00 1134.50 [illegible]	12535. 1126.00 9025. 9850. [illegible]	8355. 1126.00 1124.50	1126.00 9055. 9960.	8420. 1126.00 [illegible]	1134.00 9215. [illegible]	8520. 1128.50	1136.00

	9488.	1126.70	9500.	1110.80	10140.	1110.80	10165.	1110.80	10168.	1109.43
10181.	1102.91	10625.	1102.91	10638.	1109.43	10639.	1110.80	10669.	1126.20	
10670.	1126.70									
	26	11120.	10337.	10795.						
	9455.	1128.30	9487.	1112.60	10130.	1112.60	10320.	1112.60	10337.	1111.19
10351.	1104.26	10782.	1104.26	10795.	1111.19	10980.	1112.60	11010.	1127.80	
11011.	1128.30									
	27	11320.	10409.	10862.						
	9415.	1129.10	9447.	1113.40	10090.	1113.40	10120.	1133.00	10185.	1133.00
10235.	1113.40	10390.	1113.40	10409.	1112.03	10423.	1105.05	10849.	1105.05	
10862.	1112.03	11133.	1113.40	11164.	1129.10					
	28	11520.	10477.	10928.						
	9351.	1129.90	9382.	1114.30	10073.	1114.30	10160.	1125.00	10250.	1132.00
10440.	1132.00	10477.	1112.93	10491.	1105.74	10914.	1105.74	10928.	1112.93	
11293.	1114.30	11324.	1129.90							
	29	11720.	10546.	10998.						
	9270.	1130.70	9301.	1115.20	10180.	1115.20	10250.	1117.40	10300.	1118.00
10350.	1117.40	10420.	1115.20	10546.	1113.83	10560.	1106.55	10984.	1106.55	
10998.	1113.83	11469.	1115.20	11500.	1130.70					
	30	12120.	10685.	11137.						
	9084.	1131.70	9085.	1131.20	9113.	1116.90	10685.	1115.64	10700.	1107.54
11123.	1107.54	11137.	1115.64	11695.	1116.90	11723.	1131.20	11724.	1131.70	
	31	12520.	10824.	11277.						
	8899.	1132.20	8900.	1131.70	8926.	1118.60	10824.	1117.52	10839.	1109.05
11262.	1109.05	11277.	1117.52	11841.	1118.60	11867.	1131.70	11868.	1132.20	
	32	12920.	10963.	11417.						
	8713.	1132.60	8714.	1132.10	8738.	1120.40	10963.	1119.32	10978.	1110.55
11401.	1110.55	11417.	1119.32	11981.	1120.40	12004.	1132.10	12005.	1132.60	
	33	13520.	11180.	11680.						
	7100.	1136.00	9220.	1130.00	9320.	1121.00	9350.	1121.10	9402.	1125.10
9530.	1126.50	11180.	1126.15	11340.	1115.66	11610.	1115.66	11680.	1123.17	
11940.	1125.20	12120.	1122.50	12230.	1126.10	12240.	1133.30			
	34	14120.	11120.	12535.						
	8225.	1138.00	8260.	1126.00	8355.	1126.00	8420.	1134.00	8520.	1136.00
8760.	1136.00	8990.	1132.00	9025.	1126.00	9055.	1126.00	9215.	1128.50	
9230.	1134.50	9820.	1134.50	9850.	1124.50	9960.	1127.00	10650.	1124.20	
10945.	1127.00	10960.	1131.20	11120.	1134.29	11570.	1117.11	11680.	1117.11	
11860.	1122.01	12535.	1127.70	12550.	1134.80					
	35	14420.	5770.	6670.						
	0.	1137.10	1140.	1130.00	1560.	1129.60	2240.	1129.30	2580.	1130.60
2640.	1127.90	3580.	1129.50	3610.	1132.70	4080.	1134.00	4410.	1126.80	
5420.	1128.40	5580.	1130.80	5770.	1132.21	6210.	1119.15	6420.	1119.15	
6670.	1133.61	7920.	1153.00							
	36	15580.	5965.	6619.						
	1500.	1139.70	2227.	1131.70	2578.	1133.10	2700.	1131.50	2733.	1124.40
2791.	1125.00	2966.	1139.10	3610.	1138.30	3740.	1134.30	3821.	1126.20	
3874.	1126.80	3909.	1135.00	4040.	1136.00	4192.	1128.30	5188.	1129.20	
5308.	1137.50	5560.	1137.10	5594.	1130.40	5965.	1137.25	6033.	1127.51	
6298.	1127.51	6379.	1122.19	6609.	1130.59	6619.	1136.53	6741.	1135.60	
6782.	1144.00									
	37	16760.	5372.	6769.						
	1432.	1143.70	2882.	1136.80	2992.	1134.70	3004.	1129.40	3049.	1128.00
3176.	1132.60	3237.	1139.60	3858.	1138.70	3880.	1132.50	4090.	1132.50	
4144.	1141.00	4634.	1141.00	4660.	1134.00	5320.	1134.00	5372.	1139.33	
5835.	1138.24	6137.	1132.57	6314.	1126.69	6391.	1126.69	6500.	1131.42	
6612.	1129.60	6664.	1127.19	6748.	1127.19	6769.	1142.90	6970.	1146.60	
	38	17920.	4705.	5580.						
	1364.	1144.90	3309.	1138.90	3340.	1133.00	3840.	1133.00	4074.	1143.60
4705.	1144.40	4723.	1132.89	5141.	1132.89	5580.	1143.46	6625.	1138.40	
6642.	1134.90	6802.	1132.00	6898.	1132.00	6921.	1141.90	7018.	1141.90	
7030.	1151.50									
	39	19070.	3604.	5160.						
	1588.	1149.40	2380.	1143.80	3604.	1143.39	3662.	1130.59	4099.	1137.63
4268.	1135.19	4641.	1132.39	5160.	1142.91	5280.	1140.00	5342.	1136.40	
5990.	1137.00	6113.	1132.00	6196.	1132.00	6423.	1152.00			
	40	20080.	4055.	5059.						
	2141.	1150.00	2307.	1146.50	3570.	1143.50	3652.	1134.00	3814.	1134.00
4055.	1145.90	4189.	1145.30	4250.	1132.00	4669.	1131.20	4925.	1134.70	
5059.	1142.20	5290.	1142.10	5490.	1136.50	5564.	1142.70	6297.	1142.20	
6333.	1153.50									
	41	21180.	3848.	4681.						
	2282.	1152.20	3030.	1147.40	3284.	1140.60	3419.	1149.30	3766.	1152.40
3848.	1151.80	4130.	1129.00	4630.	1132.10	4681.	1140.90	4800.	1144.50	
[illegible]	[illegible]	[illegible]	[illegible]							

APPENDIX C

LIST OF PROGRAM VARIABLES

LIST OF PROGRAM VARIABLES

The following is a list of the variables used in the program. For each variable there is a definition, common block name (if applicable) and array size. If the variable is not in a common block, the subroutine(s) in which the variable is used is shown in brackets under the definition. If a variable's dimension is problem dependent, the array size is given as the name of a program variable that the array size should equal or exceed.

Variable	Array Size	Common Block	Definition
A	NCS,3	//	Flow area in (ft^2).
A			Value of intercept of the least squared regression. [LSQ]
AD	10		Log value of depth. [CHANGEO]
ALPHA		CONST	Velocity head correction coefficient.
ATA	10		Log value of flow area. [CHANGEO]
ATC	NCS	CHANVA	Temporary value used to compute the coefficient of the hydraulic power function for the conveyance relation.
ATP	10		Log value of the wetter perimeter. [CHANGEO]
A1	NCS	CHANVA	Coefficient of the hydraulic power function for the flow area.
A2	NCS	CHANVA	Coefficient of the hydraulic power function for the wetter perimeter.
A3	NCS	CHANVA	Coefficient for the hydraulic power function for the conveyance.
A4	NCS	CHANVE	Coefficient of the hydraulic power function for the hydraulic radius.
B			Slope of the least squared regression value (log value). [LSQ]
BET	NCS	CHANVA	Temporary value for the calculation of BETA.
BETA	NCS	CHANVE	Coefficient for the computation of the Kleitz-Seddon wave celerity.
BSF	NCS		Total energy slope. [BACKW]
BTAV	NCS		Flow area. [BACKW]
BTRV	NCS		Hydraulic radius. [BACKW]
BVV	NCS		Flow velocity value. [BACKW]
B1	NCS	CHANVA	Power of the hydraulic power function for the flow area.

Variable	Array Size	Common Block	Definition
B2	NCS	CHANVA	Power of the hydraulic power function for the wetter perimeter.
B3	NCS	CHANVA	Power of the hydraulic power function for the conveyance.
B4	NCS	CHANVA	Power of the hydraulic power function for the hydraulic radius.
B5	NCS	CHANVA	Power of the hydraulic power function for the channel roughness.
CC		CONST	Contraction loss coefficient.
CCE		CONST	Expansion loss coefficient.
COEF			Ratio of time increment to space increment. [CORDA]
COVST			Coefficient needed to solve the continuity equation. [CORDA]
COV1			Coefficient needed to solve the continuity equation. [CORDA]
COV1	NCS		Coefficient needed to solve for the flow area. [NEWFLO]
COV2			Coefficient needed to solve the continuity equation. [CORDA]
COV2	NCS		Coefficient needed to solve for the flow area. [NEWFLO]
COV3	NCS		Coefficient needed to solve for the flow area. [NEWFLO]
DA	NR	SED	Change in cross-sectional area
DA			Average area flow between two cross section points. [GEOM]
DD	NR	WDV	Average reach depth
DDIS			Distance travelled by a wave point. [NEWFLO]
DDT			Time increment. [NEWFLO]
DELQ			Discharge increment. [NEWFLO]

Variable	Array Size	Common Block	Definition
DELQA			Interpolated value of DELQ. [NEWFLO]
DEP	NCS,3	//	Flow depth in (ft).
DEQ			Constant discharge in a river reach. [NEWFLO]
DF			Value of the derivative with respect to QE of the continuity equation. [CORDA]
DH			Denominator in ratio for stability control. [NEWDIS]
DI			Denominator in ratio for stability control. [NEWDIS]
DIF			Measure of relative error in iteration. [CORDA]
DIS			River mile of new wave point. [NEWFLO]
DIST			Temporary value for the travel distance of a wave point. [NEWFLO]
DMB	NS	SED	Sediment diameter
DP			Average wetted perimeter between two cross section points. [GEOM]
DQDT			Acceleration slope for the dynamic equation. [BACKW]
DQDTV			Acceleration slope loss over a river reach. [BACKW]
DSF			Relative increase in time for the energy slope. [NEWDIS]
DT		//	Time period length in seconds.
DWS			Increment of water surface elevation. [CHANGEO]
DX	NCS	SYST	Horizontal distance between cross sections.
DY			Flow depth correction in standard step backwater computations. [BACKW]

