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EXECUTIVE SUMMARY

This report documents the CHARIMA numerical simulation program for computation of long-term bed evolution in multiply-connected fluvial channels. The code was initially developed in response to the need of Harza-Ebasco Susitna Joint Venture to forecast the effect of possible flow modulation by two proposed Susitna hydropower dams on sediment deposition patterns in the highly braided 15-mile reach at the Susitna River from the Chulitna-Talkeetna confluence down to the Sunshine bridge. This original code, BRALLUVIAL, was subsequently generalized for unsteady water flow and renamed CHARIMA.

The quasi-two-dimensionality of deposition patterns in the area of the Chulitna-Talkeetna-Susitna confluence necessitated development of a simulation technique based on recognition of individual braided channels. The sedimentation methodology is based on that previously developed for simple channels and incorporated in the IALLUVIAL code. However it was necessary to develop a totally new water flow methodology to handle the multiple flow paths of the braided system. The resulting combination of new and existing techniques is based on an assumption of one-dimensional unsteady flow, and incorporates procedures for treatment of highly non-uniform sediments, sediment sorting, bed armoring, flow-dependent friction factor, and alternate drying and flooding of perched channels.

This report includes a theoretical analysis of the problem, detailed documentation of the CHARIMA program, instructions for program use, example applications, and Appendices containing programmer's and users' information as well as listings of the source code and a sample data set. Users of the PC version should refer to Appendix H and carefully follow its instructions.

ACKNOWLEDGEMENTS

Development of BRALLUVIAL and CHARIMA has been a collaborative effort, incorporating considerable previous developmental activity on the IALLUVIAL code. The IALLUVIAL development was supported by the Omaha District, U.S. Army Corps of Engineers; the Iowa State Water Resources Research Institute; and the National Science Foundation. BRALLUVIAL incorporates several subroutines written by Dr. M.F. Karim.
Dr. J.F. Kennedy guided, and provided considerable technical input to the IALLUVIAL development.

The unsteady-flow generalization was performed by Dr. J.C Yang. CHARIMA was further refined and documented by Ms. Patricia Schwarz and Dr. Joseph Schaefer, with support from the National Science Foundation's Research Experiences for Undergraduates and Research Opportunity programs, respectively. Mr. Robert Einhellig and S.H. Hsu contributed to the development and documentation of CHARIMA. Continuing CHARIMA development and application to Cho-Shui River is supported by NSF Grant MSM-8518166.

SOURCE-CODE LICENSE

The complete CHARIMA source code, and a license for its use, are available for a nominal handling and transfer fee from the Iowa Institute of Hydraulic Research.
I. INTRODUCTION

Analysis of the long-term effects of river-development schemes on alluvial-channel morphology has become an essential element of planning and feasibility studies for river engineering projects. Despite the present weaknesses in understanding of the extremely complex mechanisms of sediment deposition onto the river-bed and reentrainment into the flow, engineers are nonetheless called upon to make their best possible predictions of bed-level changes over extended periods of time. These predictions are commonly based on the use of numerical simulation techniques.

Virtually all developmental efforts consecrated to the bed-evolution simulation problem have dealt with simple systems of a single river channel, branched channel systems, or systems having a few isolated multiply-connected flow paths. But when a river carries an extremely high sediment load imposed upon it by a tributary, it tends to form a braided system of multiply connected channels, thus increasing overall sediment-transport capacity. Existing bed-evolution computational techniques are inadequate for treatment of this multi-channel problem.

In 1984 the Harza-Ebasco Susitna Joint Venture requested the Iowa Institute of Hydraulic Research (IIHR) to develop and furnish a computational code for the prediction of the long-term bed evolution in a portion of the Susitna River, Alaska. As can be seen in Figure I.1, this 14-mile reach of the Susitna (from near Talkeetna to the Sunshine Bridge, RM 98.1 to RM 83.9), is highly braided due to the heavy sediment inflows coming from the Chulitna and Talkeetna tributaries. During preliminary review of existing data, it became apparent that it would be impossible to perform reliable long-term simulation through assimilation of the multiple braided channels into a single equivalent channel. Indeed, in the vicinity of the Chulitna-Talkeetna confluence, the channel evolution patterns must be considered as at least quasi-two-dimensional. The Chulitna water and sediment inflows enter primarily the right-bank channel, whereas the Talkeetna inflows enter primarily the left-bank channel. It would have been impossible to study the detailed interactions among water and sediment from the three sources (Susitna, Chulitna, Talkeetna) in this zone without explicit recognition of the multiple flow paths. Therefore the needs of the Susitna project required that a new technique for treatment of multiply-connected alluvial systems be developed. The BRALLUVIAL and CHARIMA codes, the latter of whose description is the primary purpose of this report, are the results of the developmental efforts.
Figure I.1. Schematic diagram of a portion of the Susitna multiply-connected network.
The BRALLUVIAL and CHARIMA programs stand on the shoulders of two existing state-of-the-art codes. The first one is IIHR's IALLUVIAL program, which computes quasi-steady water and sediment movement, and bed evolution, in a single channel having non-uniform bed sediments and subject to bed armoring and sorting processes. (Karim and Kennedy, 1982; Karim and Holly, 1983; Holly and Karim, 1983; Karim, Holly, and Kennedy, 1983; Holly, Yang, and Karim, 1984). The second code is SOGREAH's CARIMA program for unsteady flow computation in branched and looped fixed-bed channel systems (Holly and Cunge, 1978).

The remainder of this report is devoted to a detailed description of the formulations and procedures employed in CHARIMA. A complete description of the Susitna application can be found in the Harza-Ebasco companion report (Lin, 1985). The BRALLUVIAL code is fully documented by Holly et al. (1985). Additional analysis of CHARIMA can be found in the thesis of Yang (1986). Most of the material in this report originally appeared in one or the other of these latter two documents.
II. THEORETICAL BASIS AND SOLUTION STRATEGY

II.1. Governing Equations and Hypotheses

The basic one-dimensional governing equations for unsteady water flow and nonuniform sediment transport in a channel are:

Water-Continuity Equation

\[ \frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \]  \hspace{1cm} (II.1)

Momentum Equation

\[ \frac{\partial Q}{\partial t} + \frac{1}{A} \left( \frac{\partial}{\partial x} (\alpha \frac{Q^2}{A}) + gA \frac{\partial y}{\partial x} + gA \frac{Q_0 Q_i}{K^2} \right) = 0 \]  \hspace{1cm} (II.2)

Sediment-Discharge Predictor

\[ F_1(Q_s, D_{50}, Q, A, d, S_f, ACF) = 0 \]  \hspace{1cm} (II.3)

Friction-Factor Predictor

\[ F_2(Q, A, D_{50}, S_f, d, ACF) = 0 \]  \hspace{1cm} (II.4)

Sediment Continuity Equation

\[ (1-p) B \frac{\partial z}{\partial t} + \frac{\partial Q_s}{\partial x} = 0 \]  \hspace{1cm} (II.5)

Channel Geometry

\[ A = A(d; x) \]  \hspace{1cm} (II.6)

\[ B = B(d; x) \]  \hspace{1cm} (II.7)
Hydraulic Sorting of Bed Material

\[ D_{50}^n \rightarrow D_{50}^{n+1} \]  \hspace{1cm} (II.8)

Armoring of Bed Surface

\[ ACF^n \rightarrow ACF^{n+1} \]  \hspace{1cm} (II.9)

where,

- \( Q \) = water discharge;
- \( A \) = cross-sectional area;
- \( y \) = water surface elevation;
- \( S_f \) = energy slope;
- \( g \) = gravitational acceleration;
- \( \alpha \) = momentum correction factor;
- \( z \) = bed elevation;
- \( Q_s \) = sediment discharge;
- \( D_{50} \) = median size of bed material;
- \( B \) = water surface width;
- \( ACF \) = armoring factor (proportion to the bed surface covered by the immovable particles);
- \( p \) = porosity;
- \( K \) = conveyance;
- \( d \) = flow depth.

The two independent variables are \( x \), the longitudinal coordinate; and \( t \), time. The gravitational acceleration \( g \), the sediment porosity \( p \), and many other physical quantities which are independent of the bed evolution process appear in the functions \( F_1 \) and \( F_2 \). Eq. (II.8) symbolizes the accounting operations which simulate the sorting, \( n \) and \( n+1 \) representing successive points in time. Eq. (II.9) symbolizes the additional accounting operations which simulate development and destruction of a stable armor layer. Continuous lateral inflow is not considered in the above formulations, but it can be added with no algorithm complication.

For water flow, the de St Venant (1871) hypotheses are essentially taken into account in the above equations:
1) the flow is one-dimensional, i.e., the velocity is uniform over the cross section and the water level across the section is horizontal;

2) hydrostatic pressure distribution prevails at any point in the channel;

3) the resistance laws for steady-state flow are applicable to unsteady flow;

4) the channel bed slope is small.

In addition to the above assumptions, when looped-channel formulations are applied, the channel network pattern must be assumed unchanged during the simulation. Channels may be dried out at low flow or flooded and indistinguishable one from another at high flow, but the total number of channels in the network and their interconnections must remain the same.

Furthermore, since only one-dimensional phenomena are considered, one has to assume something about how the section changes as a consequence of bed evolution. In this study, the cross section is assumed to rise or fall without changing its shape. Again, due to the one-dimensional restriction, the effect of river meanders on sediment transport, which may be considered as a dominant factor for a study reach with many small-curvature bends, cannot be covered in the above formulations. Many other restrictions associated with sediment-routing processes have also to be imposed, for example, those required for sorting and armoring processes, and sediment discharge and friction-factor predictors as described in subsequent sections. Finally, a basic assumption is that the sediment transport at a given time and location is a function only of local hydraulic and bed-sediment conditions.

**II.2. Iterative Coupled Approach**

At any instant, the entire system of equations (II.1) to (II.7) must be simultaneously satisfied and consistent with the sorting and armoring processes of Eqs. (II.8) and (II.9). Were it possible to obtain an analytical solution to the entire system, this requirement of simultaneity would naturally be satisfied. But of course such an analytical solution cannot be obtained, due to the inherent nonlinearities; the tabular nature of Eqs. (II.6) and (II.7) for natural channels; the ad-hoc procedures (as opposed to mathematical relationships) of Eqs. (II.8) and (II.9); and the need to solve Eq. (II.5) for each size fraction, followed by a reconstitution of the total change in bed elevation, z.
Since no analytical solution is possible, a numerical method whose central feature is Preissmann's finite-difference approximation to Eqs. (II.1), (II.2), and (II.5) is used. The scheme replaces a continuous function, e.g., \( Q \), its time derivative and its space derivative by the following formulae:

\[
Q = \theta \left[ \phi Q_{i+1}^{n+1} + (1 - \phi) Q_{i}^{n+1} \right] + (1 - \theta) \left[ \phi Q_{i+1}^{n} + (1 - \phi) Q_{i}^{n} \right] \tag{II.10}
\]

\[
\frac{\partial Q}{\partial t} = \frac{1}{\Delta t} \left[ \phi \left( Q_{i+1}^{n+1} - Q_{i}^{n+1} \right) + (1 - \phi) \left( Q_{i+1}^{n} - Q_{i}^{n} \right) \right] \tag{II.11}
\]

\[
\frac{\partial Q}{\partial x} = \frac{1}{\Delta x} \left[ \theta \left( Q_{i+1}^{n+1} - Q_{i}^{n+1} \right) + (1 - \theta) \left( Q_{i+1}^{n} - Q_{i}^{n} \right) \right] \tag{II.12}
\]

in which the superscript \( n \) denotes the time level, the subscript \( i \) denotes the computational section; \( \Delta t \) is the computational time step; \( \Delta x \) is the distance between points \( i \) and \( i+1 \) (not necessarily constant); and \( \theta \) and \( \phi \) are weighting factors between 0 and 1. In CHARIMA, \( \phi = 1/2 \) is adopted throughout. Therefore, Eqs. (II.1), (II.2), and (II.5) take the following algebraic forms, after use of the Preissmann discretizations:

\[
\frac{1}{2\Delta t} \left( A_{i+1}^{n+1} - A_{i}^{n+1} \right) + \frac{1}{2\Delta t} \left( A_{i}^{n+1} - A_{i}^{n} \right) + \frac{\theta}{\Delta x} \left( Q_{i+1}^{n+1} - Q_{i}^{n+1} \right) + \frac{1-\theta}{\Delta x} \left( Q_{i+1}^{n} - Q_{i}^{n} \right) = 0 \tag{II.13}
\]

\[
\frac{1}{2\Delta t} \left( Q_{i+1}^{n+1} - Q_{i+1}^{n} \right) + \frac{1}{2\Delta t} \left( Q_{i}^{n+1} - Q_{i}^{n} \right) + \alpha \theta \left( \frac{Q_{i}^{n+1}}{A_{i}^{n+1}} + \frac{Q_{i}^{n+1}}{A_{i+1}^{n+1}} \right) + \alpha (1 - \theta) \left( \frac{Q_{i}^{n}}{A_{i}^{n}} + \frac{Q_{i+1}^{n}}{A_{i+1}^{n+1}} \right)
\]

\[
\frac{\theta}{\Delta x} \left( Q_{i+1}^{n+1} - Q_{i}^{n+1} \right) + \frac{1-\theta}{\Delta x} \left( Q_{i+1}^{n} - Q_{i}^{n} \right)
\]
\[-\alpha \left[ \frac{\theta}{4} \left( \frac{Q_i^{n+1}}{A_i^{n+1}} + \frac{Q_{i+1}^{n+1}}{A_{i+1}^{n+1}} \right)^2 + \frac{1-\theta}{4} \left( \frac{Q_i^n}{A_i^n} + \frac{Q_{i+1}^n}{A_{i+1}^n} \right)^2 \right] \]

\[\frac{\theta}{\Delta x} \left( A_{i+1}^{n+1} - A_i^{n+1} \right) + \frac{1-\theta}{\Delta x} \left( A_{i+1}^n - A_i^n \right) \]

\[+ \frac{\theta}{2} \left( A_i^{n+1} + A_{i+1}^{n+1} \right) + \frac{1-\theta}{2} \left( A_i^n + A_{i+1}^n \right) \]

\[\frac{\theta}{\Delta x} \left( y_{i+1}^{n+1} - y_i^{n+1} \right) + \frac{1-\theta}{\Delta x} \left( y_{i+1}^n - y_i^n \right) \]

\[+ \frac{\theta}{2} \left( A_i^{n+1} + A_{i+1}^{n+1} \right) + \frac{1-\theta}{2} \left( A_i^n + A_{i+1}^n \right) \]

\[\left\{ \beta \left[ \frac{Q_i^{n+1} |Q_i^{n+1}|}{(K_i^{n+1})^2} + (1-\beta) \frac{Q_{i+1}^{n+1} |Q_{i+1}^{n+1}|}{(K_{i+1}^{n+1})^2} \right] \right\} = 0 \quad \text{(II.14)} \]

\[\frac{z_i^{n+1} - z_i^n + z_{i+1}^{n+1} - z_{i+1}^n}{\Delta t} = \frac{4\theta(Q_{S_i}^{n+1} - Q_{S_i}^{n+1})}{(1-p)(B_i^{n+1} + B_{i+1}^{n+1}) \Delta x} \]

\[+ \frac{4(1-\theta)(Q_{S_i}^n - Q_{S_i+1}^n)}{(1-p)(B_i^n + B_{i+1}^n) \Delta x} \quad \text{(II.15)} \]
Since all needed values are known at time level n (from the initial condition or from the results of the previous time step), the problem becomes one of solving the nonlinear algebraic system of Eqs. (II.3), (II.4), (II.6-II.9), and (II.13-II.15) in which the nine unknowns would be understood to be at time level n+1. But even this formal approach is not feasible, since Eqs. (II.8) and (II.9) are non-analytical accounting procedures which have not been expressed as closed-form mathematical expressions.

This apparent impossibility of obtaining a simultaneous solution to even the algebraic equivalent of the original differential system leads to the adoption of a decoupling technique. The solution proceeds in three stages:

1) Equations (II.3, II.4, II.6, II.7, and II.13-II.14) are solved in a "hydraulic sweep". During this sweep, the bed elevation $z$, median diameter $D_{50}$, and armoring factor ACF are held constant, as if the bed were temporarily frozen. The essential result of this sweep is a calculation of the sediment transport capacity, and associated hydraulic parameters, at every point $i$ and for every size fraction of bed material.

2) Equation (II.15) is solved in a "downstream sweep" from the upstream to the downstream boundaries to yield the new bed elevations $z_{i}^{n+1}$ at each point $i$. This sweep treats the $Q_{Si}^{n+1}$ values as constant, as if the sediment transport capacity were temporarily unaffected by bed elevation, armoring, or median sediment size changes.

3) The accounting processes of Eqs. (II.8) and (II.9) are finally executed using the degradation or aggradation computed in step (2) above.