Variable	Array Size	Common Block	Definition
DZ	NCS	SED	Instantaneous bed elevation change
EA			Intercept of the least squared regression (log value). [LSQ]
F		SED	Darcy-Weisbach friction factor
FA			Correction factor in standard step backwater computations. [BACKW]
FA1		ROUGHN	Coefficient of the power function for the channel roughness-discharge relation.
FB1		ROUGHN	Power of the power function for the channel roughness-discharge relation.
FMV	NCS	SYST	Manning's roughness coefficient.
FN			Square of the Froude number. [BACKW]
FX			Average x values in linear regression. [LSQ]
FY			Average y values in linear regression. [LSQ]
G	NR, 3	SED	Total sediment transport
GLAT	NT, 3	SED	Later sediment inflow
GLATN	NS	SED	Sediment inflow by sizes
GS	NR, NS	SED	Sediment transport by sizes
GSC	NR, NS	SED	Sediment transport capacity by sizes
GRA		CONST	Value of earth acceleration: 32.2 (ft sec^{-1}).
GRAL		CONST	Value obtained by dividing GRA2 by the velocity correction coefficient ALPHA.
GRA2		CONST	Two times GRA: 64.4 (ft sec^{-1}).
H	NCS		Total head. [BACKW]

Variable	Array Size	Common Block	Definition
HE			Difference between estimated and computed total head for upstream cross section. [BACKW]
HEDL			Energy losses between two adjacent cross section due to expansion or contraction of the channel. [BACKW]
HT			Sum of total head and energy loss at downstream cross section. [BACKW]
HV	NCS		Velocity head. [BACKW]
I			Increment and loop counter for cross sections. [DYWAR], [BACKW], [CHANGEO], [CORDA], [INITIAL], [INPUT], [LSQ], [NEWDIS], [NEWFLO], [OUTPUT]
IC			Increment and loop counter. [INPUT]
ICOUNT		//	Time period counter.
IT		//	Counter for time level.
J			Increment and loop counter. [NEWFLO]
K			Increment and loop counter. [DYWAR], [CORDA], [GEOM], [NEWDIS], [NEWFLO], [NVAL], [OUTPUT]
L			Increment and loop counter. [CHANGEO], [GEOM], [INPUT], [NEWDIS], [NEWFLO].
M			Increment and loop counter. [CHANGEO], [GEOM], [INPUT], [NVAL]
N			Increment and loop counter. [CHANGEO], [GEOM], [LSQ], [NEWDIS], [NEWFLO], [NVAL]
NAP			Number of water surface elevations used for linear regression of hydraulic properties relationship. [CHANGEO]
NCS		//	Number of cross sections.

Variable	Array Size	Common Block	Definition
NCSM1			Number of cross sections minus one: NCS-1. [DYWAR]
NCSP1			Number of cross sections plus one: NCS+1. [NEWFLO]
ND	NCS	SECT	Number of points in each cross section.
NDC			Number of the cross sections for which the computations have already been performed. [NEWDIS], [NEWFLO]
NR		REACH	Number of reaches
NRL	NR	REACH	Lower section number in reach
NRU	NR	REACH	Upper section number in reach
NS		SED	Number of sediment sizes
NT		SED	Number of tributaries
NTP		//	Number of time periods.
NUM			Increment and loop counter. [BACKW]
PBA	NR, NS	SED	Adjusted sediment percentages
PBO	NS	SED	Original sediment percentages
PORB		SED	Porosity of the bed
PTRIB	NS	SED	Tributary sediment percentages
PH			Weighting factor for stability control on the discharge. [NEWDIS]
P1			Weighting factor for stability control on the energy slope. [NEWDIS]
Q	NCS,3	//	Total discharge in cfs.
QD			Summation of lateral inflows. [NEWFLO]
QE			Temporary value of discharge in iteration. [CORDA]

Variable	Array Size	Common Block	Definition
QE1			Temporary value of discharge in iteration. [CORDA]
QIN	NCS,3	//	Inflows at each cross section in cfs.
RC			Correlation coefficient of hydraulic properties relationship. [LSQ]
RCK	NCS,2	CHANVA	Correlation coefficient in the derivation of the hydraulic power functions.
RD	NCS	SYST	River mile of cross section in miles.
RDT	NT	SED	River mile of tributary
RIVNIL	NCS	SYST	River mile of cross section in feet.
SBAR			Standard error of the estimate for hydraulic properties relationship. [LSQ]
SD	NCS,2	CHANVA	Standard deviation in the derivation of the hydraulic power function.
SF	NCS,3	//	Total energy slope.
SFM			Average energy slope for two adjacent cross sections. [BACKW]
SFO	NCS		Friction slope. [BACKW]
SNU		SED	Kinematic viscosity
SUMA			Sum used in least squares regression $\Sigma\ (x_i-\bar{x}) \cdot (y_i-\bar{y})$. [LSQ]
SUMB			Sum used in least squares regression $\Sigma\ (x_i-\bar{x})^2$. [LSQ]
SUMC			Sum used in least squares regression $\Sigma\ (y_i-\bar{y})^2$. [LSQ]
SUMD			Sum used in least squares regression $\Sigma\ (y_i-A+Bx_i)^2$. [LSQ]

Variable	Array Size	Common Block	Definition
SUMX			Sum used in least squares regression. [LSQ]
SUMXX			Sum used in least squares regression. [LSQ]
SUMXY			Sum used in least squares regression. [LSQ]
SUMY			Sum used in least squares regression. [LSQ]
TA			Total area at the cross section and for the given flow depth. [CHANGEO], [GEOM]
TAU	NCS	SED	Shear stress
TCR	NS	SED	Critical shear stress
TKVNCS			Total conveyance at the first cross section upstream. [NEWDIS]
TKV1			Total conveyance at the first cross section downstream. [INITIAL], [NEWDIS]
TP			Wetted perimeter for the given flow depth. [CHANGEO], [GEOM]
TQ(80)			Working array containing discharges. [NEWFLO]
VEL			Velocity of wave point. [NEWFLO]
VQ			Discharge multiplied by Manning's roughness coefficient and divided by 1.486. [BACKW]
VV	NR	WDV	Average reach velocity
VX			Distance for discharge interpolation. [NEWFLO]
VY			Distance for discharge interpolation. [NEWFLO]
WCH	NCS	_____	Total bank to bank main channel width

Variable	Array Size	Common Block	Definition
WS			Water surface elevation in the computation of the linear regression of hydraulic-properties relationship.
WSE	NCS,3	//	Water surface elevation.
WW	NR	WDV	Average water surface width
X	NCS,ND	SECT	Array of horizontal distances for each cross section.
XL	NCS	SECT	Left bank station
XR	NCS	SECT	Right bank station
XSECT	NCS	SECT	Section identifier
XX	NCS,ND		Working array containing originally the horizontal distance of the cross section points.
XX		10	Array of log values of depth used in least squares regression. [LSQ]
Y		10	Array used in least squares regression. [LSQ]
YB		10	Array used in least squares regression. [LSQ]
XT			Temporary flow depth in iteration. [BACKW]
Z	NCS,ND	SECT	Array of bed elevation.
ZBL	NR	SED	Total loose soil depth
ZBLM	NR, NS	SED	Loose soil depth by sizes
ZMIN	NCS	SYST	Thalweg elevation for each cross section.
ZOMIN	NCS	SED	Original Thalweg elevation
ZOB	NCS	SYST	Overbank elevation for each cross section.
ZZ	NCS,ND		Working array containing originally the elevation of the cross section points.