This methodology is referred to as "uncoupled", since it assumes that the three processes occur sequentially, and not concurrently, within a given time step. This apparent blatant violation of the principle of simultaneity of all mechanisms involved is rendered necessary by the practical difficulties associated with the lack of a closed-form representation of the armoring and sorting processes.

Most numerical models of physical processes use such a decoupling procedure, whose validity rests on the assumption that the change in any one variable during a time step is small enough that its effect on the other variables (during the time step) can be ignored. The objective of the iterative coupling procedure is to obtain, through iterative repetition within one time step, a genuine simultaneous solution of Eqs. (II.3, II.4, II.6-
II.9, II-13-II.15). The required sequence of iteration operations within one time step can be expressed as follows:

1) Load imposed boundary conditions (mainstem and tributary water and sediment inflows, downstream water surface elevation).

2) Using a fixed-bed elevation \( z \) (latest estimate), and the latest estimates of \( D_{50} \) and ACF, compute the depth \( d \), flow area \( A \), energy slope \( S_e \), water surface width \( B \), water discharge \( Q \), and sediment-discharge capacity \( Q_s \) at each computational point through simultaneous solution of Eqs. (II.3, II.4, II.6, II.7, II.13, and II.14).

3) Using the values of \( Q_s \) and \( B \) computed in step 2) above, compute the new estimates of bed surface elevation \( z \) from Eq. (II.15).

4) Using the change in bed surface elevations computed in 3) above, compute the new estimates of armoring factor ACF and median sediment diameter \( D_{50} \) from Eqs. (II.8) and (II.9).

Steps (2)-(4) are repeated iteratively until successive estimates of \( z_1^{n+1} \) no longer change. When this convergence is reached, one is assured that the values of \( Q_s \) and \( B \) in Eq. (II.15) result from simultaneous solution of Eqs. (II.3, II.4, II.6-II.9, II.13-II.14) at each time level \( n \) and \( n+1 \). A flow chart for the above-mentioned solution strategy within one-time step is shown in Figure II.1.

**II.3 Supplementary Empirical Relations**

**II.3.1. Sediment-Discharge Capacity.** Morphological computations for streams having nonuniform sediment requires that the sediment discharge be computed for each particle-size fraction. Many investigations have been focused on extending uniform-sediment transport models to the nonuniform sediment transport problem. A well-known example in which the sediment transport is separated for each particle size fraction is Einstein's bed-load concept (1950). The dimensionless transport of fraction \( j \) per Einstein's bed-load formula can be written as
Figure II.1. Flow chart for solution strategy in one time step.
\[
\frac{q_{sj}}{\sqrt{(s-1)gD_j^3}} = \frac{P_{tj}}{A_s} \frac{P}{1-P}
\] (II.16)

in which \(A_s\) is a universal constant; \(P\) is the probability of erosion; \(q_{sj}\) is the sediment discharge for particle size \(j\); \(D_j\) is the diameter of particle size \(j\); \(P_{tj}\) is the proportion of the size fraction \(j\) in the mixture; \(g\) is the gravitational constant; and, \(s\) is the specific gravity of sediment. The parameter \(P\) contains a hiding factor which is used to take into account the sheltering effect of smaller particles hiding behind larger ones.

Based on Einstein's concept, Meyer-Peter and Mueller (1948) developed a classical formula for transport of each size fraction:

\[
\frac{q_{sj}(1-p)}{\sqrt{(s-1)gD_j^3}} = 13.3 \ P_{tj} \left( \frac{C_f R_b S}{(s-1)D_j} - 0.047 \right)^{3/2}
\] (II.17)

where \(C_f\) is a function of the bed roughness; \(p\) is the porosity of the bed material; \(R_b\) is the hydraulic radius with the wall effect correction; and \(S\) is the bed slope.

Ashida and Michine (1973) considered a hiding effect appearing in the calculation of critical shear stress, and introduced this effect in a transport predictor as follows:

\[
\frac{q_{sj}}{\sqrt{(s-1)gD_j^3}} = 17 \ P_{tj} \left( \frac{3/2}{\tau_*} \left( 1 - \frac{\tau_{c*j}}{\tau_*} \right) \left( 1 - \frac{u_{c*j}}{u_*} \right) \right)
\] (II.18)

where \(u_*\) is the shear velocity; \(u_{c*j}\) is the critical shear velocity; \(\tau_*\) is the dimensionless shear stress; and \(\tau_{c*j}\) is the dimensionless critical shear stress developed by Egizaroff (1965):
\[
\tau_{e^*j} = \frac{\tau_{ej}}{(\gamma_s - \gamma_f) D_j} = \frac{0.1}{\log \left(19 \frac{D_L}{D_m}\right)} \tag{II.19}
\]

with

\[
D_m = \sum_{j+1}^{n} P_{tj} D_j \tag{II.20}
\]

where \(\gamma_s\) is the specific weight of sediment, and \(\gamma_f\) is the specific weight of fluid.

The above-mentioned methods were developed on the basis of bed-load transport formulae. There are a few methods which were developed on the basis of the total-load (bed plus suspended) formulae. The most commonly used are the modified TLTM method (Karim, 1985), the modified Ackers-White method (Proffitt and Sutherland, 1983), and the Laursen formulation (1958).

TLTM was developed by Karim and Kennedy (1982) to compute sediment discharge based on a representative particle size but coupled with the dependence of friction factor on the sediment discharge. In the original development, the size distribution of the transported material can be predicted, but the procedure requires the separation of suspended load and bed load. In addition, the size-distribution relations used for bed load and suspended load are not identical; therefore an accurate separation procedure for suspended load and bed load is required. This has been modified to a simplified form (i.e., the modified TLTM method, Karim, 1985) in which the sediment discharge for each particle size can be computed directly, as discussed in the following section.

The Ackers-White (1973) formula is a total-load predictor, and was extended by Proffitt and Sutherland (1983) to compute nonuniform sediment transport but limited to bed-load transport. A verification with the use of flume data was carried out.

Laursen's formula can also be used to compute the sediment discharge for each particle size fraction, but due to its complexity it is not appropriate for numerical modelling.
Engelund-Hansen’s formula is also coded in CHARIMA, but not evaluated herein. It has been pointed out (Garde et al., 1977) that the mechanism conceived by Engelund and Hansen does not describe the phenomenon of suspended-load transport adequately. In addition, no specific formulation has been developed yet to use this formula for computing sediment discharge by size fraction.

The four total-load predictors adopted for use in CHARIMA are the modified TLTM method, the modified Ackers-White method, the Engelund-Hansen method, and a power-law predictor.

**Modified TLTM Method:**

In reference to Karim’s development (1985) the dependence of friction factor on sediment transport can be decoupled from the full system of equations. The sediment discharge predictor used is:

\[
\log \left( \frac{q_s}{\sqrt{g(s-1)d_{50}^3}} \right) = a_0 + a_1 \log V_1 + a_2 \log V_1 \log V_3 + a_3 \log V_2 \log V_3 \quad (II.21)
\]

in which

\[
V_1 = \frac{U}{\sqrt{g(s-1)d_{50}}} ; V_2 = \frac{d}{d_{50}} ; V_3 = \frac{u_* - u_{*c}}{\sqrt{g(s-1)d_{50}}}
\]

where \( q_s \) is the total sediment discharge per unit width; \( U \) is mean velocity; \( d \) is mean depth of flow; and \( a_0, a_1, a_2, a_3 \) are the coefficients determined from regression analysis (\( a_0 = -2.278; a_1 = 2.972; a_2 = 1.06; \) and \( a_3 = 0.299 \) for the 615 flows analyzed by Karim and Kennedy (1982)). The relation proposed for the sediment discharge by size fraction is:

\[
q_{sj} = q_s(D_j) W_j P_{tj} \quad (II.22)
\]
where \( q_{sj} \) is the sediment discharge for particle size \( j \); \( q_s(D_j) \) is the sediment discharge computed from Eq. (II.21) by the use of \( D_j \) instead of \( D_{50} \); \( P_{tj} \) is the proportion of size fraction \( j \) in the bed material; and, \( W_j \) is a correction factor. In Karim's original approach (i.e., TLTM, 1982), the sediment discharge is computed by the use of median size \( D_{50} \) and then distributed to each size fraction by a distribution relation developed by Karim and Kennedy (1982). This original method requires the total load to be separated into suspended and bed loads.

Karim's proposed relation for \( W_j \) is as follows:

\[
W_j = b_1 \left( \frac{D_j}{D_u} \right)^{b_2}
\]

(II.23)

where \( b_1 \) and \( b_2 \) are coefficients which may have to be calibrated for particular models; and, \( D_u \) is the representative size of the bed material. Usually \( D_{50} \) is taken as the representative size, in this and other studies. \( W_j \) can be recognized as a hiding factor, which reflects the fact that smaller particles seem to "hide" behind larger ones. Although no definitive relation for \( W_j \) has yet been found, a successful application of Eq. (II.23) to the schematized Missouri-River model has been performed by Karim (1985):

**Modified Ackers-White Method:**

The formula developed by Ackers and White for uniform bed material is:

\[
\bar{C}_T = \frac{\gamma_s D_c 2 \left( \frac{F_0}{c_3} - 1 \right) c_4}{(u_* / U)^{c_1} \gamma_f d}
\]

(II.24)

in which
\[ F_0 = \left( \frac{u^c_1}{\sqrt{(s-1) g D_{35}}} \right) \left( \frac{U}{\sqrt{32 \log (10d/D_{35})}} \right)^{1-c_1} \]  

(II.25)

\[ d_\ast = ((s-1) g/v^2)^{1/3} D_{35} \]  

(II.26)

For \( 1.0 < d_\ast < 60.0 \),

\[ c_1 = 1.0 - 0.56 \log d_\ast \]

\[ c_2 = 10^{(2.86 \log d_\ast - (\log d_\ast)^2 - 3.53)} \]

\[ c_3 = 0.23/d_\ast^{1/2} + 0.14 \]

\[ c_4 = 9.66/d_\ast + 1.34 \]

For \( d_\ast > 60.0 \)

\[ c_1 = 0.0 \]

\[ c_2 = 0.025 \]

\[ c_3 = 0.17 \]
\[ c_4 = 1.5 \]

where \( \bar{C}_T \) is sediment flux concentration (sediment mass flux per unit mass flow rate). To apply this formula to nonuniform material, \( D_{35} \) has to be replaced by each particle size, and the mobility number \( F_0 \) has to be modified by the exposure correction factor \( \varepsilon_j \) which is defined as:

\[
\varepsilon_j = \frac{F_0 \text{ (to satisfy the measured data)}}{F_0 \text{ (from Eq. (II.25) with } D = D_j)}
\] (II.27)

Proffitt and Sutherland give \( \varepsilon_j \) as follows:

\[
\varepsilon_j = 1.3, \quad D_j / D_u > 3.7 \tag{II.28}
\]
\[
\varepsilon_j = 0.53 \log \left( \frac{D_j}{D_u} \right) + 1.0, \quad 0.075 < \frac{D_j}{D_u} < 3.7 \tag{II.29}
\]
\[
\varepsilon_j = 0.4, \quad \frac{D_j}{D_u} < 0.075 \tag{II.30}
\]

The scaling size \( D_u \) can be determined by another relation given by Proffitt and Sutherland:

\[
\frac{D_u}{D_{50}} = f \left[ u^2 / g(s-1) D_{50} \right] \tag{II.31}
\]

However, in practice \( D_{50} \) can always be used as the effective size \( D_u \).

**Engelund-Hansen Method:**

The formula developed by Engelund and Hansen (1967) for the total bed-material load capacity is:
\[ g_s = 0.05 \gamma_s V^2 \sqrt{\frac{D_{50}}{\gamma_s (\gamma_s - 1)}} \left[ \frac{\tau_0}{(\gamma_s - \gamma)D_{50}} \right]^{3/2} \]  

Equation (II.31A)

\[ q_s \text{ (discharge per unit width)} = \frac{g_s}{\gamma_s} \]

in which \( g_s \) = the bed material discharge in weight per unit width; \( V \) = mean flow velocity; \( D_{50} \) = median fall diameter of bed sediment; \( \tau_0 = \gamma d \) = average shear stress at bed level; \( d \) = flow depth. This formula is unit-consistent.

This formula is based on data from four sets of experiments in a large flume 8 ft wide and 150 ft long. The sediments in these experiments had median full diameters of 0.19 mm, and 0.27 mm, 0.45 mm and 0.93 mm, respectively, and geometric standard deviations of particle sizes of 1.3 for the finest sediment and 1.6 for the others.

Power-Law Method:

From a practical point of view, when a river or flume under simulation already has its own empirical relations between flow condition and sediment-transport rate, it is more reliable to use those relationships instead of a more general sediment-transport predictor. Based on measured data, one can construct a power-law relation between sediment transport rate and several flow parameters, e.g. discharge \( Q \), velocity \( V \) etc. The most reasonable way is generally to choose the effective velocity, that is the surplus velocity beyond that needed for incipient motion \((U - U_c)\):

\[ q_s = a \ (U - U_c)^b \]  

Equation (II.31b)

in which \( q_s \) = sediment discharge per unit width \((L^3/TL)\); \( a, b \) = regression constants from analysis of available data; \( U \) = average velocity; \( U_c \) = critical velocity when sediment
begins to move. $U_c(\text{ft/s})$ can be based, for example, on the ASCE manual "Sedimentation Engineering" Eq. (2.121),

$$U_c = 0.5 \left( \frac{\gamma_s}{\gamma} - 1 \right)^{1/2} d_g^{4/9} \tag{II.31c}$$

in which $d_g$ = the appropriate sediment size in millimeters, often taken as the geometric mean of the sizes defining size-class intervals for sediment mixtures. It is important to use the correct units which are consistent with the regression data since this formula is empirical and not dimensionless.

**II.3.2. Critical Shear Stress** As pointed out by many researchers, the rate of sediment transport is very sensitive to the transporting power, which can be expressed as a function of bed-shear force. This relationship can be observed in many of the sediment-discharge formulae commonly used. Inaccuracy in the determination of the critical shear force for the particle's incipient motion will lead to large errors of prediction of sediment transport capacity under given flow conditions.

Many studies have been performed to determine the critical tractive stress. However, every resulting predictive formulation has its own limitation due to the fact that the experiment carried out by each researcher used a limited range of sediment size and other constraints. The curve that Rouse (1939) fitted to Shields' diagram is still the most commonly used predictor, although some limitations have been pointed out. Egiazaroff (1965) indicated that the nonuniformity of the mixture greatly influences the mobility of particles. When particle diameter is greater than the average diameter of both particles in movement and bed material, the dimensionless critical shear stress will be less than the value of 0.06 which was obtained by Shields for large Reynolds number as shown in Figure II.2; the particle is more mobile than uniform particles of the same size. If particle diameter is less than the average diameter of both particles in movement and bed material, then the dimensionless critical shear stress will be greater than 0.06; the mobility of such particles is less than that of uniform particles. Thus, larger particles have high mobility in the mixture, and these larger particles tend to shelter the smaller particles. For a completely rough boundary, Neill (1968) has observed that the dimensionless critical shear stress value is on the high side and the true critical condition may occur for a critical shear stress.
of about 0.03. Furthermore, in a recent study by Shen and Lu (1983), the authors indicated that the effects of turbulence level and protrusion are important in the determination of critical shear stress for nonuniform bed material. As the standard deviation increases, the true critical shear stress will deviate increasingly from Rouse's curve. They therefore used a modification of Rouse's curve in their study.

Many other techniques have been developed to take into account the effect of nonuniformity for the determination of critical shear stress. Some examples pointed out by Garde and Ranga Raju (1977) are those of Kramer (1939), USWES (1937), Chang (1939), Indri (1956), Aki and Sata (1956), and Sakai (1956). However, in spite of the fact that many such methods are available, they are always rather difficult to formulate in the context of numerical modelling due to the difficulty of adjusting some empirical coefficients appearing in the formulation.

Based on the above-mentioned phenomena of sheltering effects and increased mobility of coarser particle in the mixture, the equation developed by Iwagaki (1956) appears to be an appropriate one and is compared with Rouse's curve herein. As shown in Figure II.2, it is obvious that the critical shear stress for the smaller particles is greater than that in Rouse's curve, and for larger particles it is smaller. Iwagaki's formulation can be expressed as follows:

\[
R_o^* = (s-1)^{1/2} g^{1/2} D^{3/2} / \nu \]  

\[
R_o^* \geq 671, \quad \tau_{oc}/(\gamma_s-\gamma_f) D = 0.05
\]

\[
162.7 \leq R_o^* \leq 671, \quad \tau_{oc}/(\gamma_s-\gamma_f) D = 8.45 \times 10^{-3} (R_o^*)^{3/11}
\]

\[
54.2 \leq R_o^* \leq 162.7, \quad \tau_{oc}/(\gamma_s-\gamma_f) D = 0.034
\]

\[
2.14 \leq R_o^* \leq 54.2, \quad \tau_{oc}/(\gamma_s-\gamma_f) D = 0.195 (R_o^*)^{-7/16}
\]

\[
R_o^* \leq 2.14, \quad \tau_{oc}/(\gamma_s-\gamma_f) D = 0.14
\]
Iwagaki (1956) considered the equilibrium of a single spherical particle placed on a rough surface and derived an analytical formulation for determining the beginning of motion of the particle. Furthermore, in order to take into account the sheltering effect, he introduced an empirical coefficient and constructed the curve as given in Figure II.2.