APPENDIX D

LISTING OF PROGRAM

```
      PROGRAM DYNWAR(OUTPUT,TAPE6,TAPE8,TAPE9,TAPE10)
C
C     THIS PROGRAM IS A  DYNAMIC WATER ROUTING MODEL UTILIZING A
C     PREDICTOR CORRECTOR METHOD.  IT IS COUPLED WITH A BED MATERIAL
C     SEDIMENT ROUTING TECHNIQUE TO PREDICT SEDIMENT TRANSPORT AND
C     AGGRADATION OR DEGRADATION.
C
C     THIS MODEL WAS DEVELOPED BY JUERGEN D. GARBRECHT AND RUH-MING LI
C     AT THE ENGINEERING RESEARCH CENTER,COLORADO STATE UNIVERSITY,
C     FT.COLLINS,COLORADO.
C
C     DISCLAIMER
C     THIS PROGRAM IS ACCEPTED AND USED BY THE RECIPIENT UPON THE
C     EXPRESS UNDERSTANDING THAT THE DEVELOPER MAKE NO WARRANTIES,
C     EXPRESSED OR IMPLIED,CONCERNING THE ACCURACY,COMPLETNESS,
C     RELIABILITY OR SUITABILITY FOR ANY ONE PARTICULAR PURPOSE,
C     AND THAT THE DEVELOPER SHALL BE UNDER NO LIABILITY TO ANY
C     PERSON BY REASON OF ANY USE MADE THEREOF.
C
      COMMON Q(80,3),QIN(80,3),SF(80,3),A(80,3),DEP(80,3),WSE(80)
     1,NCS,NTP,DT,IT,ICOUNT,P(80,3)
      COMMON /SED/ GSC(80,12),G(80,3),DMB(12),PBO(12),PBA(80,12),
     1PTRIB(12),SNU,F,TAU(80),TCR(12),NT,NS,PORB,RDT(12),ZBL(80),
     2ZBLM(80,12),ZZ(80,3),GLAT(80,3),GLATN(12),SUMDA(80),
     3SMDDA(80),SMADA(80),DZ(80),ZOMIN(80),GS(12,12),DA(80)
C
C     READ PROGRAM,RIVER AND CHANNEL GEOMERTY DATA
C
      CALL INPUT
C
C     READ INITIAL INFLOW DATA
C
      CALL FLOW
C
C     COMPUTE THE HYDRAULIC PROPERTY RELATIONSHIPS FOR EACH CROSS
C     SECTION
C
      DO 9 I=1,NCS
    9 CALL CHANGED (I)
C
C     COMPUTE THE INITIAL FLOW CONDITIONS
C
      CALL INITIAL
C
      CALL QS
      CALL SROUT
C     PRINT THE RESULTS FOR THE INITIAL FLOW CONDITIONS
C
      CALL OUTPUT
      IF(NTP.EQ.1) STOP
      IT=2
   10 ICOUNT=ICOUNT+1
C
C     READ THE INFLOW DATA FOR THE CURRENT TIME LEVEL
C
      CALL FLOW
C
C     PREDICT THE WATER DISCHARGE,FLOW AREA AND FRICTION SLOPE
C     FOR THE CURRENT TIME LEVEL
C
      CALL NEWDIS
      NCSM1=NCS-1
      DO 20 K=1,NCSM1
      I=NCS-K
C
C     CORRECT THE WATER DISCHARGE AND THE FLOW AREA FOR THE
C     CURRENT TIME LEVEL
C
      CALL CORDA (I)
   20 CONTINUE
C
C     COMPUTE THE CHANNEL ROUGHNESS FACTOR FOR EACH CROSS SECTION
C
      CALL NVAL
C
C     COMPUTE THE WATER SURFACE ELEVATION,THE FRICTION SLOPE AND
C     THE FINAL HYDRAULIC PROPERTIES FOR EACH CROSS SECTION
C
      DO 30 I=2,NCS
      CALL BACKW (I)
   30 CONTINUE
C
C     CALL SEDIMENT ROUTING SUBROUTINES
C
      CALL QS
      CALL SROUT
C
C     PRINT THE RESULTS FOR THE CURRENT TIME LEVEL
C
      CALL OUTPUT
      IF(ICOUNT.GE.NTP) STOP
      IF(IT.EQ.2) GO TO 40
C
C     TIME LEVEL SHIFT BY ONE
C
      CALL TIMCHA
      GO TO 10
```

```
40 IT=3
   GO TO 10
   END
   SUBROUTINE BACKW (I)
C
C     THIS SUBROUTINE COMPUTES THE WATER SURFACE ELEVATION AT A
C     UPSTREAM CROSS SECTION ONCE THE CONDITONS AT THE DOWNSTREAM
C     SECTION IS KNOWN.IT SOLVES THE TOTAL HEAD EQUATION,WHICH
C     INCLUDES THE UNSTEADYNESS OF THE FLOW,BY THE STANDARD STEP
C     METHOD.
C
      COMMON Q(80,3),QIN(80,3),SF(80,3),A(80,3),DEP(80,3),WSE(80)
     1,NCS,NTP,DT,IT,ICOUNT,P(80,3)
      COMMON /CONST/ GRA,GRA2,ALPHA,CC,CE,GRAL
      COMMON /SYST/RD(80),RIVMIL(80),DX(80),ZOB(80),ZMIN(80),FMV(80)
      COMMON /SECT/ ND(80),X(80,50),Z(80,50),XL(80),XR(80),XSECT(80)
      COMMON /ROUGHN/FA1,FB1,FA2,FB2,FA3,FB3
      COMMON /CHANVA/ A1(80),B1(80),A2(80),B2(80),A3(80),B3(80)
     1,A4(80),B4(80),B5(80),RCK(2,80),SD(2,80),BETA(80),ATC(80),BET(80)
C
C     SET DIMENSIONS, ITERATION COUNTER AND CONSTANTS
C
      DIMENSION BSF(80),SFO(80),BTAV(80),BTRV(80),BVV(80),H(80),HV(80)
      NUM=0
      SFO(1)=SF(1,IT)
      VQ=Q(I,IT)*FMV(I)/1.486
C
C     COMPUTATION OF THE ACCELERATION SLOPE
C
      DQDT=0.0
      IF(IT.NE.1) DQDT=(Q(I,IT)-Q(I,IT-1)+Q(I-1,IT)-Q(I-1,IT-1))/2.
     1/(GRA*DT)
      DQDTV=DQDT*DX(I)
C
C     DOWNSTREAM VELOCITY HEAD AND TOTAL HEAD
C
      HV(I-1)=((Q(I-1,IT)-QIN(I-1,IT))/A(I-1,IT))**2./GRAL
      H(I-1)=HV(I-1)+DEP(I-1,IT)+ZMIN(I-1)
C
C     FIRST APPROXIMATION FOR THE UPSTREAM FLOW DEPTH
C
      YT=DEP(I,IT)
   10 NUM=NUM+1
C
C     CHECK NEW FLOW DEPTH AND ITERATION COUNTER
C
      IF(YT.LE.0.0) YT=1.0
      IF(NUM.GT.30) GO TO 60
C
C     COMPUTE THE HYDRAULIC PROPERTIES FOR THE GIVEN DEPTH (YT)
C
   11 IF (NUM.EQ.30) NUM=31
      BTAV(I)=A1(I)*YT**B1(I)
      BTRV(I)=A4(I)*YT**B4(I)
C
C     COMPUTE THE UPSTREAM VELOCITY (BVV),THE VELOCITY HEAD (HV),
C     THE TOTAL HEAD (H) AND THE FRICTION SLOPE (BSF)
C
      BVV(I)=Q(I,IT)/BTAV(I)
      HV(I)=BVV(I)*BVV(I)/GRAL
      H(I)=HV(I)+YT+ZMIN(I)
      BSF(I)=(VQ/(BTAV(I)*BTRV(I)**0.66666))**2
C
C     COMPUTE TOTAL HEAD LOSS
C
      SFM=(BSF(I)+SFO(I-1))/2.0
      CCE=CE
      IF(HV(I).LT.HV(I-1)) CCE=CC
      HEDL=CCE*ABS(HV(I-1)-HV(I))
      HT=H(I-1)+HEDL+SFM*DX(I)+DQDTV/((BTAV(I)+A(I-1,IT))/2.)
C
C     CHECK FOR ACCURACY IN THE TOTAL HEAD
C
      ERROR=0.5
      IF (NUM.GT.15) ERROR=0.75
      IF (NUM.GT.25) ERROR=1.00
      IF (NUM.EQ.31) GO TO 50
      IF (NUM.EQ.30) GO TO 31
      GO TO 32
   31 SLP=(ZMIN(NCS)-ZMIN(1))/(RIVMIL(NCS)-RIVMIL(1))
      TKNORM=Q(I,IT)/SQRT(SLP)
      YT=(TKNORM/A3(I))**(1./B3(I))
      GO TO 11
   32 CONTINUE
      IF(ABS(HT-H(I))-ERROR) 50,50,20
C
C     COMPUTE THE NEW FLOW DEPTH (YT)
C
   20 HE=H(I)-HT
      FN=(2.0*HV(I))/BTRV(I)
      FA=1.5*BSF(I)*DX(I)/BTRV(I)
      DY=ABS(HE/(1.-FN+FA))
      IF(HT-H(I)) 30,50,40
   30 YT=YT-DY
      GO TO 10
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```
   40 YT=YT+DY
      GO TO 10
C
C     SET NEW FLOW DEPTH (YT) INTO DEFINITIVE ARRAY (DEP) AND COMPUTE
C     THE WATER SURFACE ELEVATION (WSE),THE TOTAL LOSS SLOPE (SF)
C     AND THE FRICTION SLOPE (SFO)
C
   50 DEP(I,IT)=YT
      A(I,IT)=A1(I)*YT**B1(I)
      WSE(I)=ZMIN(I)+DEP(I,IT)
      SF(I,IT)=BSF(I)+DQDT/((BTAV(I)+A(I-1,IT))/2.)+HEDL/DX(I)
      SFO(I)=BSF(I)
C
C     CHECK FOR OVERBANK FLOW
C
      RETURN
      IF(WSE(I).GE.ZOB(I)) GO TO 80
      RETURN
C
C     ERROR MESSAGES
C
   60 WRITE(6,70)I,ICOUNT
   70 FORMAT(2X,*BACKWATER COMPUTATIONS DID NOT CONVERGE,CALCULATIONS
     1STOP HERE*,/,2X,*CROSS SECTION *,I4,2X,*TIME PERIOD *,I4)
      STOP
   80 WRITE(6,90) I,ICOUNT
   90 FORMAT(2X,*OVER BANK FLOW AT SECTION *,I5,2X,*FOR TIME PERIOD *
     1,I4)
      STOP
      END
      SUBROUTINE CHANGEO (I)
C
C     THIS SUBROUTINE COMPUTES POWER RELATIONS THAT ARE USED TO
C     CALCULATE TOTAL AREA(TA),WETTED PERIMETER(TP) AND
C     HYDRAULIC RADIUS(HR).
C
      COMMON Q(80,3),QIN(80,3),SF(80,3),A(80,3),DEP(80,3),WSE(80)
     1,NCS,NTP,DT,IT,ICOUNT,P(80,3)
      COMMON /SYST/RD(80),RIVMIL(80),DX(80),ZOB(80),ZMIN(80),FMV(80)
      COMMON /SECT/ ND(80),X(80,50),Z(80,50),XL(80),XR(80),XSECT(80)
      COMMON /CHANVA/ A1(80),B1(80),A2(80),B2(80),A3(80),B3(80)
     1,A4(80),B4(80),B5(80),RCK(2,80),SD(2,80),BETA(80),ATC(80),BET(80)
      COMMON /SED/ GSC(80,12),G(80,3),DMB(12),PBO(12),PBA(80,12),
     1PTRIB(12),SNU,F,TAU(80),TCR(12),NT,NS,PORB,RDT(12),ZBL(80),
     2ZBLM(80,12),ZZ(80,3),GLAT(80,3),GLATN(12),SUMDA(80),
     3SMDDA(80),SMADA(80),DZ(80),ZOMIN(80),GS(12,12),DA(80)
C
C     SET DIMENSIONS AND NUMBER OF WATER SURFACE ELEVATIONS USED
C     FOR THE LINEAR REGRESSION
C
      DIMENSION ATA(12),AD(12),ATP(12)
      DIMENSION ZMAX(80)
      DATA NAP/10/