In order to have the new code as general as possible, both Rouse's and Iwagaki's curves are coded in the program. If any better formulations are developed, they also can be easily inserted in these codes without any major change in the program structure.

II.3.3. Friction Factor  The friction-factor predictor developed by Karim and Kennedy (1982) is used herein, as follows:

\[
\frac{U}{\sqrt{g(s-1)D_{50}}} = c_5 \left( \frac{q}{\sqrt{g(s-1)D_{50}^3}} \right)^{c_6} (S_f \cdot 10^3)^{c_7} \tag{II.34}
\]

where \( q \) = unit water discharge; and \( c_5 \), \( c_6 \), and \( c_7 \) are the coefficients determined from the regression analysis of a given data base. For the 615 flows analyzed by Karim and Kennedy (1982), these coefficients are \( c_5 = 0.33 \), \( c_6 = 0.376 \), and \( c_7 = 0.310 \).

II.3.4. Dune-Height Predictor  Allen's relation (1978) is as follows:

\[
H_d = d \left[ e_0 + e_1 \left( \frac{\eta}{3} \right) + e_2 \left( \frac{\eta}{3} \right)^2 + e_3 \left( \frac{\eta}{3} \right)^3 + e_4 \left( \frac{\eta}{e} \right)^4 \right];
\]

\[(0.25 \leq \eta \leq 1.5) \tag{II.35}\]

where \( \eta = \tau_o/(\rho(s-1)gD_{50}) \); \( \tau_o \) = bed shear stress; \( e_0 = 0.079865 \); \( e_1 = 2.23897 \); \( e_2 = -18.1264 \); \( e_3 = 70.9001 \); and \( e_4 = -88.3293 \). The relation developed by Yalin et al. (1979) is:

21
Figure II.2. Condition for incipient motion.
\[ \frac{\delta}{\delta_{\text{max}}} = \epsilon_d \exp(1-\epsilon_d) \]  \hspace{1cm} (II.36)

in which

\[ \epsilon_d = x \sqrt{x} \]

\[ x = \text{dimensionless excess of the tractive force}; \]

\[ \bar{x} = \text{value of } x \text{ corresponding to } \delta_{\text{max}}; \]

\[ \delta = H_d/\Lambda = \text{dune steepness}; \]

\[ \delta_{\text{max}} = \text{maximum value of } \delta \text{ corresponding to a given } \bar{x}; \]

From Eq. (II.36) if \( d/D \) and \( x \) are known, then \( H_d \) can be solved. Based on Yalin et al. (1978),

\[ \delta_{\text{max}} = 0.0095, \bar{x} = 2.03; \hspace{1cm} 20 \leq d/D \leq 30 \]

\[ \delta_{\text{max}} = 0.018, \bar{x} = 3.85; \hspace{1cm} 40 \leq d/D \leq 50 \]

\[ \delta_{\text{max}} = 0.027, \bar{x} = 5.78; \hspace{1cm} 65 \leq d/D \leq 75 \]  \hspace{1cm} (II.37)

\[ \delta_{\text{max}} = 0.006, \bar{x} = 12.84; \hspace{1cm} 100 \leq d/D \]

In order to compute the dune height \( H_d \), the length of dune has to be determined. In general, under the assumption of fully developed turbulent flow, the following relation can be used for the dune length:

23
\[ \Lambda = 2\pi d \]  

(II.38)

However, if \( d/D \) is smaller than about 25, then

\[ \Lambda = 20d \]  

(II.39)

Therefore, from Eqs. (II.37-39), the dune height can be obtained.

II.4. Unsteady Flow Computation

II.4.1. Introduction  In a single-channel model, each computational point is hydraulically linked only to two other points, immediately upstream and downstream. Moreover, the flow at a point is governed by the conditions at two boundary points at which the discharge, the water level, or relation between them is known. The flow paths from a point to its governing boundary points are unique; the significant result is that the matrix of linearized flow equations for the network is not only sparse, but also banded (tri-diagonal or penta-diagonal). This type of matrix can be efficiently solved using techniques such as the double-sweep method (Carnahan et al, 1969; Liggett and Cunje, 1975). The same conclusions hold true for branched networks in which channel junctions serve as interior boundary conditions, making it possible to use single-channel solution techniques.

In multiply-connected networks, on the other hand, flow at a point can directly depend on flow at several other points, and there is no unique path to boundary points. In this case the matrix of flow equations is sparse but not simply banded. Taking advantage of this sparsity, the algorithm described in the following sections still allows the system of equations to be solved without inverting the whole matrix, at the price of considerable increase in algorithmic complexity.
Figure II.3 establishes some definitions to be used in the sequel. A node is any junction of two or more links, or a boundary point; a link is any flow path beginning at one node and ending at another; a point is any location along a link at which the cross section is known and with which hydraulic parameters are associated; a reach is any stretch of channel between two points. Any link always has at least two points, one associated with the node at each end.

II.4.2. Node Continuity  At nodes, the water-continuity equation (inflow = outflow) is applied. For any node \( m \) at time level \( n+1 \), the continuity equation can be written:

\[
Q_m(t_{n+1}) + \sum_{\ell=1}^{L(m)} Q_{m,\ell}^{n+1} = 0, \quad m = 1, 2, ..., M
\]  

(II.40)

where \( L(m) \) denotes the total number of links connected to node \( m \), \( M \) is the total number of nodes in the network, and \( Q(t_{n+1}) \) is any external inflow to node \( m \) at time \( t_{n+1} \). If the discharge is expressed as the sum of the latest estimate \( Q \) and a correction to that estimate \( \Delta Q \) Eq. (II.40) can be rewritten as

\[
Q_m(t_{n+1}) + \sum_{\ell=1}^{L(m)} Q_{m,\ell} + \sum_{\ell=1}^{L(m)} \Delta Q_{m,\ell} = 0, \quad m = 1, 2, ..., M
\]  

(II.41)

Now \( Q_m(t_{n+1}) \) and \( Q_{m,\ell} \) are known quantities, but the \( \Delta Q_{m,\ell} \) values are unknown. The nodal solution strategy consists in using the de St. Venant equations along the links between nodes to express the \( \Delta Q \) values in terms of corrections to water surface elevations at the nodes.
Figure II.3. Topological definition sketch.
II.4.3. Discretization of Equations  The discretized continuity and momentum equations, based on Preissmann's finite-difference approximations, are given earlier as Eqs. (II.13) and (II.14).

As described by Liggett and Cunge (1975), with the use of Taylor's Series expansion Eqs. (II.13) and (II.14) can be written as:

\[
A_0 \Delta y_{i+1} + B_0 \Delta Q_{i+1} = C_0 \Delta y_i + D_0 \Delta Q_i + G_0
\]  

(II.42)

\[
A'_0 \Delta y_{i+1} + B'_0 \Delta Q_{i+1} = C'_0 \Delta y_i + D'_0 \Delta Q_i + G'_0
\]

(II.43)

where \( i \) and \( i+1 \) are indices of computational points at either end of the reach, \( \Delta Q \) and \( \Delta y \) are the increments of discharge and water surface elevation for every point during one iteration, and the positive flow direction is defined from \( i+1 \) to \( i \). Coefficients \( A_0, B_0, C_0, D_0, G_0, A'_0, B'_0, C'_0, D'_0, G'_0 \) are as follows:

\[
A_0 = \frac{\phi B_{i+1}}{\Delta t}
\]

(II.44)

\[
B_0 = D_0 = \frac{\theta}{\Delta x}
\]

(II.45)

\[
C_0 = - (1-\phi) \frac{B_i}{\Delta t}
\]

(II.46)

\[
G_0 = \frac{\phi}{\Delta t} \left( A_i^{n+1} - A_{i+1}^{n+1} \right) + \frac{(1-\phi)}{\Delta t} \left( A_i^{n} - A_i^{n+1} \right)
\]

\[
+ \frac{\theta}{\Delta x} \left( Q_{i+1}^{n} - Q_{i+1}^{n+1} \right) + \frac{(1-\theta)}{\Delta x} \left( Q_i^{n} - Q_{i+1}^{n} \right)
\]

(II.47)
\[
A_o^n = \frac{-\alpha \theta Q_i^{n+1} B_i^{n+1}}{(A_i^{n+1})^2} \left[ \frac{\theta}{\Delta x} \left( Q_{i+1}^{n+1} - Q_i^{n+1} \right) + \frac{(1-\theta)}{\Delta x} \left( Q_i^{n+1} - Q_i^n \right) \right]
\]

\[
\frac{\alpha \theta B_{i+1}^{n+1}}{\Delta x} \left[ \frac{\theta}{4} \left( \frac{Q_i^{n+1}}{A_{i+1}^{n+1}} + \frac{Q_{i+1}^{n+1}}{A_i^{n+1}} \right)^2 + \frac{1-\theta}{4} \left( \frac{Q_i^n}{A_i^n} + \frac{Q_{i+1}^n}{A_{i+1}^n} \right)^2 \right]
\]

\[
+ \frac{\alpha \theta Q_{i+1}^{n+1} B_{i+1}^{n+1}}{2(A_{i+1}^{n+1})^2} \left[ \frac{\theta}{\Delta x} \left( A_{i+1}^{n+1} - A_{i}^{n+1} \right) \right]
\]

\[
+ \frac{1-\theta}{\Delta x} \left( A_{i+1}^n - A_i^n \right)
\]

\[
+ \frac{\theta g}{\Delta x} \left[ \frac{\theta}{2} \left( A_{i+1}^{n+1} + A_{i+1}^n \right) + \frac{1-\theta}{2} \left( A_i^{n+1} + A_i^n \right) \right]
\]

\[
+ \frac{\theta g B_{i+1}^{n+1}}{2} \left[ \frac{\theta}{\Delta x} \left( y_{i+1}^{n+1} - y_i^{n+1} \right) + \frac{1-\theta}{\Delta x} \left( y_{i+1}^n - y_i^n \right) \right]
\]
\[ \begin{align*}
\theta g(1-\beta) \frac{Q_{i+1}^{n+1} Q_{i+1}^{n+1} (K_{i+1}^{n+1})}{(K_{i+1}^{n+1})^3} & \left[ \theta \left( A_i^{n+1} + A_{i+1}^{n+1} \right) + (1-\theta) \left( A_i^n + A_{i+1}^n \right) \right] \\
+ \frac{\theta g B_{i+1}^{n+1}}{2} & \left[ \theta \left( \frac{Q_i^{n+1} Q_i^{n+1}}{(K_i^{n+1})^2} + (1-\beta) \frac{Q_{i+1}^{n+1} Q_{i+1}^{n+1}}{(K_{i+1}^{n+1})^2} \right) \\
+ (1-\theta) \left( \frac{Q_i^n Q_i^n}{(K_i^n)^2} + (1-\beta) \frac{Q_{i+1}^n Q_{i+1}^n}{(K_{i+1}^n)^2} \right) \right] \\
& \text{(II.48)}
\end{align*} \]

\[ B'_o = \frac{\phi}{\Delta t} + \alpha \frac{\theta}{\Delta x} \left[ \theta \left( \frac{Q_i^{n+1} + Q_{i+1}^{n+1}}{A_i^{n+1} + A_{i+1}^{n+1}} \right) + (1-\theta) \left( \frac{Q_i^n + Q_{i+1}^n}{A_i^n + A_{i+1}^n} \right) \right] \\
+ \alpha \frac{\theta}{\Delta x A_{i+1}^{n+1}} \left[ \theta \left( Q_{i+1}^{n+1} - Q_i^{n+1} \right) + (1-\theta) \left( Q_{i+1}^n - Q_i^n \right) \right] \]

\[ - \frac{\alpha \theta}{2 A_{i+1}^{n+1} A_i^{n+1}} \left( \frac{Q_i^{n+1}}{A_i^{n+1}} + \frac{Q_{i+1}^{n+1}}{A_{i+1}^{n+1}} \right) \left[ \theta \left( A_i^{n+1} + A_{i+1}^{n+1} \right) + (1-\theta) \left( A_i^n + A_{i+1}^n \right) \right] \]
\[ g \theta (1 - \beta) \frac{Q_i^{n+1}}{|K_{i+1}|^2} \left[ \theta \left( A_i^{n+1} + A_{i+1}^{n+1} \right) + (1 - \theta) \left( A_i^n + A_{i+1}^n \right) \right] \quad (II.49) \]

\[ C' = \frac{\alpha \theta B_i^{n+1} Q_i^{n+1}}{(A_i^{n+1})^2} \left[ \frac{\theta}{\Delta x} \left( Q_i^{n+1} - Q_i^n \right) + \frac{1 - \theta}{\Delta x} \left( Q_{i+1}^n - Q_i^n \right) \right] \]

\[ \alpha \theta B_i^{n+1} \frac{Q_i^{n+1}}{(A_i^{n+1})^2} \left[ \frac{\theta}{4} \left( \frac{Q_i^{n+1}}{A_i^{n+1}} + \frac{Q_{i+1}^{n+1}}{A_{i+1}^{n+1}} \right)^2 + \frac{1 - \theta}{4} \left( \frac{Q_i^n}{A_i^n} + \frac{Q_{i+1}^n}{A_{i+1}^n} \right)^2 \right] \]

\[ \frac{\alpha \theta B_i^{n+1} Q_i^{n+1}}{(A_i^{n+1})^2} \frac{Q_{i+1}^{n+1}}{(A_i^{n+1}) + \frac{Q_{i+1}^{n+1}}{A_{i+1}^{n+1}}} \left[ \frac{\theta}{\Delta x} \left( A_i^{n+1} - A_i^n \right) + \frac{1 - \theta}{\Delta x} \left( A_{i+1}^n - A_i^n \right) \right] \]

\[ + \frac{\theta g}{2 \Delta x} \left[ \theta \left( A_i^{n+1} + A_{i+1}^{n+1} \right) + (1 - \theta) \left( A_i^n + A_{i+1}^n \right) \right] \]

\[ \frac{\theta g B_i^{n+1} y_i^{n+1}}{2 \Delta x} \left[ \theta \left( y_{i+1}^{n+1} - y_i^{n+1} \right) + (1 - \theta) \left( y_{i+1}^n - y_i^n \right) \right] \]
\[
\theta \beta g \frac{K_i^{n+1}}{K_i^{n+1}} Q_{i+1}^{n+1} | Q_i^n | + \frac{\theta g B_i^{n+1}}{2} \left\{ \theta \left( \frac{Q_i^{n+1} | Q_i^n |}{(K_i^{n+1})^2} + (1-\theta) \frac{Q_{i+1}^{n+1} | Q_{i+1}^n |}{(K_{i+1}^{n+1})^2} \right) \right. \\
\left. + (1-\theta) \left( \frac{Q_i^n | Q_i^n |}{(K_i^n)^2} + (1-\beta) \frac{Q_{i+1}^n | Q_{i+1}^n |}{(K_{i+1}^n)^3} \right) \right\} 
\]

\[
D_0' = \frac{\phi - 1}{\Delta t} + \frac{\alpha \theta}{\Delta x} \left[ \theta \left( \frac{Q_i^{n+1} | Q_i^{n+1} |}{A_i^{n+1}} + \frac{Q_{i+1}^{n+1} | Q_{i+1}^{n+1} |}{A_{i+1}^{n+1}} \right) + (1-\theta) \left( \frac{Q_i^n | Q_i^n |}{A_i^n} + \frac{Q_{i+1}^n | Q_{i+1}^n |}{A_{i+1}^n} \right) \right] \\
- \frac{\alpha \theta}{A_i^{n+1}} \left[ \frac{\theta}{\Delta x} (Q_{i+1}^{n+1} - Q_i^{n+1}) + \frac{1-\theta}{\Delta x} (Q_{i+1}^n - Q_i^n) \right] \\
+ \frac{\alpha \theta}{2A_i^{n+1}} \left( \frac{Q_i^{n+1} | Q_i^{n+1} |}{A_i^{n+1}} + \frac{Q_{i+1}^{n+1} | Q_{i+1}^{n+1} |}{A_{i+1}^{n+1}} \right) \left[ \theta \left( A_i^{n+1} - A_i^n \right) + \frac{(1-\theta)}{\Delta x} (A_{i+1}^n - A_i^n) \right]
\]
\[
- g \phi \gamma \left| Q_i^{n+1} \right| \frac{1}{K_i^{n+1}} \left[ \theta \left( A_i^{n+1} + A_{i+1}^{n+1} \right) + (1-\theta) \left( A_i^n + A_{i+1}^n \right) \right]
\]