C
C     SET NUMBER OF CROSS SECTION POINTS AND COMPUTE THE THALWEG
C     ELEVATION
C
      M=ND(I)
      ZMIN(I)=1.0E20
      DO 10 L=1,M
      IF (X(I,L).LT.XL(I)) GO TO 10
      IF (X(I,L).GT.XR(I)) GO TO 10
      IF(Z(I,L).GE.ZMIN(I)) GO TO 10
      ZMIN(I)=Z(I,L)
   10 CONTINUE
      ZMAX(I)=0.
      DO 11 L=1,M
      IF (Z(I,L).LE.ZMAX(I)) GO TO 11
      ZMAX(I)=Z(I,L)
   11 CONTINUE
      IF (IT.EQ.1) ZOMIN(I)=ZMIN(I)
C
C     COMPUTE EVENLY SPACED WATER SURFACE ELEVATIONS
C
      ZDIF=ZOB(I)-ZMIN(I)-1.0E-2
C     USE ZMAX NOT ZOB FOR THIS CASE
      ZDIF=ZMAX(I)-ZMIN(I)-.01
      IF (ZDIF.LE.5.) ZDIF=10.
      DWS=ZDIF/FLOAT(NAP)
      WS=ZMIN(I)
C
C     COMPUTE THE EXACT HYDRAULIC PROPERTIES: TOTAL AREA (TA)
C     AND WETTED PERIMETER(TP) FOR EACH WATER SURFACE ELEVATION
C     AND TAKE THE LOG OF THE VALUES
C
      DO 20 N=1,NAP
      WS=WS+DWS
      CALL GEOM(I,WS,TA,TP)
      ATA(N)=ALOG(TA)
      ATP(N)=ALOG(TP)
      AD(N)=ALOG(WS-ZMIN(I))
   20 CONTINUE
```

```
C
C     CALL LEAST SQUARES LINEAR REGRESSION SUBROUTINE TO COMPUTE
C     THE HYDRAULIC POWER FUNCTIONS
C
      IF (IT.EQ.1) GO TO 900
  900 CONTINUE
      CALL LSQ(NAP,AD,ATA,A1(I),B1(I),RCK(1,I),SD(1,I))
      CALL LSQ(NAP,AD,ATP,A2(I),B2(I),RCK(2,I),SD(2,I))
C
C     COMPUTE THE COEFFICIENTS FOR THE HYDRAULIC RADIUS(HR)
C     AND VARIOUS CONSTANTS
C
      A4(I)=A1(I)/A2(I)
      B4(I)=B1(I)-B2(I)
      ATC(I)=1.486*A1(I)*A4(I)**0.666666
      B3(I)=B1(I)+0.666666*B4(I)
      BET(I)=5.-2.*B2(I)/B1(I)
   30 CONTINUE
      RETURN
      END
      SUBROUTINE CORDA (I)
C
C     THIS SUBROUTINE CORRECTS THE DISCHARGES AT ALL CROSS SECTIONS
C     BY APPLYING THE MASS CONSERVATION PRINCIPLE.THE CONTINUITY
C     EQUATION IS SOLVED BY THE NEWTON RAPHSON ITERATION TECHNIQUE
C
      COMMON Q(80,3),QIN(80,3),SF(80,3),A(80,3),DEP(80,3),WSE(80)
     1,NCS,NTP,DT,IT,ICOUNT,P(80,3)
      COMMON /SYST/RD(80),RIVMIL(80),DX(80),ZOB(80),ZMIN(80),FMV(80)
      COMMON /CHANVA/ A1(80),B1(80),A2(80),B2(80),A3(80),B3(80)
     1,A4(80),B4(80),B5(80),RCK(2,80),SD(2,80),BETA(80),ATC(80),BET(80)
C
C     SET THE FIRST ESTIMATION FOR THE DISCHARGE AND THE CONSTANTS
C
      K=0
      QE=Q(I,IT)
      COEF=DT/DX(I+1)
      COVST=SQRT(SF(I,IT))*A3(I)
      COV1=B1(I)/B3(I)
      COV2=A1(I)*COV1
      COV3=COV1-1.
      GO TO 20
C
C     NEWTON RAPHSON ITERATION TO SOLVE FOR THE DISCHARGE (QE)
C
   10 QE=QE1
   20 F=-COEF*(-Q(I+1,IT-1)-Q(I+1,IT)-QIN(I,IT-1)+Q(I,IT-1)+QE
     1-QIN(I,IT))+A(I+1,IT-1)
     2+A(I,IT-1)-A(I+1,IT)-A1(I)*(QE/COVST)**COV1
      DF=-COEF-COV2/COVST*(QE/COVST)**COV3
      QE1=QE-F/DF
C
C     CHECK FOR ACCURACY AND FOR THE LOOP COUNTER
C
      IF(QE1.LE.0.0) QE1=1.0
      DIF=ABS((QE1-QE)/QE)
      K=K+1
      IF(K.GT.10) GO TO 30
      IF(DIF.GT.0.005) GO TO 10
C
C     COMPUTE THE DEPTH (DEP) AND THE AREA (A)
C
      Q(I,IT)=QE1
      DEP(I,IT)=(QE/(SQRT(SF(I,IT))*A3(I)))**(1./B3(I))
      A(I,IT)=A1(I)*DEP(I,IT)**B1(I)
      RETURN
C
C     ERROR  MESSAGE
C
   30 WRITE(6,40) I,ICOUNT
   40 FORMAT(//,10X,*CORRECTED VALUE FOR DISCHARGE NOT REACHED  IN
     1SUBROUTINE CORDA.*,/,10X,*COMPUTATIONS STOPED AT CROSS SECTION *,
     2I5,2X,*AND TIME PERIOD *,I5)
      STOP
      END
      SUBROUTINE FLOW
C
C     THIS SUBROUTINE READS THE FLOWS FOR THE CURRENT TIME LEVEL
C
      COMMON Q(80,3),QIN(80,3),SF(80,3),A(80,3),DEP(80,3),WSE(80)
     1,NCS,NTP,DT,IT,ICOUNT,P(80,3)
      COMMON /SED/ GSC(80,12),G(80,3),DMB(12),PBO(12),PBA(80,12),
     1PTRIB(12),SNU,F,TAU(80),TCR(12),NT,NS,PORB,RDT(12),ZB(80),
     2ZBLM(80,12),ZZ(80,3),GLAT(80,3),G[illegible]N(12),SUMDA(80),
     3SMDDA(80),SMADA(80),DZ(80),ZOMIN(80),GS(12,12),DA(80)
```

```
C
C     READ FLOWS
C
      READ(9,10) (QIN(I,IT),I=1,NCS)
   10 FORMAT(10F8.2)
C
C     READ TRIBUTARY SEDIMENT INFLOWS
C
      IF (NT.EQ.0) RETURN
      READ (9,11) (GLATN(J),J=1,NT)
   11 FORMAT (8F10.2)
      END
      SUBROUTINE GEOM(I,WS,TA,TP)
C
C     THIS SUBROUTINE COMPUTES THE EXACT HYDRAULIC PROPERTIES OF
C     A CROSS SECTION,ONCE GIVEN THE CHANNEL GEOMETRY AND THE WATER
C     SURFACE ELEVATION.
C
      COMMON Q(80,3),QIN(80,3),SF(80,3),A(80,3),DEP(80,3),WSE(80)
     1,NCS,NTP,DT,IT,ICOUNT,P(80,3)
      COMMON /SECT/ ND(80),X(80,50),Z(80,50),XL(80),XR(80),XSECT(80)
C
C     SET DIMENSIONS,THE NUMBER OF CROSS SECTION POINTS (ND) AND THE
C     INITIAL VALUES
C
      DIMENSION XXX(100),ZZZ(100)
      N1=ND(I)
      TA=0.0
      TP=0.0
      DO 170 K=2,N1
      XB=X(I,K)-X(I,K-1)+0.001
      IF (Z(I,K).GE.WS) GO TO 120
      IF (Z(I,K-1).GE.WS) GO TO 110
      DZ=WS-0.5*(Z(I,K-1)+Z(I,K))
      DA=XB*DZ
      ZB=ABS(Z(I,K)-Z(I,K-1))
      DP=SQRT(XB*XB+ZB*ZB)
      GO TO 160
  110 ZB=WS-Z(I,K)
      XB=XB*ZB/(Z(I,K-1)-Z(I,K))
      GO TO 150
  120 IF (Z(I,K-1).GE.WS) GO TO 170
      ZB=WS-Z(I,K-1)
      XB=XB*ZB/(Z(I,K)-Z(I,K-1))
  150 DA=0.5*XB*ZB
      DP=SQRT(XB*XB+ZB*ZB)
  160 TA=TA+DA
      TP=TP+DP
  170 CONTINUE
      RETURN
C
C     SET (X,Z) COORDINATES OF THE CROSS SECTION POINTS INTO WORKING
C     ARRAY
C
      DO 10 K=1,N1
      XXX(K)=X(I,K)
      ZZZ(K)=Z(I,K)
   10 CONTINUE
C
C     COMPUTE THE COORDINATES OF THE WATER SURFACE ELEVATION ON THE
C     RIGHT OVER BANK
C
      DO 40 K=1,N1
      IF(ZZZ(K)-WS) 30,20,40
   20 N=K
      GO TO 50
   30 N=K-1
      IF (N.EQ.0) STOP
      XXX(N)=(ZZZ(K-1)-WS)*(XXX(K)-XXX(K-1))/(ZZZ(K-1)-ZZZ(K))+XXX(K-1)
      ZZZ(N)=WS
      GO TO 50
   40 CONTINUE
   50 CONTINUE
C
C     COMPUTE THE COORDINATES OF THE WATER SURFACE ELEVATION ON THE
C     LEFT OVER BANK
C
      DO 80 L=1,N1
      K=N1-L+1
      IF(ZZZ(K)-WS) 70,60,80
   60 M=K
      GO TO 90
   70 M=K+1
      XXX(M)=(WS-ZZZ(K))*(XXX(K+1)-XXX(K))/(ZZZ(K+1)-ZZZ(K))+XXX(K)
      ZZZ(M)=WS
      GO TO 90
   80 CONTINUE
C
C     COMPUTE THE TOTAL AREA (TA) AND THE WETTED PERIMETER (TP)
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```
C
   90 K=M-1
      DO 100 L=N,K
      DA=((2.*ZZZ(N)-ZZZ(L+1)-ZZZ(L))/2.0)*(XXX(L+1)-XXX(L))
      DP=SQRT((ZZZ(L)-ZZZ(L+1))**2+(XXX(L+1)-XXX(L))**2)
      TA=TA+DA
      TP=TP+DP
  100 CONTINUE
      RETURN
      END
      SUBROUTINE INITIAL
C
C     THIS SUBROUTINE COMPUTES THE FLOW CHARACTERISTICS FOR THE
C     INITIAL TIME LEVEL
C
      COMMON Q(80,3),QIN(80,3),SF(80,3),A(80,3),DEP(80,3),WSE(80)
     1,NCS,NTP,DT,IT,ICOUNT,P(80,3)
      COMMON /SYST/RD(80),RIVMIL(80),DX(80),ZOB(80),ZMIN(80),FMV(80)
      COMMON /CHANVA/ A1(80),B1(80),A2(80),B2(80),A3(80),B3(80)
     1,A4(80),B4(80),B5(80),RCK(2,80),SD(2,80),BETA(80),ATC(80),BET(80)
C
C    COMPUTE THE RIVER MILE(RIVMIL(I)) IN FEET AND THE REACH LENGTH
C     (DX(I))
C
      RIVMIL(1)=5280.*RD(1)
      DX(1)=0.0
      DO 10 I=2,NCS
      RIVMIL(I)=5280.*RD(I)
      DX(I)=RIVMIL(I)-RIVMIL(I-1)
   10 CONTINUE
C
C     COMPUTE THE DISCHARGE (Q) FOR ALL CROSS SECTIONS
C
      NCSM1=NCS-1
      Q(NCS,IT)=QIN(NCS,IT)
      DO 20 IC=1,NCSM1
      I=NCS-IC
      Q(I,IT)=Q(I+1,IT)+QIN(I,IT)
   20 CONTINUE
C
C     COMPUTE THE FRICTION FACTOR (FMV)
C
      CALL NVAL
C
C     COMPUTE THE HYDRAULIC PROPERTIES AT THE FIRST CROSS SECTION
C
      SF(1,IT)=(ZMIN(NCS)-ZMIN(1))/(RIVMIL(NCS)-RIVMIL(1))
      TKV1=Q(1,IT)/SQRT(SF(1,IT))
      DEP(1,IT)=(TKV1/A3(1))**(1./B3(1))
      A(1,IT)=A1(1)*DEP(1,IT)**B1(1)
C