\[
- Q_i^n = \frac{\phi}{\Delta t} \left( Q_{i+1}^{n+1} - Q_i^n \right) + \frac{1-\phi}{\Delta t} \left( Q_i^{n+1} - Q_i^n \right)
\]

\[
+ [\alpha \theta \left( \frac{Q_i^{n+1}}{A_i^{n+1}} + \frac{Q_{i+1}^{n+1}}{A_{i+1}^{n+1}} \right) + \alpha (1-\theta) \left( \frac{Q_i^n}{A_i^n} + \frac{Q_{i+1}^n}{A_{i+1}^n} \right)]
\]

\[
\left[ \frac{\theta}{\Delta x} \left( Q_{i+1}^{n+1} - Q_i^{n+1} \right) + \frac{1-\theta}{\Delta x} \left( Q_i^{n+1} - Q_i^n \right) \right]
\]

\[
- \alpha \left[ \frac{\theta}{4} \left( \frac{Q_i^{n+1}}{A_i^{n+1}} + \frac{Q_{i+1}^{n+1}}{A_{i+1}^{n+1}} \right)^2 + \frac{1-\theta}{4} \left( \frac{Q_i^n}{A_i^n} + \frac{Q_{i+1}^n}{A_{i+1}^n} \right)^2 \right]
\]

\[
\left[ \frac{\theta}{\Delta x} \left( A_{i+1}^{n+1} - A_i^{n+1} \right) + \frac{1-\theta}{\Delta x} \left( A_i^{n+1} - A_i^n \right) \right]
\]

\[
+ g \left[ \frac{\theta}{2} \left( A_i^{n+1} + A_{i+1}^{n+1} \right) + \frac{1-\theta}{2} \left( A_i^n + A_{i+1}^n \right) \right]
\]
\[
\begin{align*}
\frac{\theta}{\Delta x} \left( y_{i+1}^{n+1} - y_i^{n+1} \right) + \frac{1-\theta}{\Delta x} \left( y_{i+1}^n - y_i^n \right) \\
+ g \left[ \frac{\theta}{2} \left( A_i^{n+1} + A_{i+1}^{n+1} \right) + \frac{1-\theta}{2} \left( A_i^n + A_{i+1}^n \right) \right] \\
\left\{ \theta \left[ \frac{Q_i^{n+1} | Q_i^n |}{(K_i^{n+1})^2} + (1-\theta) \frac{Q_{i+1}^{n+1} | Q_{i+1}^n |}{(K_{i+1}^{n+1})^2} \right] \\
+ (1-\theta) \left[ \frac{Q_i^n | Q_i^n |}{(K_i^n)^2} + (1-\theta) \frac{Q_{i+1}^n | Q_{i+1}^n |}{(K_{i+1}^n)^2} \right] \right\}
\end{align*}
\] (II.52)

II.4.4. Formulation of Nodal Matrix Equation The unsteady flow algorithm is essentially that described by Cunge et al. (1980) for multiply connected networks.

Suppose that there are I computational points along a link \( \ell \). For any pair of points \((i, i+1)\), Eqs. (II.42) and (II.43) may be written as,

\[
\Delta y_{i+1} = L_{i+1} \Delta y_i + M_{i+1} \Delta Q_i + N_{i+1}
\] (II.53)

where,

\[
L_{i+1} = (C_o B_o^i - C_o B_o^i)/x1
\] (II.54)

\[
M_{i+1} = (D_o B_o^i - D_o B_o^i)/x1
\] (II.55)

\[
N_{i+1} = (G_o B_o^i - G_o B_o^i)/x1
\] (II.56)
\[ x_1 = A_0 B'_0 - A_0 B_0 \]

Again, suppose that it is possible to express the discharge increment at any intermediate point \( i \) of the link \( \mathcal{L} \) as a function of two water level increments:

\[ \Delta Q_i = E_i \Delta y_i + F_i + H_i \Delta y_1 \]  \hspace{1cm} (II.57)

where,

\[ E_i = \left[ C_0 - L_{i+1}(A_0 + B_0 E_{i+1}) \right]/x_2 \]  \hspace{1cm} (II.58)

\[ F_i = \left[ G_0 - (A_0 + B_0 E_{i+1}) N_{i+1} - B_0 F_{i+1} \right]/x_2 \]  \hspace{1cm} (II.59)

\[ H_i = -B_0 H_{i+1}/x_2 \]  \hspace{1cm} (II.60)

\[ x_2 = (A_0 + B_0 E_{i+1}) M_{i+1} - D_0 \]

and \( \Delta y_1 \) is the water-level correction at point \( i = I \), the last point on the link.

Coefficients \( E, F, \) and \( H \) at point \( i = I \) for each link cannot be obtained directly, since the hydraulic conditions are not known \textit{a priori} (except at a boundary point). However, the recursion relation can always proceed downstream without knowing the conditions at point \( I \), because coefficients \( E, F, \) and \( H \) at the second point can be obtained directly from Eqs. (II.42, II.43, and II.54):

\[ E_{I(\mathcal{L})-1} = (C_0 B'_0 - C_0 B_0')/x_3 \]  \hspace{1cm} (II.61)

\[ F_{I(\mathcal{L})-1} = (G_0 B'_0 - G_0 B_0')/x_3 \]  \hspace{1cm} (II.62)

\[ H_{I(\mathcal{L})-1} = (A_0 B'_0 - A_0 B_0')/x_3 \]  \hspace{1cm} (II.63)

\[ x_3 = D'B' - D'B \]

Thus, once \( E, F, \) and \( H \) have been initialized by Eqs. (II.61-II.63), the remaining \( E_i, F_i, H_i \) coefficients can be calculated by recurrence using Eqs. (II.58-60) for \( i = I(\mathcal{L}) - 1, \ldots, 2 \). In particular, once \( E_i, F_i, \) and \( H_i \) for \( i = 2 \) are known, Eqs. (II.57) can be written for \( i = 1 \) as:
\[
\Delta Q_i = E_i \Delta y_1 + F_1 + H_1 \Delta y_{l(\ell)} \quad \text{(II.64)}
\]

Now the same procedures are needed to find the nodal relation for point I. Again, suppose

\[
\Delta Q_{l(\ell)} = E'_{i+1} \Delta y_{i+1} + F'_{i+1} + H'_{i+1} \Delta y_{l(\ell)} \quad \text{(II.65)}
\]

From Eqs. (II.42, II.53, II.57, II.65), the following recursion relations can be obtained:

\[
E'_i = E'_{i+1}(C_0 M_{i+1} - D_0 L_{i+1})/x4 \quad \text{(II.66)}
\]

\[
F'_i = E'_{i+1}[(G_0 - B_0 F_{i+1}) M_{i+1} - D_0 N_{i+1}]/x4 \quad \text{(II.67)}
\]

\[
H'_i = -B_0 H'_{i+1} E'_{i+1} M_{i+1}/x4 \quad \text{(II.68)}
\]

\[
x4 = (A_0 + B_0 E_{i+1}) M_{i+1} - D_0
\]

Now for \(i = I(\ell)-1\),

\[
E'_{I(\ell)-1} = (C_0 D_0 - C_0 B_0)/x5 \quad \text{(II.69)}
\]

\[
F'_{I(\ell)-1} = (G_0 D_0 - G_0 D_0)/x5 \quad \text{(II.70)}
\]

\[
H'_{I(\ell)-1} = (A_0 D_0 - A_0 D_0)/x5 \quad \text{(II.71)}
\]

\[
x5 = B_0 D_0 - B_0 D_0
\]

Therefore,

\[
\Delta Q_{I(\ell)} = E'_1 \Delta y_1 + F'_1 + H'_1 \Delta y_{l(\ell)} \quad \text{(II.72)}
\]
A relation among the water-level changes at adjacent nodes is established by substituting Eqs. (II.64) and (II.72) into the node continuity equation, Eq. (II.41). This leads to the matrix equation

$$[A][\Delta y] = [B]$$  \hspace{1cm} (II.73)

where $[A]$ is a coefficient matrix comprising appropriate summations of $E$, $H$, $E'$, and $H'$ coefficients, and $[B]$ is a known vector whose elements are imposed inflows, and sums of latest discharge estimates, $F$, and $F'$ coefficients.

II.4.5. Solution Strategy in One Iteration The preceding section outlines the computational elements which are used to obtain corrections to a given set of water levels at points and discharges in links. The corrections may be needed because the inflows to the system have changed (typically the case for the first iteration); or because the sediment operations have changed the system geometry since the last estimate; or because several iterations may be needed to converge to obtain a set of levels and discharges which simultaneously satisfy node continuity, reach continuity and momentum equations (even when neither system inflows nor system geometry are changing). The purpose of this section is to outline the procedure for computing a set of corrections.

The general solution algorithm comprises four phases for each iteration: link forward sweep, node matrix loading, node solution, link backward sweep. These are described as follows:

**Link Forward Sweep**

- For each link $k$, $k = 1$, LINKS
- For each point $i$, $i = 1$, $I(k)-1$:
  * compute $A_0$, $B_0$, $C_0$, $D_0$, $G_0$, $A_0'$, $B_0'$, $C_0'$, $D_0'$, and $G_0'$ by Eqs. (II.44-52)
**Node Matrix Loading**

- For downstream boundary nodes acquire the imposed water level $Y_m(t_{n+1})$, and replace the downstream boundary nodes' "continuity" equations by

\[ \Delta Y_m = Y_m(t_{n+1}) - Y_m^n \]  

(II.74)

- For each non-boundary node $m$:
  * acquire the external inflow $Q_m(t_{n+1})$, if any, and load in appropriate term of \{B\}.
- For each link attached to node $m$, $k = 1, L(m)$
  * retrieve $E_1, F_1, H_1, E'_1, F'_1, H'_1$
  * accumulate $Q_1$ (or $Q_l$), $F_1$ (or $F'_1$) in appropriate term of \{B\}
  * accumulate $E_1, H_1, E'_1, H'_1$ in appropriate elements of \{A\}

\[ \{\Delta Y\} = [A]^{-1} \{B\} \]  

(II.75)

**Link Backward Sweep**

- For each link, $k$, $k = 1, \text{LINKS}$:
  * set $\Delta y_{1,k} = \Delta Y_{m1}$, $m1 =$ node to which the $i = 1$ end of link $k$ is attached
  * set $\Delta y_{l,k} = \Delta Y_{ml}$, $m1 =$ node to which the $i = I(k)$ end of link $k$ is attached
  * compute $\Delta Q_1, \Delta Q_l$ from Eqs. (II.57) and (II.64)
- For each point $i$, $i = 2, I(k)-1$:
  * compute $\Delta Q_i, \Delta y_i$ from Eqs. (II.57) and (II.53)
  * compute $y_i^{n+1} = y_i + \Delta y_i; \ Q_i^{n+1} = Q_i + \Delta Q_i$

It should be noted that in the above procedures, the upstream boundary conditions (imposed discharge entering any upstream limits) are handled naturally through the inflow $Q_m(t_{n+1})$ appearing in Eq. (II.41). Indeed, this external inflow is strictly optional for all interior nodes, but absolutely essential for all boundary nodes.

**II.4.6. Inversion of Nodal Coefficient Matrix** The node-solution computation of Eq. (II.73) is straightforward in principle, but must be examined more carefully in practice. Since the size of the matrix (number of nodes in the network) may be
quite large, any direct inversion computation would be prohibitively expensive, unless performed using a dedicated matrix processor. Although it is tempting to employ an iterative or overrelaxation inversion procedure such as Gauss-Seidel, this too can be expensive due to the large number of iterations, and possibly troublesome when the matrix loses diagonal dominance. Moreover, node continuity requires a more accurate solution for the node water-level changes than an approximate iterative procedure generally can achieve.

These difficulties have led to the adoption of a block tri-diagonal matrix solution technique which, though algebraically complex and delicate to program, offers both computational economy and high accuracy. The method used in this study closely parallels that described in Mahmood and Yevjevich (1975).

The basic goal of the block tridiagonal matrix technique is to replace the inversion of a NODES x NODES matrix by the inversion of NG matrices, each of size MAXG x MAXG, where NG is the total number of node groups, and MAXG is the maximum number of nodes in a node group.

By definition, a node group is a group of nodes which contains nodes which are linked only to each other, or to nodes of the previous group, or to nodes of the following group. In the following derivations the subscript ng denotes the node group numbers, 1 < ng < NG.

The node continuity equations Eq. (II.73) for a node group which is neither the first, nor the last, can be written:

\[
[R]_{ng} \{\Delta Y\}_{ng-1} + [S]_{ng} \{\Delta Y\}_{ng} + [T]_{ng} \{\Delta Y\}_{ng+1} = \{V\}_{ng} \quad (II.76)
\]

where \{\Delta Y\}_{ng} denotes the vector of nodal water-level corrections in node group ng, etc., matrices \{R\}, \{S\}, \{T\} can be thought of as sub-matrices of \{A\} in Eq. (II.73) and the vector \{V\} can be thought of as a sub-vector of \{B\} in Eq. (II.73).

If NGS denotes the number of nodes in a node group then the dimensions of the elements in Eq. (II.76) are as shown in Table II.1.
In order to develop an algorithm which requires inversion of matrices having square dimensions no larger than the number of nodes in the largest node group, one first proposes a relation of the form:

\[(\Delta Y)_{ng-1} = [E]_{ng-1} (\Delta Y)_{ng} + (F)_{ng-1}\]  \hspace{1cm} (II.77)

where \([E]_{ng-1}\) is an (unknown) matrix having \(NGS_{ng}\) columns and \(NGS_{ng-1}\) rows, and \((F)_{ng-1}\) are (unknown) vectors having \(NGS_{ng-1}\) rows. If Eq. (II.77) is substituted into Eq. (II.76), the resulting expression becomes a relationship between \((\Delta Y)_{ng}\) and \((\Delta Y)_{ng+1}\) which can be written:

<table>
<thead>
<tr>
<th>Table II.1</th>
<th>Dimensions of block tri-diagonal matrix elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Element</td>
<td>Number of Columns</td>
</tr>
<tr>
<td>((\Delta Y)_{ng-1})</td>
<td>1</td>
</tr>
<tr>
<td>((\Delta Y)_{ng})</td>
<td>1</td>
</tr>
<tr>
<td>((\Delta Y)_{ng+1})</td>
<td>1</td>
</tr>
<tr>
<td>([R]_{ng})</td>
<td>(NGS_{ng-1})</td>
</tr>
<tr>
<td>([S]_{ng})</td>
<td>(NGS_{ng})</td>
</tr>
<tr>
<td>([T]_{ng})</td>
<td>(NGS_{ng+1})</td>
</tr>
<tr>
<td>((V)_{ng})</td>
<td>1</td>
</tr>
</tbody>
</table>

\[(\Delta Y)_{ng} = [E]_{ng} (\Delta Y)_{ng+1} + (F)_{ng}\]  \hspace{1cm} (II.78)

in which \((E)_{ng}\) and \((F)_{ng}\) are recognized as:
\[ [E]_{ng} = -[T]_{ng} \left( [R]_{ng}[E]_{ng-1} + [S]_{ng} \right)^{-1} \]  

(II.79)

\[ \{F\}_{ng} = \left( [R]_{ng}[E]_{ng-1} + [S]_{ng} \right)^{-1} \left\{ \{V\}_{ng} - [R]_{ng}\{F\}_{ng-1} \right\} \]  

(II.80)

Therefore, if \([E]_{ng-1}\) and \({F}\)_{ng-1} are known, they can be used with the always-known matrices of Eq. (II.76) to compute \([E]_{ng}\) and \({F}\)_{ng} for \(ng = 2,3,\ldots, NG\). As for \([E]_1\), and \({F}\)_1, they can be determined by writing Eq. (II.76) for the first node group, \(ng = 1\), for which case there is no "previous" group \(ng-1\):

\[ [S]_1 \{\Delta Y\}_1 + [T]_1 \{\Delta Y\}_2 = \{V\}_1 \]  

(II.81)

In Eq. (II.31) it can be immediately recognized that:

\[ [E]_1 = -[S]_1^{-1}[T]_1 \]  

(II.82)

\[ \{F\}_1 = [S]_1^{-1}\{V\}_1 \]  

(II.83)

Consequently it is possible, through Eqs. (II.76, 79, 80, 82, and 83), to compute and store \([E]_{ng}\), \({F}\)_{ng}, \(ng = 1,\ldots, NG\). In this process, which can be thought of as a "matrix forward sweep", the matrix inversions appearing in Eqs. (II.79, 80, 82, and 83) involve square matrices whose dimensions are no longer than the maximum number of nodes per group.

The only remaining task is to find \(\{\Delta Y\}_NG\), on the basis of which a "matrix return sweep" can be initiated. Eq. (II.76) is first written for \(ng = NG\) (no "following" group) as:

\[ [R]_{NG}\{\Delta Y\}_{NG-1} + [S]_{NG}\{\Delta Y\}_{NG} = \{V\}_NG \]  

(II.84)

However, \(\{\Delta Y\}_NG\) can be eliminated from Eq. (II.84) by use of Eq. (II.77) written for \(ng = NG\),

\[ \{\Delta Y\}_{NG-1} = [E]_{NG-1}\{\Delta Y\}_{NG} + \{F\}_{NG-1} \]  

(II.85)
Substitution of Eq. (II.85) into Eq. (II.84) and solution for \( \{\Delta Y\}_{NG} \) yields an expression identical to the right-hand-side of Eq. (II.80) for \( ng = NG \); in other words,

\[
\{\Delta Y\}_{NG} = \{F\}_{NG} \quad \text{(II.86)}
\]

(One could have obtained Eq. (II.86) directly by recognizing that in Eq. (II.78) written for \( ng = NG \), \([E]_{NG} \) must be identically zero.)

Once \( \{\Delta Y\}_{NG} \) has thus been obtained, Eq. (II.77) can be applied recursively for \( ng = NG, ..., 2 \) yielding the desired \( \{\Delta Y\}_{NG} \) vectors. The significance of the method is that it replaces inversion of the large \([A] \) matrix in Eq. (II.76) by the inversion of NG small matrices, resulting in an enormous saving of computation time.

**II.4.7. Treatment of Weir-Equivalent Flows** Although the water-routing computation is based primarily on fluvial hydraulics as incorporated in the energy equation or the de St. Venant equations, it is useful to be able to represent certain flow paths as equivalent to flow over a weir. When overflow occurs at locations where the bank is particularly low or where man-made structures have been built or where natural levees exist, the physical situation clearly indicates the need to formulate the flow path as a weir-type link. In addition, supercritical-slope links often exist in a complex looped-channel system; in order to avoid the hydraulic anomaly caused by the supercritical flows, the weir-type link is usually used to replace the supercritical-slope channel.

Once the weir-type flow can be represented in the form of a linear relation among corrections of a discharge and two water levels, then weir-type and fluvial links need not be distinguished in the node-continuity structure upon which the water routing is based. The derivation of linear coefficients for weir-type links in both the steady and unsteady cases is given as follows:

For any non-fluvial flow such as that over a weir, the applicable flow law in general, can be written as:

\[
Q^{n+1} = Q + \Delta Q = f(y_u + \Delta y_u, y_d + \Delta y_d) \quad \text{(II.87)}
\]
where \( u \) denotes upstream, \( d \) denotes downstream, \( Q, y_u \) and \( y_d \) denote latest known estimates, \( \Delta Q, \Delta y_u, \) and \( \Delta y_d \) are unknown corrections to those estimates, and the function \( f \) denotes the appropriate hydraulic law. Through Taylor Series linearization, Eq. (II.87) can be written as:

\[
Q + \Delta Q \approx f(y_u, y_d) + \frac{\partial f}{\partial y_u} \Delta y_u + \frac{\partial f}{\partial y_d} \Delta y_d
\]

(II.88)

Using this general expression, the coefficients of Eqs. (II.42, 43) can be immediately recognized for the two possible relations between upstream-downstream (which may change over the course of calculation) and \( i \cdots i+1 \) (which is fixed).

i) Flow from point \( i+1 \) toward point \( i \):

Here \( y_u = y_{i+1}, y_d = y_i \), and \( Q > 0 \) by the sign convention of Section II.4.3. For the dynamic equation,

\[
A_o = \frac{\partial f}{\partial y_u}
\]

\[
B_o = -1
\]

\[
C_o = -\frac{\partial f}{\partial y_d}
\]

(II.89)

\[
D_o = 0
\]

\[
G_o = -f(y_u, y_d) + Q_{i+1}^n
\]

For the continuity equation,
\[ A'_0 = C'_0 = 0 \]
\[ B'_0 = D'_0 = 1 \]  \hspace{1cm} (II.90)
\[ G'_0 = Q^n_i - Q^n_{i+1} \]

ii) Flow from point \( i \) toward point \( i+1 \):

Here \( y_d = y_{i+1}, y_u = y_i \), and \( Q < 0 \). For the dynamic equation,

\[ A_0 = -\frac{\partial f}{\partial y_d} \]
\[ B_0 = -1 \]
\[ C_0 = \frac{\partial f}{\partial y_u} \]  \hspace{1cm} (II.91)
\[ D_0 = 0 \]
\[ G_0 = Q^n_{i+1} + f(y_u, y_d) \]

For the continuity equation,

\[ A'_0 = C'_0 = 0 \]
\[ B'_0 = D'_0 = 1 \]  \hspace{1cm} (II.92)
\[ G'_0 = Q^n_i - Q^n_{i+1} \]

The remaining task is to identify the appropriate function \( f \) for a weir. A rectangular weir is considered. Two distinct weir regimes must be treated: free flowing and flooded.
Free-Flowing Weir: Direct application of the Bernoulli Equation, neglecting approach velocity and recognizing a critical-flow control at the weir, leads to:

$$Q = f = C_{ff} B_w \frac{2}{3} \sqrt{1/3} \sqrt{2g} (y_u - y_w)^{3/2}$$  \hspace{1cm} (II.93)

with $C_{ff}$ = free-flow discharge coefficient, $B_w$ = crest width, and $y_w$ = crest elevation. The required derivatives are recognized as:

$$\frac{\partial f}{\partial y_u} = C_{ff} B_w \sqrt{1/3} \sqrt{2g} (y_u - y_w)^{1/2}$$  \hspace{1cm} (II.94)

$$\frac{\partial f}{\partial y_d} = 0$$  \hspace{1cm} (II.95)

Flooded Weir: The assumptions used for the free-flowing case, along with an additional assumption that all velocity head over the weir is dissipated (no kinetic-energy recovery) lead to:

$$Q = f = C_{f\ell} B_w \sqrt{2g} (y_u - y_d)^{1/2} (y_d - y_w)$$  \hspace{1cm} (II.96)

with $C_{f\ell}$ = flooded discharge coefficient, and

$$\frac{\partial f}{\partial y_u} = C_{f\ell} B_w \sqrt{2g} \frac{1}{2} (y_u - y_d)^{-1/2} (y_d - y_w)$$  \hspace{1cm} (II.97)

$$\frac{\partial f}{\partial y_d} = C_{f\ell} B_w \sqrt{2g} [(y_u - y_d)^{1/2} - \frac{1}{2} (y_d - y_w) (y_u - y_d)^{-1/2}]$$  \hspace{1cm} (II.98)
It can be shown that the condition which distinguishes between the two regimes is:

Flooded: \( y_d - y_w > \frac{2}{3} (y_u - y_w) \)  \hspace{1cm} (II.99)

Free Flowing: \( y_d - y_w < \frac{2}{3} (y_u - y_w) \)  \hspace{1cm} (II.100)

When \( y_d - y_w = 2(y_u - y_w)/3 \), both regimes yield the same discharge.

A practical difficulty associated with Eqs. (II.97-98) is that these derivatives approach infinity as \( y_u \) approaches \( y_d \). The implications are that, whenever the water levels on either side of a weir are nearly or exactly equal (as in an arbitrary initial condition), a nearly singular or singular situation exists in which a small correction to either the upstream or downstream water level can induce an extremely large correction to the discharge. This singularity is obviated by linearizing Eq. (II.96) for \( (y_u - y_d) < \epsilon_w \), where \( \epsilon_w \) is the order of 0.25 feet. The linearization is written:

\[
Q = f = C_{f,k} B_w \sqrt{2g} \left( \frac{y_u - y_d}{\epsilon_w} \right)^{1/2} (y_d - y_w) \tag{II.101}
\]

Then the derivatives, which replace Eqs. (II.96-97), become:

\[
\frac{\partial f}{\partial y_u} = C_{f,k} B_w \sqrt{2g} \left( y_d - y_w \right) / \epsilon_w^{1/2} \tag{II.102}
\]

\[
\frac{\partial f}{\partial y_d} = C_{f,k} B_w \sqrt{2g} \left[ \frac{(y_u - y_d) / \epsilon_w^{1/2} - (y_d - y_w) / \epsilon_w^{1/2}}{y_d - y_w} \right] \tag{II.103}
\]

II.4.8. Flow Stabilization Procedure for Quasi-Steady Flow Steady flow calculations are required as part of an unsteady flow simulation study to provide a reasonable initial condition from which an unsteady simulation can be performed. For a complex river system, it is impossible to furnish an initial condition for every computational point which is close to the desired steady state. A common procedure is to
start with constant depths and an arbitrary chosen discharge, which can be zero. Obviously, a stabilization procedure is required to smooth out the discontinuities caused by the inconsistency between the initial condition, boundary conditions and the governing equations. The procedure expressed in this section basically follows the algorithm developed by Cuneg et al. (1980).

The basic idea of this procedure is to allow disturbances (waves) generated by the initial discharge and water-level discontinuities to propagate out of the system as rapidly as possible. A certain systematic structure of time-step variations is used to stabilize the hydraulic conditions into a steady flow. The series of time steps must start with several small ones, so the computation will not be destroyed due to the rapid variation of water level in the early stages of flow adjustment. After the initial local disturbances are thus smoothed, the model must be run for a long equivalent time, with boundary conditions fixed, to allow for volume adjustment by following a systematic series of time steps which are progressively increased.

The time step could be increased by a certain factor whenever the maximum change in water levels becomes smaller than a specified value $\varepsilon$. As the time steps increase, the specified criterion $\varepsilon$ itself becomes smaller and smaller. In addition, if there is danger of the flow passing locally and temporarily into supercritical regime during the stabilization phase, the convective acceleration terms in the de St. Venant equations can be suppressed for a preliminary volume stabilization; then the process can be repeated retaining the convective term to let the water-surface slope adjust itself to differences in velocity from one section to another.

Through test experience, the systematic time-step variations and the corresponding specified criterion $\varepsilon$ used to control the simulation (i.e., when the maximum water-level change is less than $\varepsilon$ the simulation proceeds to the next iteration with the larger time step), have been established as shown in the following table:
Table II.2

Systematic time-step Variations and corresponding criteria for flow stabilization procedure

<table>
<thead>
<tr>
<th>Δt</th>
<th>.2t_b</th>
<th>.5t_b</th>
<th>t_b</th>
<th>2t_b</th>
<th>5t_b</th>
<th>10t_b</th>
<th>20t_b</th>
<th>30t_b</th>
<th>40t_b</th>
<th>50t_b</th>
</tr>
</thead>
<tbody>
<tr>
<td>ε</td>
<td>50ε_b</td>
<td>50ε_b</td>
<td>50ε_b</td>
<td>15ε_b</td>
<td>7ε_b</td>
<td>5ε_b</td>
<td>4ε_b</td>
<td>3ε_b</td>
<td>2ε_b</td>
<td>ε_b</td>
</tr>
</tbody>
</table>

where t_b is a specified fundamental time step which is determined on the basis of the given initial condition (input variable FDELTB). If the initial condition is close to the true steady-state condition, t_b can be relatively large, otherwise it must be relatively small. ε_b is the specified fundamental value for the water level change, usually 0.01 feet.

As shown in the above table, the time step Δt is maintained until the maximum water-level change between two successive cycles is less than ε, then the next larger time step is adopted, and so on. At the end of this procedure the flow is fully stabilized.

Taking the complex network of channels comprising a portion of the Susiina River as shown in Figure I.1 as an example consisting of 249 nodes, 306 links and 918 computational points, the total stabilization time, which is the sum of all time steps used to stabilize the model, is about 15 hours (the fundamental time step t_b is 5 minutes).

II.5. Sediment-Continuity Computation

II.5.1. Introduction Changes in bed elevation are computed through application of the principles of sediment continuity, i.e. sediment conservation. These bed-elevation changes are often the primary variable of interest in an alluvial model (long-term aggradation/degradation), and are fundamental input quantities for the computation of bed armoring and sediment sorting. All bed-level changes are interpreted strictly one-dimensionally, i.e., no attempt is made to estimate the transverse allocation, within a channel, of aggraded or degraded sediment volumes.
The principles of sediment continuity are invoked for the treatment of three distinct degradation/aggradation processes: bed-level changes in fluvial raches, at boundary inflow points, and at nodes. The computational principles are described in the remainder of this section.

II.5.2. Sediment Continuity in Fluvial Reaches. Through application of Preissmann's finite difference approximation, Exner's equation for sediment continuity, Eq. (II.5), can be written in discrete form for a fluvial reach which is the stretch of channel between two computational points $i$ and $i+1$:

\[
\frac{\delta_{i,j}}{\Delta t} = \frac{\theta}{(1-p)\Delta x} \left( q_{s,i,j}^{n+1} - q_{s,i,j}^{n+1} \right) + \frac{1-\theta}{(1-p)\Delta x} \left( q_{s,i,j}^{n} - q_{s,i+1,j}^{n} \right)
\]  

(II.104)

where $\delta_{i,j} = \text{depth-equivalent of volume of sediment size fraction } j$, removed from the reach between points $i$ and $i+1$ over time interval $\Delta t$; $q_{s,i,j} = \text{sediment discharge per unit width for each size fraction}$, and $\theta = \text{weighting factor between zero and unity}$, usually taken as 0.5. The component depth-equivalents $\delta_{i,j}$ serve as input to the armoring and sorting computations described in subsequent sections. In particular, the sorting operations include a computation of total aggradation or degradation through summation of $\delta$ - values subject to certain constraints relative to changes in mixed-layer thickness. The $q_s$ values in Eq. (II.104) are known at time-levels $n$ and $n+1$ from the sediment-discharge computations of section II.3.1, so $\delta_{i,j}$ can be obtained directly for each computational reach. Then the bed-elevation changes can be computed by Eq. (II.105) below.

II.5.3. Upstream Boundary Condition for Sediment. It may be sufficient simply to apply Eq. (II.104) to the computational reach adjacent to an upstream inflow point, using, for example, the imposed load to supply $q_{s,i+1,j}^{n+1}$ and thus compute the bed-elevation changes at the upstream inflow point. However, this procedure has serious defects, which appear when one considers the overall boundary condition problem represented by Eqs. (II.1 - II.9).
From a purely mathematical point of view, the boundary condition requirements are clear. The backwater and/or unsteady-flow computations require the imposition of a downstream water-surface elevation, and an upstream discharge hydrograph, and the sediment-routing computation is meaningless without the imposition of an upstream sediment discharge entering the system.

If these formal requirements are clear, the practical ones are less so. The sediment continuity Eq. (II.104) ultimately leads to computation of $\Delta z_i$, the bed elevation change in the reach between two computational points $i$ and $i+1$. These reach elevations must be somehow allocated to computational points so that the subsequent unsteady-flow computation can work with current thalweg elevations as the channel aggrades or degrades. This allocation consists of modifying the thalweg elevation at a computational point by the weighted average of the changes in the two adjacent computational reaches, i.e.

$$z_i^{n+1} - z_i^n = \frac{1}{\Delta x_i \Delta z_i} (\Delta x_{i-1} \Delta z_{i-1} + \Delta x_i \Delta z_i)$$  \hspace{1cm} (II.105)

in which it is understood that $\Delta z_i$ refers to reach $i$ and $z_i$ refers to point $i$. When the reaches are all of constant length $\Delta x$, Eq. (II.105) reduces to a simple averaging process.

The practical ambiguity arises from the fact that Eq. (II.105) cannot be written for points 1 (downstream) and I (upstream), as they have computational reaches on only one side. The problems associated with this difficulty will be described in the sequel.

At the upstream boundary (point I), the difficulty is best appreciated by considering the sudden shut-off of upstream sediment inflow into a stream which was in equilibrium, i.e., transporting the imposed sediment load with no degradation or aggradation. In Eq. (II.104), if $i = I-1$, then in the first computational time interval after the shut-off of sediment inflow, $(Q_s)_{I+1} = 0$ while $(Q_s)_i$ remains the equilibrium sediment transport capacity. (Note $Q_s \equiv Bq_s$ and Eq. (II.104) is being interpreted as applying to total load.) Now whatever the values of $\Delta x$ and $\Delta t$ the degradation in the first time step will always be proportional to $\Delta t/\Delta x$, since $(Q_s)_I = 0$ and $(Q_s)_{I-1} = $ equilibrium value. For a given $\Delta x$ the degradation at point I is thus proportional to $\Delta t$, which is physically reasonable; as $\Delta t$ becomes smaller, the volume of material removed from the first reach becomes smaller, and therefore the degradation in one time step is less. But for a given $\Delta t$, the degradation is
inversely proportional to Δx; as Δx becomes smaller, the volume of material removed from the first reach remains the same, but the degradation depth increases. In other words, the degradation thus computed in the first reach depends on Δx, and tends to infinity as Δx tends to zero. This is a purely computational anomaly, having no physical basis, and thus warrants the investigation of an improved procedure as described below.