C     CHECK FOR OVERBANK FLOW
C
      WSE(1)=ZMIN(1)+DEP(1,IT)
      IF(WSE(1).GE.ZOB(1)) GO TO 40
C
C     COMPUTE THE BACKWATER CURVE
C
      DO 30 I=2,NCS
C
C     FIRST GUESS OF DEPTH (DEP) AND COMPUTE THE HYDRAULIC PROPERTIES
C     WITH THE BACKWATER COMPUTATIONS
C
      DEP(I,IT)=DEP(I-1,IT)
      CALL BACKW (I)
   30 CONTINUE
      RETURN
C
C     ERROR MESSAGE
C
   40 WRITE(6,50) I  ,ICOUNT
   50 FORMAT(2X,*OVER BANK FLOW AT SECTION *,I5,2X,*FOR TIME PERIOD *
     1,I4)
      STOP
      END
      SUBROUTINE INPUT
C
C     THIS SUBROUTINE PROVIDES THE NECESSARY DATA FOR THE PROGRAM.
C
      COMMON Q(80,3),QIN(80,3),SF(80,3),A(80,3),DEP(80,3),WSE(80)
     1,NCS,NTP,DT,IT,ICOUNT,P(80,3)
      COMMON /CONST/ GRA,GRA2,ALPHA,CC,CE,GRAL
      COMMON /SYST/RD(80),RIVMIL(80),DX(80),ZOB(80),ZMIN(80),FMV(80)
      COMMON /SECT/ ND(80),X(80,50),Z(80,50),XL(80),XR(80),XSECT(80)
      COMMON /ROUGHN/FA1,FB1,FA2,FB2,FA3,FB3
      COMMON /SED/ GSC(80,12),G(80,3),DMB(12),PBO(12),PBA(80,12),
     1PTRIB(12),SNU,F,TAU(80),TCR(12),NT,NS,PORB,RDT(12),ZBL(80),
     2ZBLM(80,12),ZZ(80,3),GLAT(80,3),GLATN(12),SUMDA(80),
     3SMDDA(80),SMADA(80),DZ(80),ZOMIN(80),GS(12,12),DA(80)
      COMMON /REACH/ NR,NRL(20),NRU(20)
      COMMON /WIDTH/ WCH(80)
C
C     SET COUNTERS
C
      IT=1
      ICOUNT=1
```

```
C
C     READ THE NUMBER OF CROSS SECTIONS (NCS),THE NUMBER OF TIME
C     PERIODS (NTP) AND THE TIME PERIOD LENGTH IN HOURS (DH)
C
      READ(10,10) NCS,NTP,DH
C
C     READ THE COEFFICIENT AND EXPONENT FOR THE CHANNEL
C     ROUGHNESS-DISCHARGE POWER FUNCTION
C
      READ(10,20)FA1,FB1
C
C     READ THE ENERGY CORRECTION COEFFICIENT (ALPHA),THE CONTRACTION
C     LOSS COEFFICIENT (CC) AND THE EXPANSION LOSS COEFFICIENT (CE)
C
      READ(10,30) ALPHA,CC,CE
C
C
C     READ CROSS-SECTION DATA IN HEC-2 FORMAT
C
      I=0
   71 READ (8,41) IA
   41 FORMAT (A2)
      IF (EOF(8).NE.0.OR.IA.EQ.2HEJ) GO TO 200
      IF (IA.EQ.2HX1) GO TO 100
      IF (IA.EQ.2HGR) GO TO 101
      GO TO 71
  100 BACKSPACE 8
      READ (8,42) IA,SECNO,XND,XLL,XRR
   42 FORMAT (A2,F6.0,3F8.0)
      I=I+1
      WCH(I)=ABS(XRR-XLL)
      XL(I)=XLL
      XR(I)=XRR
      XSECT(I)=SECNO
      ND(I)=INT(XND+.1)
      NPTS=ND(I)
      RD(I)=SECNO/5280.
      GO TO 71
  101 BACKSPACE 8
      READ (8,43) (Z(I,N),X(I,N),N=1,NPTS)
   43 FORMAT (2X,F6.0,9F8.0)
      DO 72 N=1,NPTS
      IF (XL.EQ.X(I,N)) ZOBL=Z(I,N)
   72 IF (XR.EQ.X(I,N)) ZOBR=Z(I,N)
      IF (ZOBR.LE.ZOBL) ZOB(I)=ZOBR
      IF (ZOBL.LE.ZOBR) ZOB(I)=ZOBL
      GO TO 71
  200 CONTINUE
C
C     SET TIME INCREMENT IN SECONDS AND CONSTANTS
C
      DT=DH*3600.
      GRA=32.2
      GRA2=64.4
      GRAL=GRA2/ALPHA
C
C     READ REACH DEFINITIONS
C
      READ (10,166) NR
  166 FORMAT (I10)
      DO 167 I=1,NR
  167 READ (10,168) NRL(I),NRU(I)
  168 FORMAT (2I10)
C
C     READ SEDIMENT DATA
C
      READ (10,61) NS,PORB,F,SNU
   61 FORMAT (I2,2F10.3,F10.8)
      READ (10,62) (DMB(M),M=1,NS)
   62 FORMAT (10F10.3)
      READ (10,62) (PBO(M),M=1,NS)
      DO 65 M=1,NS
      DO 66 K=1,NR
   66 PBA(K,M)=PBO(M)
      DMB(M)=DMB(M)/304.8
   65 TCR(M)=0.047*1.65*62.4*DMB(M)
```

```
C
C     READ TRIBUTARY SEDIMENT DATA
C
      READ (10,63) NT
   63 FORMAT (I2)
      IF (NT.EQ.0) RETURN
      READ (10,64) (RDT(J),J=1,NT)
   64 FORMAT (10F10.4)
      READ (10,62) (PTRIB(M),M=1,NS)
C
C     FORMAT STATMENTS
C
   10 FORMAT(2I5,F5.2)
   20 FORMAT(6F10.7)
   30 FORMAT(3F5.2)
   40 FORMAT(2X,I5,F10.2)
   50 FORMAT((8X,6(F6.0,F6.1)))
   60 FORMAT(F10.2,F10.5)
      RETURN
      END
      SUBROUTINE LSQ(N,XX,Y,EA,B,RC,SBAR)
C
C     THIS SUBROUTINE DERIVES THE COEFFICIENT OF THE HYDRAULIC
C     POWER FUNCTIONS,BY USING A LEAST SQUARES REGRESSION.
C
C     SET DIMENSIONS AND INITIAL VALUES
C
      DIMENSION XX(12),Y(12),YB(12)
      SUMX=0.0
      SUMXX=0.0
      SUMY=0.0
      SUMXY=0.0
      SUMA=0.0
      SUMB=0.0
      SUMC=0.0
      SUMD=0.0
C
C     SUM THE DIFFERENT COMPONENTS AND COMPUTE THE MEAN OF THE TWO
C     VARIABLES
C
      DO 10 I=1,N
      SUMX=SUMX+XX(I)
      SUMY=SUMY+Y(I)
      SUMXX=SUMXX+XX(I)*XX(I)
      SUMXY=SUMXY+XX(I)*Y(I)
   10 CONTINUE
      FX=SUMX/FLOAT(N)
      FY=SUMY/FLOAT(N)
C
C     COMPUTE THE COEFFICIENTS OF THE LINEAR REGRESSION LINE AND
C     RAISE E TO THE (A) POWER.IT WILL BE USED IN THE POWER FUNCTION
C
      B=(SUMXY-FLOAT(N)*FX*FY)/(SUMXX-FLOAT(N)*FX*FX)
      A=FY-B*FX
      EA=EXP(A)
C
C     COMPUTE THE CORRELATION COEFFICIENT AND THE STANDARD DEVIATION
C
      DO 20 I=1,N
      SUMA=SUMA+(XX(I)-FX)*(Y(I)-FY)
      SUMB=SUMB+(XX(I)-FX)*(XX(I)-FX)
      YB(I)=A+B*XX(I)
      SUMC=SUMC+(Y(I)-FY)*(Y(I)-FY)
   20 CONTINUE
C
C     CORRELATION COEFFICIENT
C
      RC=SUMA/SQRT(SUMB*SUMC)
      DO 30 I=1,N
      SUMD=SUMD+(Y(I)-YB(I))*(Y(I)-YB(I))
   30 CONTINUE
C
C     STANDARD DEVIATION
C
      SBAR=SQRT(SUMD/(FLOAT(N)-2.))
      RETURN
      END
      SUBROUTINE NEWDIS
C
C     THIS SUBROUTINE TRANSLATES THE FLOOD WAVE FOR ONE TIME
C     INCREMENT.IT COMPUTES THE DISCHARGE (Q),THE FLOW AREA(A)
C     AND THE FLOW DEPTH (DEP) FOR THE NEW TIME LEVEL.
C
      COMMON Q(80,3),QIN(80,3),SF(80,3),A(80,3),DEP(80,3),WSE(80)
     1,NCS,NTP,DT,IT,ICOUNT,P(80,3)
      COMMON /SYST/RD(80),RIVMIL(80),DX(80),ZOB(80),ZMIN(80),FMV(80)
      COMMON /CHANVA/ A1(80),B1(80),A2(80),B2(80),A3(80),B3(80)
     1,A4(80),B4(80),B5(80),RCK(2,80),SD(2,80),BETA(80),ATC(80),BET(80)
C
C     SET CONSTANTS AND UPSTREAM DISCHARGE
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C
      PH=0.0
      PI=0.0
      NCSM1=NCS-1
      Q(NCS,IT)=QIN(NCS,IT)
C
C     ESTIMATE THE FRICTION SLOPE AT THE UPSTREAM CROSS SECTION
C
      IF(IT.LE.2) GO TO 10
      DSF=(SF(NCS,IT-1)-SF(NCS,IT-2))/((SF(NCS,IT-1)+SF(NCS,IT-2))*0.5)
      SF(NCS,IT)=SF(NCS,IT-1)*(1.+DSF*0.5)
      GO TO 20
   10 SF(NCS,IT)=SF(NCS,IT-1)
C
C     COMPUTE THE TOTAL CONVEYANCE (TKV),THE FLOW DEPTH (DEP)
C     AND THE FLOW AREA (A) FOR THE UPSTREAM CROSS SECTION
C
   20 TKVNCS=Q(NCS,IT)/SQRT(SF(NCS,IT))
      A3(NCS)=1.486/FMV(NCS)*A1(NCS)*A4(NCS)**0.6666666
      DEP(NCS,IT)=(TKVNCS/A3(NCS))**(1./B3(NCS))
      A(NCS,IT)=A1(NCS)*DEP(NCS,IT)**B1(NCS)
C
C     COMPUTE THE DISCHARGE FOR THE NEW TIME LEVEL
C
      CALL NEWFLO (NCD)
C
C     COMPUTE ADDED DISCHARGE AND SLOPE FROM INFLOW HYDROGRAPH
C
      N=NCD
      IF(N.GE.NCSM1) GO TO 40
      NP1=N+1
      DO 30 K=NP1,NCSM1
      L=NCSM1+NP1-K
      Q(L,IT)=Q(L+1,IT)+QIN(L,IT)
   30 CONTINUE
C
C     COMPUTE THE FRICTION FACTOR (FMV)
C
   40 CALL NVAL
C
C     COMPUTE THE HYDRAULIC PROPERTIES AT THE DOWNSTREAM CROSS SECTION
C     BY SETTING THE FRICTION SLOPE TO THE CONSTANT VALUE SF(1,IT)
C     (DOWNSTREAM BOUNDARY CONDITION)
C
      SF(1,IT)=SF(1,IT-1)
      TKV1=Q(1,IT)/SQRT(SF(1,IT))
      DEP(1,IT)=(TKV1/A3(1))**(1./B3(1))
      A(1,IT)=A1(1)*DEP(1,IT)**B1(1)
      WSE(1)=ZMIN(1)+DEP(1,IT)
C
C     COMPUTE THE BACKWATER CURVE AND THE HYDRAULIC PROPERTIES FOR
C     ALL THE REMAINING CROSS SECTIONS,USING THE LAST TIMES FLOW
C     DEPTH AS THE FIRST APPROXIMATION FOR THE ITERATION
C
      DO 50 I=2,NCS
      DEP(I,IT)=DEP(I,IT-1)
      CALL BACKW(I)
   50 CONTINUE
C
C     STABILITY CONTROL IF NECESSARY
C
      IF(PH.EQ.0.0.AND.PI.EQ.0.0) RETURN
      DO 60 I=2,NCSM1
      DI=1.+2.*PH