The key to eliminating the sensitivity of the bed elevation changes to Δx at the upstream limit is adoption of a procedure described by Cunge (1980). The procedure makes no attempt to compute the bed level at the upstream point I through the normal sediment-continuity Eq. II.104. Instead, it implements the physical requirement that the channel bed level must ultimately change in such a way that its sediment transport capacity is equal to the imposed load. For example, if the imposed load is zero, then the channel must deepen until the transport capacity is zero; this becomes the mechanism for computing the bed level change at the upstream point.

This straightforward physical principle must nonetheless be slightly modified to account for the fact that the channel cannot instantaneously adjust to a change in the imposed load. Instead, it is assumed that some local degradation or aggradation due to imbalance between the imposed and transportable load can occur in a special computational reach βbΔx adjacent to the upstream limit. One seeks the bed elevation change which satisfies a special sediment continuity equation written for the buffer reach,

\[
(\theta \left( \bar{Q}_s^{n+1} - \bar{Q}_s^n \right) + (1-\theta) \left( \bar{Q}_s^n - \bar{Q}_s^{n+1} \right)) \Delta t = \beta_b \Delta x B_I (1-p) \Delta z_I \quad (II.106)
\]

in which \( \bar{Q}_s \) = imposed total sediment load at the upstream boundary; \( \bar{Q}_s \) = sediment discharge capacity; \( B_I \) = some appropriate width; \( p \) = sediment porosity; and, \( \Delta z_I \) = change in bed elevation of reach \( \beta_b \Delta x \) (and point I) in time \( \Delta t \). In keeping with the usual uncoupled procedure (if only during one global iteration), the bed change \( \Delta z_I \) is expressed as

\[
\Delta z_I = z_1^{n+1} - z_1^n = y_1^{n+1} - d_1^{n+1} - z_1^n \quad (II.107)
\]
Here the water surface elevation $y_I^{n+1}$ is known from the latest hydraulic sweep, and the previous bed elevation $z_I^n$ is also known, leaving the depth $d_I^{n+1}$ as an unknown in Eq. (II.107). Since $Q_s^{n+1}$ and $Q_s^n$ are given and $Q_s^n$ is known from the previous time step, the only remaining unknown is $Q_s^{n+1}$, which can be thought of as the sediment-transport capacity at the downstream end of reach $\beta_b \Delta x$ with the armoring factor taken into account;

$$Q_s^{n+1} = B_I (\exp(-2.99573 \cdot ACF_I)) \bar{q}_s^{n+1}$$  \hspace{1cm} (II.108)

where $q_s^{n+1}$ can be considered as a function only of $d_I^{n+1}$ through the sediment-discharge predictor, all parameters other than $q_s^{n+1}$ being known from the most recent water routing sweep and sorting/armoring operations. Consequently Eq. (II.106) reduces to a nonlinear algebraic equation in the single unknown $d_I^{n+1}$, whose value can be determined through a Newton-Raphson iteration.

It is instructive to note that if one suppresses the buffer reach by setting $\beta_b = 0$, then the procedure outlined above simply requires that the bed level adjust immediately so that the sediment discharge capacity at point I becomes equal to the imposed load. If $\beta_b > 0$, then the effect is to require the sediment-discharge capacity to approach, but not equal, the imposed load, the difference being absorbed in aggradation or degradation in the buffer reach.

The value of $\beta_b \Delta x$ is guided by the physical principle that the buffer reach should correspond roughly to the distance travelled by a bed perturbation in time $\Delta t$. If the bed perturbation celerity is denoted by $c$, this yields

$$\beta_b = c \Delta t / \Delta x$$ \hspace{1cm} (II.109)

The value of $c$ is difficult to ascertain exactly, and depends on changing flow conditions and sediment composition. Experience on the Missouri River suggests that $c$ would appear to be the order of 10 miles per year. However, the procedure does not appear to be particularly sensitive to $\beta_b$, as is shown in the tests reported by Holly et al. (1984).

Once the bed level at the upstream point has been determined as described above, a normal sediment-continuity equation is applied to $(1-\beta_b) \Delta x$ for use in ultimately
determining $z^{-n+1}$. In its present form, this equation uses the imposed load $Q_s^{n+1}$ as inflow to the shortened reach, though an equally plausible argument could be made for using $Q_s^{n+1}$. It is implicitly assumed--and virtually always true--that $0 < \beta_b < 1$.

The sediment discharge appearing in Eq. (II.106) is computed on the basis of median particle size, or effective diameter of the bed material. This procedure is inconsistent with the sediment continuity equation, Eq. (II.104) in which the sediment discharge has to be computed on the basis of particle-size fraction. When the sudden shut-off upstream boundary condition is considered, this procedure can still be used without any problems. For this case, since there is no sediment inflow from the upstream boundary, the inconsistency for the size distribution between the imposed inflow and the computed load does not exist. The transport capacity can always be computed from the mean geometric size of that reach after the processes of sorting and armoring. If a free-end upstream boundary is considered, e.g., whereby the sediment inflow and the size distribution are given as input, the above procedure still can be used but should be performed for each particle size, introducing additional computational complexity and cost. Fortunately, for a free-end boundary the singular problem described above usually does not exist, since in principle, the given sediment input should be very close to the transport rate computed for the neighboring point, when the length of this reach is small. If the reach length is equal to zero, the given input and the computed value should be the same. Therefore, there is no ambiguity. Further, this implies that the normal sediment continuity equation, Eq. (II.104) can be applied for this case. The bed-level change at the upstream boundary point can simply be taken as that of the upstream reach computed by Eq. (II.104) when the above conditions are satisfied.

II.5.4. Sediment Continuity at Nodes. The application of Eq. (II.104) to interior computational reaches effectively imposes a sediment-continuity condition, whereby any net sediment inflow to a reach must cause an addition of sediment volume to the reach. However, application of this constraint to internal reaches is not sufficient to assure sediment continuity at nodes, for the following reasons:

* as demonstrated in the discussion following Eq. (II.105), the bed-level change at an end point (such as at a node) cannot be simply determined based on the change in the adjacent reach;

* in general, the sum of all sediment capacities in the links flowing into a node is not equal to the sum of the sediment-outflow capacities, either due to the inherent
inaccuracy of the highly non-linear transport predictor, or because the system is not in a state of equilibrium. There is, therefore, a need to apply an additional sediment-continuity constraint at nodes, in order to provide a mechanism for computing bed-level changes at the points associated with a node, and to assure as strict an adherence as possible to the principle of conservation of sediment.

The difference of sediment capacity between inflows and outflows is redistributed to the outflow channels by the following relation:

\[
\Delta Q_{sj,\ell} = \sum_{\ell=1}^{LI(m)} Q_{sj,\ell} - \sum_{\ell=1}^{LO(m)} Q_{sj,\ell} = \sum_{\ell=1}^{LO(m)} Q_{sj,\ell}'
\]

\[\ell' = 1,2,\ldots,LO(m)\]  

(II.110)

where, \(LI(m)\) = the total number of links flowing into the node \(m\); \(LO(m)\) = the total number of links leaving the node \(m\); \(Q_{sj,\ell}\) = the sediment discharge for size fraction \(j\) in link \(\ell\). This relation indicates that the imbalance of sediment load at a node is distributed to the attached outflow links in linear proportion to the ratio of the computed transport capacity of that link to the sum of the outflow transport capacity.

II.6. Hydraulic Sorting of Bed Material

II.6.1. Introduction. The computational procedures for sorting used in BRALLUVIAL are essentially the same as those employed in IALLUVIAL. Their description given in this section follows that of Karim and Kennedy (1982).

II.6.2. The Mixed Layer. The upper level of the bed of a stream which is actively transporting its own bed sediment is characterized by continuous agitation, dilation, mixing, and overturning. For the flat-bed configuration, the thickness of the agitated layer is only a few grain diameters thick. In the case of beds in the ripple or dune regimes, the migration of the bed forms produces continual overturning and agitation of a bed-material layer with thickness comparable to the bed-form height. The horizon of bed material undergoing continual mixing due to turbulence, bed-form-migration, etc. is
referred to herein as the mixed layer, and is assumed to be homogeneous in its size
distribution at any time. It is reasonable to expect the thickness of the mixed layer to be of
the order of the average height of the ripples or dunes. Unfortunately, no satisfactory
relation has been established for predicting bed-form height. In CHARIMA, the thickness
of the mixed layer is assumed to be equal to the average height of the bed forms. Empirical
expressions for the dune height are given in Section II.3.4.

The height and/or steepness of the ripples and dunes is observed to decrease as the
bed becomes armored. To account for this, the thickness of the mixed layer, $T_m$, is
assumed to decrease with increasing armoring of the bed surface in accordance with the
linear relation

$$T_m = \frac{1}{2} H_d (1 - C_3 A_f)$$  \hspace{1cm} (II.111)

where $C_3 = \text{coefficient with value between 0 and 1}$, $H_d$ is given by Eq. (II.35), and the
armor factor $A_f$ is described in Section II.7.

II.6.3. **Changes in Bed-material Composition.** Calculation of the
evolution of the bed-material size distribution accompanying degradation or aggradation
during a time period is made under the assumption that the different sediment-particle size
fractions are homogeneously distributed throughout the mixed layer. When the bed
degrades, sediment with the parent bed-material size distribution enters the mixed layer
from below. In the case of an aggrading bed, material with the size distribution of the
mixed layer leaves the mixed layer and becomes part of the inactive bed, see Figure
II.4(a),(b). The principle of volume conservation in the mixed layer is applied to each size
class. The net change of volume of a given size class $j$ in the mixed layer within one reach
can be attributed to the net influx or efflux of bed load, suspended load, and exchange with
the parent bed material, although it is understood in the CHARIMA implementation that the
total sediment load is attributed to the "bedload" $G$, as the suspended-load is not explicitly
recognized in this total-load approach. This can be expressed as:
Figure II.4. Schematic illustration of mixed layer during degradation and aggradation.
\[ \frac{\partial V_{ML}}{\partial t} = G_j - (G_j + \frac{\partial G_i}{\partial x} \Delta x) - S_j \Delta x - \frac{\partial V_{under}}{\partial t} \]  \hspace{1cm} (II.112)

where \( V_{ML} \) = total volume of size-class \( j \) in the mixed layer within the computational reach; \( G_j \) = volumetric transport rate of bedload for size-class \( j \) at the upstream end of the reach; \( S_j \) = total suspended-load efflux from the reach; \( V_{under} \) = total volume of size-class \( j \) in the parent bed material.

In Eq. (II.111A), one can recognize

\[ V_{ML} = (1-p)\beta_j B T_m \Delta x \]  \hspace{1cm} (II.113)

and

\[ V_{under} = (1-p)\beta_j^* B (z - T_m \Delta x) \]  \hspace{1cm} (II.114)

In these expressions, \( p \) = sediment porosity; \( B \) - channel width; \( \beta_j \) = fractional representation of size-class \( j \) in the mixed layer; \( \beta_{oj} \) = fractional representation of size-class \( j \) in the bed material underlying the mixed layer; \( \beta_j^* = \beta_j \) if the floor of the mixed layer is rising, or \( \beta_j^* = \beta_{oj} \) if the floor is descending; and \( z \) = arbitrary datum elevation under the parent bed. Figure II.5 illustrates these definitions.

Eq. (II.111A) can be rewritten

\[ (1-p) \frac{\partial (\beta_j B T_m)}{\partial t} = - \frac{\partial G_i}{\partial x} \cdot S_j - (1-p) \frac{\partial [\beta_j^* B (Z - T_m)]}{\partial t} \] \hspace{1cm} j = 1,2,3,...J  \hspace{1cm} (II.115)

and its finite-difference form is written as:

\[ (1-p) \left[ \beta_j^{n+1} \cdot B^{n+1} \cdot T_m^{n+1} - \beta_j^n \cdot B^n \cdot T_m^n \right] = (\delta G_j) \cdot \Delta t \]

\[ - (\mu S_j) \cdot \Delta t - (1-p) (\mu \beta_j^* \cdot (\mu B) \left[ (Z - T_m)^{n+1} - (Z - T_m)^n \right]) \]  \hspace{1cm} (II.116)
Figure II.5. Volume conservation in the mixed layer (sorting).
in which $\mu = \text{space-time mean}$ and $\delta = \text{spatial gradient}$, defined as:

In Eq. (II.112A), the only unknown is $\beta_{j}^{n+1}$ in this uncoupled scheme. If the floor of the mixed layer is descending, i.e. if $(Z_{j}^{n+1} - Z_{j}^{n}) - (Z - T_{m}^{n}) < 0$, and $\beta_{j}^{*} = \beta_{oj}$, then

$$
\beta_{j}^{n+1} = \\
(1-p)\beta_{j}^{n} \cdot B_{n} \cdot T_{m}^{n} + (\delta G_{j}) \Delta t - (1-p) \cdot (\mu B_{oj}) \cdot (\mu B) \cdot \left[ \left( Z_{j}^{n+1} - T_{m}^{n+1} \right) - \left( Z_{j}^{n} - T_{m}^{n} \right) \right] \\
\left(1-p\right) B_{n+1} \cdot T_{m}^{n+1} 
$$

(II.117)

If the floor of the mixed layer is rising, then $\beta_{j}^{*} = \beta_{j}^{n+1}$, and:

$$
\beta_{j}^{n+1} = \\
(1-p)\beta_{j}^{n} \cdot B_{n} \cdot T_{m}^{n} + (\delta G_{j}) \Delta t - (1-p) \cdot (\mu B) \cdot (1-\theta) \cdot \beta_{j}^{n} \cdot \left[ (Z-T_{m})^{n+1} - (Z-T_{m})^{n} \right] \\
\left(1-p\right) B_{n+1} \cdot T_{m}^{n+1} + (1-p)(\mu B) \cdot \theta \cdot \left[ (Z-T_{m})^{n+1} - (Z-T_{m})^{n} \right] 
$$

(II.118)

II.7. Armoring of Bed Surface

II.7.1. Introduction. Armoring of the bed surface, along with general coarsening of the bed-material, are the principal mechanisms through which a degrading river bed attempts to achieve a new equilibrium condition. Representation of the bed armoring process in a computer-based mathematical model is a critical component on which depends the accuracy in prediction of future river bed evolution. The armoring process is a complex phenomenon which depends on several interdependent factors, e.g., size
distribution of bed material and its variation in the vertical direction below the bed, intensity of flow discharge and sediment transport, the formation and movement of bed features like ripples and dunes, and the continual sorting and mixing of bed sediments as affected by these bed features. The armoring process as it begins and evolves during the gradual degradation process of an alluvial river bed is not well understood. Nevertheless, existing knowledge in this area has been used to develop the present formulation of bed armoring used in CHARIMA.

The material in this section is taken primarily from Karim, Holly, and Kennedy (1983). (Complete theoretical and experimental justification for the procedures adopted can be found therein.) Indeed, the armoring procedures in CHARIMA are identical to those used in IALLUVIAL.

II.7.2. Degradation and Armoring on a Plane Bed. For flow conditions which produce a nearly flat bed in rivers, gradual degradation (downstream of a dam, for example) of a bed containing a significant amounts of coarse sediments which cannot be moved by the flow will lead to rapid armoring of the bed surface. The extent of armoring in such a case can be determined by relating the depth of degradation to the corresponding volume of non-moving sediment size fractions and then converting the volume of accumulated sediments into an areal distribution by assuming some thickness of the top layer. Even though the experimental works of Gessler (1967) and Little and Mayer (1972) and field observations indicate that the armor coat contains sediments of all size fractions of the original bed material, it is assumed in the present analysis that as the armoring develops with increasing bed degradation, the bed surface is segregated into two parts: the armor coat, and the part of the bed containing the movable size fractions, as depicted in Figure (II.6). It is assumed that the parameter of interest is the fraction of the bed covered by the nonmoving armoring particles, because the finer particles in between the larger ones do not contribute to the stability of the bed and will become part of the sediment transport at one time or another, even though some of them may be sheltered by the armoring particles. From this point of view, determination of the complete size distribution of an armor coat is not necessary and is not attempted in this study. Instead, the fraction of bed surface covered by nonmoving particles at any given time is used as a measure of the extent of armoring on a degrading bed.