      SF(I,IT)=(PH*SF(I,IT-1)+SF(I,IT)+PH*SF(I,IT-1))/DI
      DH=1.+3.*PI
      Q(I,IT)=(2.*PI*Q(I,IT-1)+Q(I,IT)+PI*Q(I,IT-2))/DH
   60 CONTINUE
      RETURN
      END
      SUBROUTINE NEWFLO (NCD)
C
C     THIS SUBROUTINE COMPUTES THE DISCHARGES (Q) OF THE CURRENT
C     TIME LEVEL
C
      COMMON Q(80,3),QIN(80,3),SF(80,3),A(80,3),DEP(80,3),WSE(80)
     1,NCS,NTP,DT,IT,ICOUNT,P(80,3)
      COMMON /SYST/RD(80),RIVMIL(80),DX(80),ZOB(80),ZMIN(80),FMV(80)
      COMMON /CHANVA/ A1(80),B1(80),A2(80),B2(80),A3(80),B3(80)
     1,A4(80),B4(80),B5(80),RCK(2,80),SD(2,80),BETA(80),ATC(80),BET(80)
      COMMON /ROUGHN/FA1,FB1,FA2,FB2,FA3,FB3
C
C     SET THE DIMENSIONS AND THE VALUES FOR THE CONSTANTS
```

```
C
      DIMENSION DIS(80),DIST(80),TQ(80),COV1(80),COV2(80),COV3(80)
      IFLAG=0
      NCSP1=NCS+1
      DO 10 I=1,NCS
C     RECOMPUTE PARAMETERS SINCE GEOMETRY MAY HAVE CHANGED
C     NOTE THESE RECOMPUTATIONS ARE BASED ON A Q THAT IS ONE
C     TIME STEP BEHIND
      FMV(I)=FA1*Q(I,IT-1)**FB1
C     CAUTION ON USE OF FA1, FA2 OR FA3 CHANGE IF NECESSARY
      B5(I)=FB1
      A3(I)=ATC(I)/FMV(I)
      BETA(I)=BET(I)/(3.*(B5(I)+1.))
      COV1(I)=SQRT(SF(I,IT-1))*A3(I)
      COV2(I)=B1(I)/B3(I)
      COV3(I)=A1(I)/(COV1(I)**COV2(I))
   10 CONTINUE
      DO 50 L=1,NCS
C
C     SET INITIAL VALUES
C
      QT=0.0
      XDDT=0.0
      DDIS=0.0
      J=0
      I=NCSP1-L
      DIST(I)=0.0
      QT=Q(I,IT-1)
      AT=A(I,IT-1)
C
C     COMPUTE THE FLOW VELOCITY AND THE DISTANCE OF TRAVEL  OF
C     THE WAVE POINT
C
   20 VEL=QT*BETA(I-J)/AT
      DDIS=VEL*(DT-XDDT)
      IF(DDIS.GE.DX(I-J)) GO TO 40
C
C     SET THE DISCHARGE AND THE DISTANCE OF TRAVEL OF THE WAVE
C     POINT INTO FINAL ARRAY
C
   30 TQ(I)=QT
      DIST(I)=DIST(I)+DDIS
      GO TO 50
   40 IF(DX(I-J).EQ.0.0) GO TO 30
C
C     COMPUTE THE TOTAL DISTANCE AND THE TOTAL TIME OF TRAVEL OF
C     THE WAVE POINT
C
      DIST(I)=DIST(I)+DX(I-J)
      DDT=DX(I-J)/VEL
      XDDT=XDDT+DDT
      J=J+1
C
C     COMPUTE THE DISCHARGE AND THE FLOW AREA FOR THE NEW SPACE POINT
C
      DELQ=QIN(I-J,IT)-QIN(I-J,IT-1)
      DELQA=DELQ*XDDT/DT
      QT=QT+QIN(I-J,IT-1)+DELQA
      AT=COV3(I-J)*QT**COV2(I-J)
      GO TO 20
   50 CONTINUE
C
C     COMPUTE THE POSITION OF THE NEW DISCHARGES IN SPACE
C
      DO 60 I=1,NCS
      DIS(I)=RIVMIL(I)-DIST(I)
   60 CONTINUE
      N=1
C
C     INTERPOLATE THE NEW DISCHARGE VALUES TO OBTAIN THE VALUES
C     AT THE FINITE DIFFERENCE GRID POINTS
C
      DO 110 I=1,NCS
      IFLAG=0
      QD=QIN(I,IT-1)
      DO 100 K=N,NCS
      IF(I.EQ.NCS) GO TO 120
      IF(DIS(K).LE.RIVMIL(I)) GO TO 90
      IFLAG=1
      VX=RIVMIL(I)-DIS(K-1)
      VY=DIS(K)-RIVMIL(I)
      J=1
   70 IF(DIS(K).LE.RIVMIL(I+J)) GO TO 80
      QD=QD+QIN(I+J,IT-1)
      J=J+1
      GO TO 70
   80 DEQ=TQ(K-1)-TQ(K)-QD
      Q(I,IT)=TQ(K)+QD+DEQ*VY/(VX+VY)
      N=K
      IF(K.EQ.NCS) GO TO 130
      GO TO 110
   90 IF(K.EQ.NCS.AND.IFLAG.EQ.0) GO TO 120
      IF(K.EQ.NCS) GO TO 130
  100 CONTINUE
  110 CONTINUE
```

```
C
C     NUMBER OF THE CROSS SECTION FOR WHICH THE COMPUTATIONS
C     HAVE BEEN COMPLETED
C
  120 I=I-1
  130 NCD=I
      RETURN
      END
      SUBROUTINE NVAL
C
C     THIS SUBROUTINE COMPUTES FOR THE CURRENT DISCHARGE (Q),THE
C     CHANNEL ROUGHNESS FACTOR (FMV),THE COEFFICIENT FOR THE CONVEYANCE
C     EQUATION (A3,B3) AND THE BETA VALUE FOR THE WAVE CELERITY (BETA)
C
      COMMON Q(80,3),QIN(80,3),SF(80,3),A(80,3),DEP(80,3),WSE(80)
     1,NCS,NTP,DT,IT,ICOUNT,P(80,3)
      COMMON /ROUGHN/FA1,FB1,FA2,FB2,FA3,FB3
      COMMON /CHANVA/ A1(80),B1(80),A2(80),B2(80),A3(80),B3(80)
     1,A4(80),B4(80),B5(80),RCK(2,80),SD(2,80),BETA(80),ATC(80),BET(80)
      COMMON /SYST/RD(80),RIVMIL(80),DX(80),ZOB(80),ZMIN(80),FMV(80)
C
C     COMPUTE THE CHANNEL ROUGHNESS FOR THE LOWER RIVER REACH
C
      DO 10 M=1,NCS
      FMV(M)=FA1*Q(M,IT)**FB1
      B5(M)=FB1
   10 CONTINUE
C
C     COMPUTE THE COEFFICIENTS FOR THE CONVEYANCE EQUATION AND THE
C     BETA VALUE FOR THE WAVE CELERITY
C
      DO 30 K=1,NCS
      A3(K)=ATC(K)/FMV(K)
      BETA(K)=BET(K)/(3.*(B5(K)+1.))
   30 CONTINUE
      RETURN
      END
      SUBROUTINE OUTPUT
C
C     THIS SUBROUTINE PRINTS FOR EACH TIME LEVEL THE MAIN RESULTS
C     COMPUTED BY THE PROGRAM
C
      COMMON Q(80,3),QIN(80,3),SF(80,3),A(80,3),DEP(80,3),WSE(80)
     1,NCS,NTP,DT,IT,ICOUNT,P(80,3)
      COMMON /SYST/RD(80),RIVMIL(80),DX(80),ZOB(80),ZMIN(80),FMV(80)
      COMMON /SECT/ ND(80),X(80,50),Z(80,50),XL(80),XR(80),XSECT(80)
      COMMON /ROUGHN/FA1,FB1,FA2,FB2,FA3,FB3
      COMMON /CHANVA/ A1(80),B1(80),A2(80),B2(80),A3(80),B3(80)
     1,A4(80),B4(80),B5(80),RCK(2,80),SD(2,80),BETA(80),ATC(80),BET(80)
      COMMON /SED/ GSC(80,12),G(80,3),DMB(12),PBO(12),PBA(80,12),
     1PTRIB(12),SNU,F,TAU(80),TCR(12),NT,NS,PORB,RDT(12),ZBL(80),
     2ZBLM(80,12),ZZ(80,3),GLAT(80,3),GLATN(12),SUMDA(80),
     3SMDDA(80),SMADA(80),DZ(80),ZOMIN(80),GS(12,12),DA(80)
      COMMON /REACH/ NR,NRL(20),NRU(20)
C
C     PRINT THE GENERAL INFORMATION
C
      IF(IT.NE.1) GO TO 10
C
C     PRINT THE NUMBER OF CROSS SECTIONS (NCS),THE NUMBER OF TIME
C     PERIODS (NTP) AND THE LENGTH OF A TIME PERIOD IN HOURS (DT)
C
      WRITE(6,30)
      WRITE (6,40) NCS,NTP,DT
C
C     PRINT THE RIVER MILE (RD),THE REACH LENGTH (DX) AND THE
C     THALWEG ELEVATION (ZMIN) FOR EACH CROSS SECTION
C
      WRITE(6,50)
      WRITE(6,60) ((I,RD(I),DX(I),ZMIN(I)),I=1,NCS)
C
C     PRINT THE COEFFICIENTS OF ALL POWER RELATIONS FOR EACH CROSS
C     SECTION
C
      WRITE(6,70)
      WRITE(6,80)((I,A1(I),B1(I),A2(I),B2(I),A3(I),B3(I)
     1,A4(I),B4(I),B5(I)),I=1,NCS)
C
C     PRINT THE CORRELATION COEFFICIENTS (RCK) AND THE STANDARD
C     DEVIATION (SD) FOR THE TWO POWER RELATIONS COMPUTE IN
C     SUBROUTINE CHANGEO
C
      WRITE(6,90)
      WRITE(6,100) ((I,RCK(1,I),SD(1,I),RCK(2,I),SD(2,I)),I=1,NCS)
C
C     PRINT THE COEFFICIENTS FOR THE CHANNEL ROUGHNESS-DISCHARGE
C     RELATION
C
      WRITE(6,110)
      WRITE(6,120)FA1,FB1
```

```
C
C     PRINT THE MAIN RESULTS AFTER EACH TIME LEVEL COMPUTATION
C
      WRITE(6,130)
   10 NCSP1=NCS+1
      WRITE(6,140) ICOUNT
C     WRITE(6,150)
      WRITE (6,151)
  151 FORMAT (2X,'SECTION ',' DISCHARGE ',' VELOCITY ','   AREA    ',
     $'  SLOPE    ',' WS ELEV   ','  DEPTH    ',' INST DZ  ',
     $' THALWEG  ','  CUM DZ   '/)
C
C     PRINT THE DISCHARGE (Q),THE FLOW AREA (A), THE TOTAL ENERGY
C     SLOPE (SF),THE WATER SURFACE ELEVATION (WSE),THE FLOW
C     DEPTH( DEP) AND THE LATERAL INFLOW (QIN) FOR EACH CROSS SECTION
C
      DO 20 K=1,NCS
      I=NCSP1-K
C     WRITE(6,160) I,Q(I,IT),A(I,IT),SF(I,IT),WSE(I),DEP(I,IT)
C    1,QIN(I,IT)
      V=Q(I,IT)/A(I,IT)
      DZMIN=ZMIN(I)-ZOMIN(I)
      WRITE (6,161) I,Q(I,IT),V,A(I,IT),SF(I,IT),WSE(I),DEP(I,IT),
     1DZ(I),ZMIN(I),DZMIN
  161 FORMAT (5X,I2,3X,2X,F8.0,5X,F5.2,4X,F6.0,2X,F8.6,2X,F8.2,
     +5X,F5.2,4X,F6.2,2X,F8.2,4X,F6.2)
   20 CONTINUE
      WRITE (6,29)
   29 FORMAT (/)
      DO 21 IR=1,NR
      WRITE (6,22) IR, G(IR,IT),(GS(IR,M),M=1,NS)
   22 FORMAT (5X,I2,1X,'G(IR),GS(IR,M) :',11E10.3)
      WRITE (6,23) (PBA(IR,M),M=1,NS)
   23 FORMAT (5X,'SEDIMENT PERCENTAGES :    ',10F10.3)
   21 CONTINUE
      WRITE (6,9990) (DA(IR),IR=1,NR)
 9990 FORMAT (10X,'AREA CHANGES (SQ FT) :',10F8.0)
      IF (ICOUNT.EQ.NTP) GO TO 900
      GO TO 999
  900 WRITE (6,901)
  901 FORMAT (////,25X,'FINAL CROSS SECTIONS'///)
      DO 902 K=1,NCS
      WRITE (6,903) K,XSECT(K),XL(K),XR(K)
  903 FORMAT (/10X,I10,3F10.0)
      NPTS=ND(K)
      WRITE (6,904) (X(K,N),Z(K,N),N=1,NPTS)
  904 FORMAT (10X,5(F10.0,F10.2))
  902 CONTINUE
  999 CONTINUE
C
C     FORMAT STATMENTS.
C
   30 FORMAT(1H1,////,20X,29H**** GENERAL INFORMATION ****,//)
   40 FORMAT(////,10X,26HNUMBER OF CROSS SECTIONS =,I5,/,10X,
     126HNUMBER OF TIME PERIODS     =,I5,/,10X,14HTIME INCREMENT,11X,*=*,
     1F10.2)
   50 FORMAT(///,10X,*CROSS SECTION*,6X,*RIVER MILE*,4X,
     1*REACH LENGTH*,2X,*THALWEG ELEVATION*,/,13X,*NUMBER*,/)
   60 FORMAT(13X,I4,7X,3E15.4)
   70 FORMAT(1H1,//////,30X,*COEFFICIENTS OF THE POWER RELATIONS*,/////
     1//,12X,*CROSS*,4X,*A1*,9X,*B1*,9X,*A2*,9X,*B2*,9X,*A3*,9X,*B3*
     2,9X,*A4*,9X,*B4*,9X,*B5*,/,11X,*SECTION*,///)
   80 FORMAT(10X,I5,9E11.4)
   90 FORMAT(1H1,///,18X,*CORRELATION COEFFICIENT AND STANDARD*,/,11X,*
     1DEVIATION FOR THE COEFFICIENTS OF THE POWER RELATIONS*,///////
     2,12X,*CROSS*,3X,*RCK1*,8X,*SD1*,7X,*RCK2*,8X,*SD2*
     3,/,11X,*SECTION*,///)
  100 FORMAT(10X,I5,4E11.4)
  110 FORMAT(1H1,////,10X,*COEFFICIENTS  OF  THE  CHANNEL  ROUGHNESS -
     1DISCHARGE RELATION*,/////////)
  120 FORMAT(25X,*FA1 = *,F15.9,/,25X,*FB1 = *,F15.9,/,25X,*FA2 = *
     1,F15.9,/,25X,*FB2 = *,F15.9,/,25X,*FA3 = *,F15.9,/,25X,
     2*FB3 = *,F15.9)
  130 FORMAT(1H1,///,25X,36H*** RESULTS FOR EACH TIME PERIOD ***,//////)
  140 FORMAT(/////,10X,13HTIME PERIOD =,I5,///)
  150 FORMAT(2X,*CROSS SECTION*,2X,*TOTAL DISCHARGE*,3X,
     1*FLOW AREA*,6X,*TOTAL ENERGY*,4X,*WATER SURFACE*,4X,
     2*FLOW DEPTH*,8X,*INFLOW*,/,5X,*NUMBER*,42X,*SLOPE*,
     310X,*ELEVATION*,/)
  160 FORMAT(5X,I4,3X,6E16.4)
      RETURN
      END
      SUBROUTINE TIMCHA
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C
C     THIS SUBROUTINE SETS THE VARIABLES ACCORDING TO THE TIME
C     LEVEL SHIFT PERFORMED AFTER EACH TIME PERIOD.
C
      COMMON Q(80,3),QIN(80,3),SF(80,3),A(80,3),DEP(80,3),WSE(80)
     1,NCS,NTP,DT,IT,ICOUNT,P(80,3)
      COMMON /SED/ GSC(80,12),G(80,3),DMB(12),PBO(12),PBA(80,12),
     1PTRIB(12),SNU,F,TAU(80),TCR(12),NT,NS,PORB,RDT(12),ZBL(80),
     2ZBLM(80,12),ZZ(80,3),GLAT(80,3),GLATN(12),SUMDA(80),
     3SMDDA(80),SMADA(80),DZ(80),ZOMIN(80),GS(12,12),DA(80)
      COMMON /REACH/ NR,NRL(20),NRU(20)
C
C     SHIFT THE TOTAL FRICTION SLOPE (SF) FROM TIME LEVEL (IT-1)
C     TO (IT-2)
C
      SF(NCS,IT-2)=SF(NCS,IT-1)
      DO 5 I=1,NCS
      Q(I,IT-2)=Q(I,IT-1)
    5 CONTINUE
C
C     SHIFT THE VARIABLES FROM TIME LEVEL (IT) TO (IT-1)
C
      DO 10 I=1,NCS
      Q(I,IT-1)=Q(I,IT)
      SF(I,IT-1)=SF(I,IT)
      QIN(I,IT-1)=QIN(I,IT)
      A(I,IT-1)=A(I,IT)
      DEP(I,IT-1)=DEP(I,IT)
      ZZ(I,IT-1)=ZZ(I,IT)
   10 CONTINUE
      DO 11 I=1,NR
      G(I,IT-1)=G(I,IT)
   11 GLAT(I,IT-1)=GLAT(I,IT)
      RETURN
      END
      SUBROUTINE QS
C
C     THIS SUBROUTINE COMPUTES THE SEDIMENT TRANSPORT CAPACITY
C
      COMMON Q(80,3),QIN(80,3),SF(80,3),A(80,3),DEP(80,3),WSE(80)
     1,NCS,NTP,DT,IT,ICOUNT,P(80,3)
      COMMON /SYST/RD(80),RIVMIL(80),DX(80),ZOB(80),ZMIN(80),FMV(80)
      COMMON /CHANVA/ A1(80),B1(80),A2(80),B2(80),A3(80),B3(80)
     1,A4(80),B4(80),B5(80),RCK(2,80),SD(2,80),BETA(80),ATC(80),BET(80)
      COMMON /SED/ GSC(80,12),G(80,3),DMB(12),PBO(12),PBA(80,12),
     1PTRIB(12),SNU,F,TAU(80),TCR(12),NT,NS,PORB,RDT(12),ZBL(80),
     2ZBLM(80,12),ZZ(80,3),GLAT(80,3),GLATN(12),SUMDA(80),
     3SMDDA(80),SMADA(80),DZ(80),ZOMIN(80),GS(12,12),DA(80)
      COMMON /REACH/ NR,NRL(20),NRU(20)
      COMMON /WDV/ WW(20),DD(20),VV(20)
      DO 100 K=1,NCS
  100 P(K,IT)=A2(K)*DEP(K,IT)**B2(K)
      DO 101 IR=1,NR
      NL=NRL(IR)
      NXS=NRU(IR)-NRL(IR)+1
      RNXS=FLOAT(NXS)
      WSUM=0.
      DSUM=0.
      VSUM=0.
      DO 102 N=1,NXS
      NN=NL+N-1
      WSUM=WSUM+P(NN,IT)
      DSUM=DSUM+DEP(NN,IT)
      VSUM=VSUM+Q(NN,IT)/A(NN,IT)
  102 CONTINUE
      WW(IR)=WSUM/RNXS
      W=WW(IR)
      DD(IR)=DSUM/RNXS
      D=DD(IR)
      VV(IR)=VSUM/RNXS
      V=VV(IR)
      CALL TRANSP (IR,W,D,V)
  101 CONTINUE
      RETURN
      END
      SUBROUTINE TRANSP (K,W,D,V)
C
C     THIS SUBROUTINE COMPUTES THE MEYER-PETER,MULLER BED LOAD
C     BY SEDIMENT SIZE AND COMPUTES THE SUSPENDED BED MATERIAL
C     LOAD BASED ON COMPUTED HYDRAULIC CONDITIONS
C
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      COMMON Q(80,3),QIN(80,3),SF(80,3),A(80,3),DEP(80,3),WSE(80)
     1,NCS,NTP,DT,IT,ICOUNT,P(80,3)
      COMMON /SYST/RD(80),RIVMIL(80),DX(80),ZOB(80),ZMIN(80),FMV(80)
      COMMON /CHANVA/ A1(80),B1(80),A2(80),B2(80),A3(80),B3(80)
     1,A4(80),B4(80),B5(80),RCK(2,80),SD(2,80),BETA(80),ATC(80),BET(80)
      COMMON /SED/ GSC(80,12),G(80,3),DMB(12),PBO(12),PBA(80,12),
     1PTRIB(12),SNU,F,TAU(80),TCR(12),NT,NS,PORB,RDT(12),ZBL(80),
     2ZBLM(80,12),ZZ(80,3),GLAT(80,3),GLATN(12),SUMDA(80),
     3SMDDA(80),SMADA(80),DZ(80),ZOMIN(80),GS(12,12),DA(80)
      RHO = 62.4/32.2                                                   TRA 0030
      TAO =  1/8.*RHO*F*V**2.
      TAU(K)=TAO
      SV = SQRT(TAO/1.9379)                                             TRA 0031
      IF (V.LE.0.) GO TO 71
      BMV = 2.5 + V/SV                                                  TRA 0032
   71 CONTINUE
      DO 61 M = 1,NS                                                    TRA 0034
      TTEM=TAO-TCR(M)
C                                                                       TRA 0037
      GSC(K,M)=0.
         IF (TTEM.LE.0.) GO TO 61                                       TRA 0038
C                                                                       TRA 0039
C     DETERMINATION OF RATIO OF SUSPENDED BED MATERIAL LOAD             TRA 0040
C                                                                       TRA 0041
         FVB = (SQRT(36.064 * DMB(M) *  * 3 + 36. * SNU *  * 2) - 6. * STRA 0046
     +   NU)/DMB(M)                                                     TRA 0047
         ZR = FVB/(0.4 * SV)                                            TRA 0048
      AR = .05/D
      AR=2.*DMB(M)/D
         IF (AR.GT.0.5) GO TO 31                                        TRA 0050
         CALL POWER (ZR,AR,FJ,SJ,1.0E - 2)                              TRA 0051
         PP= AR *  * (ZR - 1.)/(11.6 * (1. - AR) *  * ZR)               TRA 0052
         SUSP= PP* (BMV * FJ + 2.5 * SJ)                                TRA 0053
         IF (SUSP.LT.0.) SUSP = 0.                                      TRA 0054
         GO TO 41                                                       TRA 0055
   31    SUSP = 0.                                                      TRA 0056
C
   41 CONTINUE
C     DETERMINATION OF TRANSPORTING CAPACITY OF BED MATERIAL LOAD       TRA 0057
C                                                                       TRA 0058
         GSC(K,M)=(1.+SUSP)*.0558*W*TTEM**1.5
   61 CONTINUE                                                          TRA 0064
      RETURN                                                            TRA 0065
      END                                                               TRA 0066