For determining the fraction of the bed surface covered by immobile particles at a given time, $A_f(t)$, it is assumed that there are a total of $m$ size fractions, of which fractions $k$ through $m(\leq m)$ cannot be transported by the flow and accumulate on the surface in a
Figure II.6. Schematic representation of armoring on a plane bed.
one-diameter-thick top layer. The total volume of these accumulating particles per unit bed area after time $t$ is

$$V(t) = (1-p) d_s(t) \sum_{j=1}^{m} p_j$$  \hspace{1cm} (II.119)

where $p =$ porosity of sediment bed material; $d_s(t) =$ cumulative depth of degradation after time $t$; and $p_j =$ fraction of sediment in size interval $j$. Assuming that the shape of particles is circular ellipsoid with a shape factor $f_s$ (ratio of the smallest principal axis to the square root of the product of the other two), the volume of a particle of fraction $j$ with diameter of its major axis equal to $D_{mj}$ is

$$V_j = \frac{\pi}{6} f_s D_{mj}^3$$  \hspace{1cm} (II.120)

and the number of armoring particles per unit bed area after time $t$ is then

$$N(t) = \sum_{j=1}^{m} \frac{V(t,j)}{V_j} = \frac{(1-p)d_s(t)}{\frac{\pi}{6} f_s} \sum_{j=1}^{m} \frac{p_j}{D_{mj}^3}$$  \hspace{1cm} (II.121)

in which $V(t,j) =$ value of $V(t)$ for grain size interval $j$. The surface area covered by the armoring particles per unit bed area after time $t$, $A_f(t)$, may then be expressed as

$$A_f(t) = N(t) \times \text{largest projected area of each particle} \left(= \frac{\pi}{4} D_{mj}^2 \right)$$

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\[ = (1-p) \frac{d_s(t)}{f_s} \cdot \frac{\pi}{6} \cdot \sum_{j=1}^{m} \frac{p_j}{D_{mj}^3} \cdot D_{mj}^2 \]

\[ = \frac{3}{2} \cdot (1-p) \frac{d_s(t)}{f_s} \cdot \sum_{j=1}^{m} \frac{p_j}{D_{mj}} \quad (\text{II.122}) \]

Writing \( V_j \) (II.120) in terms of an equivalent spherical particle of diameter \( D_j \),

\[ V_j = \frac{\pi}{6} \cdot f_s \cdot D_{mj}^3 = \frac{\pi}{6} \cdot D_j^3 \quad (\text{II.123}) \]

yields the following expression for \( D_{mj} \) in terms of \( D_j \):

\[ D_{mj} = \frac{1}{f_s^{1/3}} D_j \quad (\text{II.124}) \]

which is substituted into Eq. (II.122) to give

\[ A_{f(t)} = \frac{3}{2} \cdot (1-p)d_s(t) \cdot \frac{f_s}{2^{3/2}} \cdot \sum_{j=1}^{m} \frac{p_j}{D_j} \quad (\text{II.125}) \]

Assuming a shape factor \( f_s = 0.70 \), Eq. (II.125) is written as

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\[ A_f(t) = C_A (1-p) \frac{d_s(t)}{D_j} \sum_{j=1}^{m} \frac{P_j}{D_j} \]  \hspace{1cm} (II.126)

in which \( C_A = 1.902 \).

The derivation of Eq. (II.126) assumes that the armor coat is one-diameter thick with the following idealized arrangement:

![Diagram of armor coat arrangement](image)

However, if the arrangement of armoring particles with two fractions (both non-moving), for example, is

![Diagram of dual fraction arrangement](image)

the armoring coefficient \( C_A \) in Eq. (II.125) then will not be constant but different for each fraction, i.e.,

\[ C_A = 1.902 \text{ for fraction } j \]
\[ = 1.902/2 \text{ for fraction } j-1 \]

If some particles lie on their minor axis with major axes perpendicular to bed, the value of \( C_A \) will be further reduced. Thus, in general, \( C_A \) will be a function of each fraction and its particular arrangement in the armoring layer.
Equation (II.126) with $C_A = 0.5$ and $\lambda = 7$ (with $m = 8$, this implies that the last two size fractions, sediment size $> 6.76$ mm, were always immobile and part of the armor coat) was utilized to account for bed armoring in the previous applications of the IALLUVIAL program to the Missouri River studies (Holly, et al., 1984). Three shortcomings of Eq. (II.126) are immediately apparent: (i) $C_A$ is assumed constant in time for each size fraction; (ii) a fixed number of size fractions is always responsible for armoring; and (iii) the possibility of a particular size fraction being part of the armor coat in some time intervals and not at other times is not included. These shortcomings are in addition to the fact that Eq. (II.126) is strictly valid only for a plane bed.

The first step in removing these shortcomings is to extend the formulation of Eq. (II.126) to a more general case in which the dependence of $A_f$ and $C_A$ on grain size fraction and time is included:

$$A_f(t,j) = A_f(t-1,j) + C_A(t,j) \cdot (1-p) \Delta d_s(t) \frac{P_i}{D_j}$$

(II.127)

$$A_f(t,j) = 0; \quad j < \lambda(t)$$

(II.128)

$$A_f(t) = \sum_{j=\lambda(t)}^{m} A_f(t,j)$$

(II.129)

in which $A_f(t,j) =$ fraction of bed area covered by grain size interval $j$ at time $t$; $C_A(t,j) =$ value of coefficient $C_A$ Eq. (II.126) at time $t$ for size fraction $j$; $\Delta d_s(t) =$ incremental depth of degradation during current time interval; and $\lambda(t) =$ lowest grain size interval which is immobile (determined from Shields' criterion) and forms the armor coat at time $t$. Equation (II.126) is a special case of Eq. (II.127) for $C_A(t,j) = C_A =$ constant and $\lambda(t) = \lambda =$ constant. The effects of the stochastic nature of sediment motion, and the effects of formation and propagation of dunes, are considered in the context of estimating the armoring coefficient $C_A(t,j)$ for each sediment size fraction as a function of flow variables at a given time in the following sections.

The procedure followed in BRALLUVIAL consists of formulating correction factors due to these effects (stochastic sediment motion and dune movement) to reduce the value of $C_A(t,j)$ in Eq. (II.127) from its maximum value of 1.902 for a plane bed.
II.7.3. Stochastic Nature of Sediment Motion. Shield's diagram is universally used to determine the critical bed shear stress above which sediment motion takes place. It has long been recognized, however, that this deterministic way of calculating a definite cut-off point needs to be replaced or supplemented by a procedure to account for the stochastic nature of sediment motion. Such a procedure is proposed by Gessler (1967) who suggested that incipient motion of grains is probabilistic and follows a Gaussian distribution, with the probability of motion being 50% when bed shear stress equals critical stress given by Shield's relation. The probability of grains remaining on the bed (which is the complement of the probability of motion), \( q_j \), as proposed by Gessler (1967), is given by Eq. (1) or Figure 1 in Karim et al. (1983). The usual assumption is that \( q_j = 1 \) if \( \tau_{ci}/\tau \geq 1 \). Instead, Gessler's work suggests that \( q_j = 0.5 \) for \( \tau_{ci}/\tau = 1 \) and approaches unity for \( \tau_{ci}/\tau \) greater than 3. This implies that larger grains are just more likely to stay, as opposed to assigning an equal probability of (100%) that all fractions greater than the critical size stay. This stochastic nature of sediment motion is accounted for indirectly by using \( q_j \) as a correction factor applied to \( C_A \):

\[
C_A(t,j) = 1.902 \, q_j \tag{II.130}
\]

It is perhaps more appropriate to consider \( q_j \) as a correction to \( p_j \), the fraction of bed material in size interval \( j \) Eq. (II.127), i.e., the availability of sediments to remain on the bed and form an armor coat is increased for larger sizes; because of the form of Eq. (II.127), this interpretation is mathematically equivalent to the formulation in Eq. (II.130).

II.7.4. Effect of Bed Forms on Armoring. An active river bed with continuous formation and propagation of dunes and ripples is less likely than a plane bed to be covered with a top layer of immobile particles forming an armor coat. Instead of staying and accumulating on the bed surface as for a plane bed, grains of different sizes within a subsurface layer (mixed layer) will be continuously mixed, the coarser sediments tending to be deposited (or even transported slowly depending on the flow intensity) close to the bottom or trough of a dune, as illustrated in Figure (II.7). As the dune moves downstream, the coarser particles at the bottom may be temporarily exposed to flow and transported as bed load before being redeposited again in the trough, or overlain by finer
Figure II.7. Schematic representation of sediment size distribution within a dune.
grains of the advancing dune immediately following from upstream. A vertical gradation in sediment sizes, with coarsest fractions at the bottom of the dune, is also likely to develop. A formulation of this rather complicated segregation process among different grain sizes within a dune is not available at present.

The present analysis is limited to development of a heuristic formulation of the reduction in the quantity of coarser sediments accumulating on bed surface due to the presence of dunes. It is assumed that this reduction can be accomplished by reducing the coefficient \( C_A(t,j) \) in Eq. (II.130) from its maximum value of 1.902 \( q_j \), for a plane bed, by multiplying \( C_A \) by a correction factor, \( \alpha_d \), as follows:

\[
C_A(t,j) = 1.902 \ q_j \ \alpha_d
\]  

(II.131)

in which \( \alpha_d \) = correction factor for \( C_A \) due to the presence of dunes, varying between 0 and 1. \( \alpha_d = 1 \) corresponds to a plane bed, and \( \alpha_d = 0 \) implies complete segregation of materials within a dune, as depicted in Figure (II.7) in which coarser sediments filter down to the dune bottom. It is further assumed that \( \alpha_b \) is a function only of relative dune height, \( H_d/d \) (\( H_d \) = dune height; \( d \) = flow depth). This means that \( \alpha_d = H_d/d = 0 \) (plane bed); and \( \alpha_d = 0 \) for the maximum value of \( H_d/d \), i.e., no armorng is possible in a fully active dune bed.

In general, \( \alpha_d \) is a function of dune height, dune velocity, and flow and sediment characteristics which determine the internal grain size distribution of dunes. It is assumed herein that \( \alpha_b \) is an inverse function of the relative dune height given in Section II.6.1.

Using the conceptual model described in the previous paragraph, a linear relation between \( \alpha_d \) and \( H_d/d \) (through \( \eta \)) is assumed, which may be expressed as:

\[
\alpha_d = 1.0 \quad ; \ \eta \leq \eta_c
\]

\[
\alpha_d = \frac{1.10 - \eta}{1.10 - \eta_c} \quad ; \ \eta_c < \eta \leq 1.10
\]  

(II.132)

\[
\alpha_d = \frac{\eta - 1.10}{1.50 - 1.10} \quad ; \ 1.10 < \eta \leq 1.50
\]

\[
\alpha_d = 1.0 \quad ; \ \eta > 1.50
\]

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in which $\eta_c$ = critical value of $\eta$ at incipient sediment motion, obtained from Shields' diagram. The limitation of this formulation for $\alpha_d$, Eq. (II.132), is recognized; future refinements or modifications of the present formulation may be necessary as better knowledge becomes available about the development, and vertical distribution, of grain size composition within bed forms.

II.7.5. Effect of Armoring on Sediment Discharge and Mixed Layer. Armoring of the bed surface tends to reduce the sediment-transport capacity of flow and diminish the average dune height or mixed-layer thickness which represents the zone of mixing of different bed-material grain sizes. These interdependencies are too complicated for a rigorous formulation, and are, therefore, approximated by the following relations in CHARIMA:

$$q_{sa} = q_s (1 - C_1 A_f(t))$$  \hspace{1cm} (II.133)

$$T_m = \frac{1}{2} H_d (1 - C_3 A_f(t))$$  \hspace{1cm} (II.134)

in which $q_{sa}$, $q_s$ = sediment discharge/unit width over the armored bed, with and without armoring, respectively; $T_m$ = mixed-layer thickness; and $C_1$, $C_2$, $C_3$ = calibration coefficients varying between 0 and 1. Variable $q_s$ is obtained from the appropriate transport relation of Section II.3.1. Calibration coefficients, $C_1$, $C_2$, and $C_3$ have been assigned values of unity in the present analysis.

Bed armoring and its effects, as described by Eqs. (II.126) through (II.134), constitute the basic armoring procedure included in CHARIMA. However, CHARIMA also includes options for use of two additional/alternative procedures were developed to account for the armoring of the bed surface in an indirect way. These are described in the next two sections.

II.7.6. Bed-Layer Procedure. In contrast to the approach described in the preceding sections, this procedure does not divide the bed surface into two parts, the armored (no transport) and unarmored (erodible) bed. This procedure assumes that a top
layer coarsens faster than the mixed layer (whose thickness is comparable to the average dune height), and this increased coarsening of the top layer, if incorporated through $D_{50}$ into the sediment discharge and friction factor calculations, should yield the same effect a consideration of an armor coat protecting the underlying finer materials in the mixed layer. This concept was first utilized by Park and Jain (1983), and is presently under further development at the Iowa Institute of Hydraulic Research. The procedure described below is based on this concept, but differs considerably from Park and Jain's analysis in its detailed formulation.

A bed layer of thickness $y_b$ given by (Karim and Kennedy, 1981)

$$y_b = D_{50} \frac{u_*}{u_{*c}}$$  \hspace{1cm} (II.135)

is assumed at the top of the mixed layer (whose thickness is equal to average dune height), as illustrated in Figure (II.8). In Eq. (II.135), $D_{50}$ = median size of the bed layer; $u_*$ = bed shear velocity; and $u_{*c}$ = critical shear velocity obtained from Shields' diagram. In the case of degradation, materials will be first scoured from the bed layer, and if the transport capacity for a particular grain size is still not satisfied, the remaining materials of that size fraction will be taken out of the mixed layer. At the end of the current time period, the composition of the bed layer is updated by assuming that the volume of sediments taken out of the bed layer is filled in by materials from the underlying mixed layer. In the case of aggradation, the bed-layer composition is updated considering the volume and size distribution of sediments deposited above it; if the thickness of deposited sediment is equal to or more than that of the bed layer given by Eq. (II.135), the composition of the bed layer will be the same as that of the deposited sediments. The size distribution of the mixed layer is updated continuously taking into account degradation or deposition in each time interval; the volume of the bed layer, whose thickness is negligible compared to the mixed layer, is ignored in this calculation.

It is important to note that the bed layer, as described above and depicted in Figure (II.8), does not act as an armor coat of immobile sediments. Neither is the separate existence of an armor coat considered, i.e., the armoring factor $A_f(t)$ is always equal to zero in Eqs. (II.133) and (II.134) which explicitly take into account the effect of armoring
Figure II.8. Schematic representation of bed-layer procedure.
on sediment discharge and mixed-layer thickness. The median size of the bed layer
material is used in all sediment discharge, friction factor and mixed-layer thickness
calculations. Because the bed layer, in general, will coarsen faster in a degrading bed than
the mixed layer, this procedure is presumed to account indirectly for the effects of
arming.

The prediction accuracy and validity of this procedure are examined in the report by
Karim et al. (1983).

II.7.7. Surface-Layer Procedure. This procedure retains the basic features
of the armoring calculations described in Sections II.7.2 through II.7.5, with the following
two differences: (i) the median size, D_{50}, used in the sediment discharge, friction factor and
mixed-layer thickness calculations is obtained from a weighted average (by surface area
exposed) of the mixed-layer and armor-coat sediment sizes; and (ii) the effects of armoring
on sediment discharge, friction factor and mixed-layer thickness are not considered, the
arming factor A_f(t) in Eqs. (II.133), and (II.134) being always equal to zero.

The median size of the surface layer, denoted by D_{50}, is calculated from

\[ D_{50S} = D_{50m} (1 - A_f(t)) + \sum_{j=A(t)}^{m} A_f(t_j) \cdot D_j \]  

(II.136)

where D_{50m} = median sediment size of the mixed layer. It is seen from Eq. (II.135) that
D_{50S} will be, in general, equal to or more than D_{50m}, since it includes contributions from
armoring sediment sizes. It is assumed in this procedure that the increased value of D_{50S}
will indirectly account for the effects of armoring on sediment discharge, friction factor and
mixed-layer thickness.

Effectiveness of this procedure is also examined through its application to the
Missouri River as reported by Karim et al. (1983).
III. PROGRAM DESCRIPTION

III.1. Introduction

The basic physical and mathematical principles of CHARIMA, as well as their formal numerical implementation, have been described in Chapter II. The purpose of the present chapter is to provide, if not an exhaustive treatment, at least an outline of the way the procedures of Chapter II are incorporated in the actual computer code of CHARIMA.

As is the case for any numerical model, some of the "pure" formal principles and procedures of Chapter II become somewhat "tainted" in their programmed implementation. This inevitable distortion arises from the constraints of the code itself, from accumulated experience in operating the code, and from anomalous hydraulic situations such as dry-bed channels, strong non-linearity of the sediment-discharge predictor, poorly conditioned node matrices, etc. Thus there is a certain amount of overlap between the descriptions of Chapter II and the present chapter. Nonetheless, the authors prefer to let the theoretical basis of Chapter II stand intact and untainted by the practical exigencies described below.

The remainder of this chapter consists of relatively independent descriptions of some of the more important special procedures and features incorporated in CHARIMA, followed by a "walk-through" of the code itself. The objective is to provide an analyst sufficient background fully to understand the code through detailed study of it. Matters related purely to operation of the code and interpretation of results are contained in Chapter IV.

III.2. Topological Identification System for Nodes and Links.