      SUBROUTINE POWER (Z,A,XJ1,XJ2,CONV)                               POW 0001
C                                                                       POW 0002
C     THIS SUBROUTINE EVALUATES J1 AND J2 INTEGRALS                     POW 0003
C     NOTATIONS                                                         POW 0004
C     XJ1 = VALUE OF J1 INTEGRAL                                        POW 0005
C     XJ2 = VALUE OF J2 INTEGRAL                                        POW 0006
C     N = ORDER OF APPROXIMATION + 1                                    POW 0007
C     CONV = CONVERGENCE CRITERION                                      POW 0008
C                                                                       POW 0009
      N = 1                                                             POW 0010
      XJ1 = 0.                                                          POW 0011
      XJ2 = 0.                                                          POW 0012
      ALG = ALOG(A)                                                     POW 0013
      C = 1.                                                            POW 0014
      D =  - Z                                                          POW 0015
      E = D + 1.                                                        POW 0016
      FN = 1.                                                           POW 0017
      AEX = A *  * E                                                    POW 0018
      GO TO 21                                                          POW 0019
   11 N = N + 1                                                         POW 0020
      C = C * D/FN                                                      POW 0021
      D = E                                                             POW 0022
      E = D + 1.                                                        POW 0023
      FN = FLOAT(N)                                                     POW 0024
      AEX = A *  * E                                                    POW 0025
   21 IF (ABS(E).LE.0.001) GO TO 31                                     POW 0026
      XJ1 = XJ1 + C * (1. - AEX)/E                                      POW 0027
      XJ2 = XJ2 + C * ((AEX - 1.)/E *  * 2 - AEX * ALG/E)               POW 0028
      GO TO 41                                                          POW 0029
   31 XJ1 = XJ1 - C * ALG                                               POW 0030
      XJ2 = XJ2 - 0.5 * C * ALG *  * 2                                  POW 0031
   41 IF (N.EQ.1) GO TO 51                                              POW 0032
      CJ1 = ABS(1. - FJ1/XJ1)                                           POW 0033
      CJ2 = ABS(1. - FJ2/XJ2)                                           POW 0034
      IF (CJ1.LE.CONV.AND.CJ2.LE.CONV) RETURN                           POW 0035
   51 FJ1 = XJ1                                                         POW 0036
      FJ2 = XJ2                                                         POW 0037
      GO TO 11                                                          POW 0038
C                                                                       POW 0039
      END                                                               POW 0040
      SUBROUTINE SROUT
C
C     THIS SUBROUTINE COMPUTES ACTUAL TRANSPORT RATE BY SIZE
C     FRACTION AND COMPUTES AGGRADATION AND DEGRADATION
C
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      COMMON Q(80,3),QIN(80,3),SF(80,3),A(80,3),DEP(80,3),WSE(80)
     1,NCS,NTP,DT,IT,ICOUNT,P(80,3)
      COMMON /SYST/RD(80),RIVMIL(80),DX(80),ZOB(80),ZMIN(80),FMV(80)
      COMMON /CHANVA/ A1(80),B1(80),A2(80),B2(80),A3(80),B3(80)
     1,A4(80),B4(80),B5(80),RCK(2,80),SD(2,80),BETA(80),ATC(80),BET(80)
      COMMON /SED/ GSC(80,12),G(80,3),DMB(12),PBO(12),PBA(80,12),
     1PTRIB(12),SNU,F,TAU(80),TCR(12),NT,NS,PORB,RDT(12),ZBL(80),
     2ZBLM(80,12),ZZ(80,3),GLAT(80,3),GLATN(12),SUMDA(80),
     3SMDDA(80),SMADA(80),DZ(80),ZOMIN(80),GS(12,12),DA(80)
      COMMON /REACH/ NR,NRL(20),NRU(20)
      COMMON /WDV/ WW(20),DD(20),VV(20)
      COMMON /SECT/ ND(80),X(80,50),Z(80,50),XL(80),XR(80),XSECT(80)
      COMMON /WIDTH/ WCH(80)
      DIMENSION GIN(12),ST(12)
      IF (ICOUNT.GT.1) GO TO 99
      DO 90 K=1,NR
      ZBL(K)=1.
      DETMAX=1.
      DZ(K)=0.
      DO 91 III=1,3
   91 GLAT(K,III)=0.
      DO 90 M=1,NS
   90 ZBLM(K,M)=ZBL(K)*PBO(M)
   99 CONTINUE
C
C     STORE LATERAL SEDIMENT INFLOW IN ARRAY
C
      IF (NT.EQ.0) GO TO 101
      JT=1
      DO 100 IR=1,NR
      IF (JT.GT.NT) GO TO 101
      NL=NRL(IR)
      NU=NRU(IR)
      IF (RDT(JT).GT.RD(NL).AND.RDT(JT).LE.RD(NU)) GO TO 102
      GO TO 100
  102 GLAT(IR,IT)=GLATN(JT)
      JT=JT+1
  100 CONTINUE
  101 CONTINUE
C     UPSTREAM SEDIMENT SUPPLY
      UPFAC=1.0
      G(NR+1,IT)=0.
      DO 9 M=1,NS
      GSC(NR+1,M)=UPFAC*GSC(NR,M)
      GS(NR+1,M)=GSC(NR+1,M)*PBA(NR,M)
    9 G(NR+1,IT)=G(NR+1,IT)+GS(NR+1,M)
      DO 10 I=1,NR
      IR=NR-I+1
      IR1=IR+1
      NL=NRL(IR)
      NU=NRU(IR)
      IF (IR.EQ.1) GO TO 11
      IF (IR.EQ.NR) GO TO 12
      DL=(RD(NU)-RD(NL)+.5*(RD(NU+1)-RD(NU)+
     $RD(NL)-RD(NL-1)))*5280.
      GO TO 13
   11 DL=(RD(NU)-RD(1)+0.5*(RD(NU+1)-RD(NU)))*5280.
      GO TO 13
   12 DL=(RD(NU)-RD(NL)+0.5*(RD(NL)-RD(NL-1)))*5280.
   13 CONTINUE
C
C     UPSTREAM SEDIMENT SUPPLY TO REACH
C
      GINT=G(IR1,IT)+GLAT(IR,IT)
      DO 107 M=1,NS
      IF (NT.EQ.0) GO TO 108
      GIN(M)=GS(IR1,M)+GLAT(IR,IT)*PTRIB(M)
      GO TO 107
  108 GIN(M)=GS(IR1,M)
  107 CONTINUE
C
C     SEDIMENT TRANSPORT CAPACITY OUT OF REACH
C
      GOUT=0.
      DO 20 M=1,NS
      GS(IR,M)=GSC(IR,M)*PBA(IR,M)
   20 GOUT=GOUT+GS(IR,M)
C
C     DETERMINE POTENTIAL EXCESS DETACHMENT
C
      DETP=(GINT-GOUT)*DT/(DL*WW(IR))
      IF (DETP.GT.0.) GO TO 60
      SDETP=DETP+ZBL(IR)
      IF (SDETP.GE.0.) GO TO 60
      DET=-SDETP
      DETM=DETMAX-ZBL(IR)
      IF (DET.GT.DETM) DET=DETM
      IF (DET.LE.0.) DET=0.
      GO TO 70
   60 DET=0.
   70 DO 75 M=1,NS
      ZBLM(IR,M)=ZBLM(IR,M)+DET*PBO(M)
   75 CONTINUE
      ZBL(IR)=ZBL(IR)+DET
```

```
C
C     DETERMINE ACTUAL TRANSPORT RATE
C
      GSSM=0.
      DO 80 M=1,NS
      ZBLM(IR,M)=(ZBLM(IR,M)*DL*WW(IR)/DT+GIN(M))/
     $            (GSC(IR,M)/ZBL(IR)+DL*WW(IR)/DT)
      GS(IR,M)=ZBLM(IR,M)*GSC(IR,M)/ZBL(IR)
   80 GSSM=GSSM+GS(IR,M)
      G(IR,IT)=GSSM
      DA(IR)=(GINT-GSSM)*DT/DL/(1.-PORB)
      SUMB=0.
      DO 111 M=1,NS
      ST(M)=ZBLM(IR,M)
  111 SUMB=SUMB+ZBLM(IR,M)
      SSUMB=SUMB
      IF (SSUMB.GT.DETMAX) GO TO 131
      GDIF=DETMAX-SSUMB
      DO 121 M=1,NS
  121 ST(M)=ST(M)+PBO(M)*GDIF
      SSUMB=DETMAX
  131 DO 141 M=1,NS
  141 PBA(IR,M)=ST(M)/SSUMB
      ZBL(IR)=SSUMB
      NXS=NRU(IR)-NRL(IR)+1
      DO 200 KK=1,NXS
      K=NL+KK-1
      WIDTH=P(K,IT)
      IF (WIDTH.GT.WCH(K)) WIDTH=WCH(K)
      DZ(K)=DA(IR)/WIDTH
      NPTS=ND(K)
      DO 301 N=1,NPTS
      IF (Z(K,N).GE.WSE(K)) GO TO 301
      IF (X(K,N).LT.XL(K)) GO TO 301
      IF (X(K,N).GT.XR(K)) GO TO 301
      Z(K,N)=Z(K,N)+DZ(K)
  301 CONTINUE
      CALL CHANGEO (K)
  200 CONTINUE
  201 CONTINUE
   10 CONTINUE
      RETURN
  999 DO 900 K=1,NCS
      DZ(K)=0.
  900 CONTINUE
      RETURN
      END
      SUBROUTINE FLUSH
      ENDFILE 6
      RETURN
      END
```