The looped-network capability of CHARIMA requires that careful attention be devoted to establishment of an efficient and effective system for describing the topology of the network. The notion of topology as used herein refers to the structure of flow paths as reflected in the complex interconnections among nodes, points, and links.

To put the topological problem in context, consider two approaches which bracket the range of possibilities. The first approach would involve incorporating in CHARIMA topological procedures so general that an extremely simple system of link-node identification in the user's data set would serve as the basis of an automatic recognition and
check of node groups, node positions, etc. In other words, the user could describe the model nodes and links on the sole basis of their physical location and characteristics, with no knowledge of, or deference to, the complex matrix-loading procedures of Sections II.4.4 and II.4.6. The obvious advantage is an enormous simplification of the task of data-set preparation. The obvious disadvantage is considerable investment of code-development time and effort to achieve this generalilty. The CARIMA and CAREDAS codes of SOGREAH Consulting Engineers offer precisely this topological generalilty, for looped networks, obtained at a cost of several man-years of development.

A second approach would involve writing the CHARIMA code in such a way that the program structure itself reflects the particular topology of the particular river network under study (through subroutine calling sequences, loop counters, etc.). The advantages would be, once again, in simple data-set preparation, and in a minimum of investment in program development. The disadvantage would be in having a program code lacking any topological generality whatsoever. To use the code for a different river system, or even to use it for some small modification of the river system for which the code was written, would require direct intervention in the code itself, necessarily by the code's developers themselves.

The topological system developed for BRALLUVIAL is a compromise between these two extremes. The objectives are two fold:

   a) allow the program code to be sufficiently general for use on any river network without need for programmer intervention.

   b) liberate the user, insofar as possible, from having to organize his data set according to computational exigencies.

In other words, the goal is to have all identity of network topology contained in the data set, not the program, and yet lighten the user's data preparation task as much as possible. These objectives have been achieved in the system described below.

The topological identification system involves points, links, and nodes, as sketched in Figure II.3. The points of any link \( k \) are numbered sequentially from 1 (point at the
lower end of the link) to II (\( \ell \)) (point at the upper end of the link, where "lower" and "upper" generally, though not necessarily, connote "downstream" and "upstream" respectively. With links and nodes are associated both sequence numbers (i.e., the order in which they are defined in the data set) and names (i.e., an integer identifier which may or may not be correlated with the sequence numbers). Thus on Figure II.3, the node names shown are 7 and 4, while the link names shown are 4, 18, 13, 27, 453, and 7.

Each link \( \ell \) is defined topologically by its name, number of points II (\( \ell \)), and by the names of the nodes at its upper and lower extremities, MU(\( \ell \)) and MD(\( \ell \)) respectively. Table III.1 shows the topological link definitions for the links of Figure II.3.

<table>
<thead>
<tr>
<th>Link Sequence Number ( \ell )</th>
<th>Link Name</th>
<th>II(( \ell ))</th>
<th>MU(( \ell ))</th>
<th>MD(( \ell ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>5</td>
<td>7</td>
<td>?</td>
</tr>
<tr>
<td>2</td>
<td>18</td>
<td>9</td>
<td>7</td>
<td>?</td>
</tr>
<tr>
<td>3</td>
<td>13</td>
<td>5</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>27</td>
<td>?</td>
<td>?</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>453</td>
<td>?</td>
<td>?</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>7</td>
<td>?</td>
<td>?</td>
<td>4</td>
</tr>
</tbody>
</table>

Each node m is defined topologically by its name, number of attached links KK(m), and by the names of these links, with the convention that the name of a link which is attached to node m at its lower end is given as negative. Table III.2 shows the topological node definitions for the nodes of Figure II.3.
Table III.2. Node topology data for Figure II.3

<table>
<thead>
<tr>
<th>Node Sequence Number m</th>
<th>Node Name</th>
<th>KKK(m)</th>
<th>Attached Links KKK(λ), λ=1, KKK(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>3</td>
<td>4 18 -13</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>4</td>
<td>13 -27 -453 -7</td>
</tr>
</tbody>
</table>

The above link and node definitions must be furnished by the user. In addition, the user must furnish, for each node, the number of the node group to which the node belongs (NGROUP(m)), and the sequence number of the node within its group (MPOS(m)). It must be said that there is redundancy in these required link-node topological definitions, since either link or node definitions should be sufficient for recognition of the unique topological structure of a network. This redundancy reflects the compromise solution described earlier, i.e., a shift of code generalization effort toward data set requirements.

Once the program has cross-checked the link and node definitions for consistency, it replaces all node and line names appearing in MU, MD, and the KK lists by their respective sequence numbers, permitting more efficient access to data at run time. Taken together, the variables II, MU, MD, KK, MPOS, and NGROUP provide sufficient information for all matrix-loading operations associated with the node continuity equations, Sections II.4.4 and II.4.6. The link and node names used in the topological definitions are retained only for identification of physical input data, results, and warning and error messages.

III.3. Dynamic Memory Allocation for Arrays

CHARIMA incorporates a dynamic memory allocation procedure designed to eliminate the need to dimension arrays and optimize memory use. The procedure involves
the use of just one working array, called T. All working arrays are stored inside T, and
dimensioned automatically at execution time according to the specific size of the problem
being solved (number of points, number of links, number of nodes, etc.) T is itself
dimensioned once in the MAIN program. Therefore to change the amount of required
memory, the user need only change the dimension of T and recompile the MAIN, without
having to worry about the dimensions of the many working arrays. Based on the general
input data to the program, the space needed for each array can be calculated at execution
time, and the position of each array inside T can then be computed. Through the use of the
dummy argument feature of FORTRAN, the arrays can be used exactly as if they were
dimensioned locally, using their proper names.

This system, which uses standard features of FORTRAN, allows the user to choose
the way he uses memory to conform to the constraints of his computer center. He may
dimension T by excess once and for all, and hopefully never have to change it, accepting
the wasted space. Or he can tailor the dimension of T to the size of each model to be run
using the formula described in Section III.9, thus using no more computer memory than
actually needed. In either case, only one numerical dimension (instead of nearly 100) is
involved. (It should be noted that on certain computing equipment, even T can be
dimensioned automatically, requiring no additional compilation of the MAIN).

As soon as the MAIN reads the first data card, containing all information necessary
to determine the required size of working arrays, it proceeds to compute the location of
each array with T, stored consecutively one after another. Thus I1 = 1, meaning the first
word of the first array (MU) coincides with the first word of T. Since the required length
of MU is its maximum dimensions LINKS, the next array (MD) has its first word stored
just after the last word of VOLIN, i.e., I2-I1 + LINKS, and so on. Thus to each working
array corresponds a unique index Ixx, each displaced from the previous one by the required
length of that array. Appendix A shows the names of the working arrays, the
corresponding indexes, the dimensions, and a brief description of each.

At the completion of this operation, the position inside T of each working array has
been assigned. At this point it is essential to verify that T is large enough, i.e., that the
position of the last word of the last array is less than the dimension of T, MEMO.

The final stage in the dynamic allocation involves establishing the correspondance
between the computed locations in T and the names of the arrays, i.e., T(I1) is equivalent
to MU(1), T(I28) = BETA(1,1), etc. This is done through a matching of argument lists in
a call to SUBROUTINE PILOT from the MAIN (note that actually this is broken into two
calls, to PILOT and ENTRY PILOT1, to avoid having too long an argument list). These
calls, which transfer control to PILOT for the duration of the computation, establish once
and for all the desired correspondance. In all subsequent use of the working arrays, their
proper names are used exactly as before. The arrays are dummy-dimensioned using the
same scalar variables used to compute their space allocation in T, no further dimensioning
is required.

A potential drawback to this procedure is the need to transmit all arrays from one
subroutine to another by argument lists, rather than in common blocks, which cannot be
dummy-dimensioned on some computers. However, the expense of transmitting these
long argument lists in repetitive calls is easily avoided by making one initial call to transmit
the list once and for all, then calling an entry point (with no arguments) for all subsequent
calls. For example, one call to DOLINK transmits all needed array addresses; all
subsequent calls are to ENTRY LINKS1 with no arguments.

III.4. Management of Cross-Section Data

The water-routing operations of CHARIMA are equivalent to, and thus require the
same input data as, a backwater computation. In particular, Eqs. (II.48-52) require, for
each computational point i, the area and conveyance functions \( A_i(y_j) \) and \( K_i(y_j) \) for the
cross-section associated with the point. In addition, the various sediment operations of
CHARIMA require the width and hydraulic radius functions for a section, \( B_i(y_j) \) and
\( RH_i(y_j) \). Moreover, these functions must be consulted literally millions of times in a single
simulation. The cross-section data management problem is one of transforming user's
geometric definition of a cross-section (e.g., elevation-width pairs) into \( A, K, B, \) and \( RH \)
functions which can be accessed as efficiently as possible during program execution.

In CHARIMA the user defines a cross-section by furnishing any number of
(elevation-width) or (distance-elevation) pairs, at regular or irregular intervals. The
program then proceeds to construct a regular elevation-width function \( B_{i,\ell}, i,\ell = 1,...,IL \) on
a regular grid of IL depths separated by vertical distance DH, through linear interpolation of
the user's (depth, width) data. Thus \( B_{i,\ell} \) is the interpolated width at depth \( (i\ell - 1)\times DH \)
above the thalweg. The final preparatory operation consists in constructing the area,
perimeter, conveyance, and hydraulic radius functions by trapezoidal integration of the \( B_{i, \ell} \) function, i.e.:

\[
A_1 = O; \quad P_1 = B_1 \tag{III.1}
\]

\[
A_{i, \ell} = A_{i, \ell-1} + \frac{1}{2} (B_{i, \ell} + B_{i, \ell-1})DH, \quad i, \ell = 2, ..., IL \tag{III.2}
\]

\[
P_{i, \ell} = P_{i, \ell-1} + 2 \left[ DH^2 + \left( \frac{B_{i, \ell} - B_{i, \ell-1}}{2} \right)^2 \right]^{1/2}, \quad i, \ell = 2, ..., IL \tag{III.3}
\]

\[
R_{H_{i, \ell}} = \frac{A_{i, \ell}}{P_{i, \ell}} \tag{III.4}
\]

\[
K_{i, \ell} = \frac{A_{i, \ell}}{\sqrt{8gR_{H_{i, \ell}}}} \tag{III.5}
\]

Actually only the \( A, RH, \) and \( K \) functions are stored for use during execution, and \( K \) is the conveyance for unit friction factor.

During execution, any time the section data are needed, the water-surface elevation above the thalweg, \( h_{i} \), is first noted. The appropriate position in the regular-grid tables is found as

\[
i, \ell = \text{INT}[h/DH] \tag{III.6}
\]

where \( \text{INT} \) denotes the integer value. An interpolation factor corresponding to the actual water surface elevation is computed as:

\[
F_{\text{INT}} = (h - i, \ell*DH)/DH \tag{III.7}
\]

Then the area, hydraulic radius, and conveyance are determined by linear interpolation in the regular grid tables, e.g.,
\[ A(h) = A_{i,t} + \text{FIN}\ast(A_{i,t+1} - A_{i,t}) \]  

(III.8)

and similarly for RH(h) and K(h). Both the width and the derivative of the conveyance are approximated by simple divided differences, e.g.,

\[ B(h) = (A_{i,t+1} - A_{i,t})/DH \]  

(III.9)

\[ \frac{\partial K}{\partial y} \bigg|_h = (K_{i,t+1} - K_{i,t})/DH \]  

(III.10)

The above procedures represent a compromise between CPU time and memory requirements. The geometric computations of Eqs. (III.1-III.5) are performed only once, during the preparation phase of a simulation. The repetitive run-time computations of A, RH, K, B etc. benefit from the extremely rapid and efficient regular-grid interpolations of Eqs. (III.6-III.10), the "cost" of which is the memory required to store the regular-grid functions.

In CHARIMA the sections are "generic" in the sense that the A, RH, K tables for a section can in principle be used for any number of computational points. This feature is quite useful for prismatic canals, as it frees the user from having to furnish redundant elevation-width data for identical sections. Any generic section is particularized for a specific computational point at run time, when that point's actual friction factor is used to convert the unit-friction-conveyance K(h) to the actual conveyance RK,

\[ RK(h) = K(h)/\sqrt{f} \]  

(III.11)

The effect of differential aggradation/degradation among computational points which share the same generic section is reflected in the computation of their individual maximum depths, which serve as "arguments" in the consultation of the A, RH, K tables.
III.5 Dry-Bed Procedures

The nemesis of Computational Hydraulics is the treatment of dry or nearly-dry channels. Several distinctly different problems are implied by the general term "dry bed":

* If all the links connected to a node are completely dry, then there is no way to compute a water-level change for the node so as to satisfy continuity. This leads to a singular matrix $[A]$ in Eq. (II.73).

* As the depth at a section gets very small, the discharge may be affected more by the decrease in conveyance than by the increase in water-surface slope. This leads to the "small-depth instability" problem discussed by Cunge et al., (1980), pp. 175-178.

* As the conveyance associated with small depth approaches zero, the energy slope approaches infinity.

* The high Froude numbers associated with small depths on supercritical slopes fundamentally change the subcritical boundary condition requirements implicitly assumed in Section II.4.4. (upstream and downstream dependence).

In most fluvial networks, all channels are constantly inundated, obviating the small-depth problem. But in networks such as the Susitna River, there are many high-flow cross channels which routinely become dry at low flows, and many of these have quite steep thalweg slopes. Consequently the dry-bed situation must be treated as a routine, common occurrence in CHARIMA.

Treatment of dry-bed situations has been based, insofar as possible, on hydraulic reasoning. A dry-bed condition is declared automatically whenever the maximum depth at a computational point is less than the vertical interval DH used for the regular-grid definition of the section assigned to that point (see Section III.4); DH is normally the order of one foot or less. In order that the hydraulic computations may proceed in spite of the anomaly, the program simply adopts for the point in question the area, width, conveyance, and hydraulic radius for a depth DH above the thalweg, i.e., the first values in the regular-
grid tables. The objective is to maintain some small but finite hydraulic connectivity among all nodes, while assuring that the finite discharges associated with this artificial connectivity are small enough to have negligible effect on the rest of the network. By convention, all sediment operations are suspended for links having one or more points declared to be dry.

Many other dry-bed schemes have been explored, most based on direct intervention in the matrix of Eq. (II.73). However, these schemes were not only generally unsatisfactory for maintaining inoffensive hydraulic connectivity, but also difficult to interpret physically.

The above programmed procedure is complemented by judicious choice of parameters when dry-bed conditions are thought to be likely. The small-depth supercritical flow problem is obviated by setting $\alpha = 0$ in Eq. (II.2); this is tantamount to ignoring the effect of velocity heads in the energy equation, but maintains the need for a downstream boundary condition for Froude numbers greater than unity. The small-depth instability problem is obviated by imposing strictly upstream conveyance weighting through manipulation of $\beta$ in Eq. (II.14). The small-conveyance problem is somewhat mollified by requiring that all sections have a certain minimum width at the thalweg, such as 50 feet.

These measures have nothing to do with the formal theoretical basis of CHARIMA, and in fact can be viewed as violating certain hydraulic principles. Their justification lies in the recognition that if a channel is nearly dry, its contribution to the overall water and sediment process under study is minimal. Therefore whatever procedures allow the remainder of the model to continue to function are justified. It is, however, incumbent upon the user of such procedures to be vigilant in assuring that they are in fact not disruptive to portions of the model where hydraulic laws must be strictly respected.

III.6 Restart Procedures

CHARIMA is designed for use in simulating both small and large river systems. For small systems, computational cost and data management are not of particular concern. On the other hand simulation of large systems may become quite expensive due to the large number of computational points, links, or nodes. For example, the Susitna model has several hundred links and nodes, and nearly 1000 computational points; the cost per time step simulated was roughly $3 per time step on the University of Iowa's IBM 3033 computer, i.e., roughly $150 per year simulated.
While every effort has been made to reduce computational cost in CHARIMA, a model such as the Susitna is nonetheless expensive to operate. Thus there is a need to eliminate any redundant computation by allowing the user to restart a previous computational whose results are stored on a disk or tape file. For example, a previously-prepared file containing a broad range of flow conditions could be used to supply initial conditions for any number of subsequent computations. Alternatively, a long-term simulation which was aborted due to some data or hydraulic anomaly could be restarted with corrected data, obviating the need to repeat all the simulation proceeding the incident.

The restart procedures in CHARIMA are based on the use of an optional output file on which are stored all results of computation as well as physical, hydraulic, and topologic data describing the model. The structure of this file is given in Appendix D, and instructions for restart are given in Chapter IV and Appendix B. The basic principle is that the initial condition for a model--i.e., discharges, water levels, thalweg elevations, mixed-layer composition, armoring factor, etc.--may be set either manually (by furnishing the data directly) or automatically (by loading from a restart file). Moreover, the user of CHARIMA can acquire most of the initial condition through automatic loading from a restart file, then modify only selected data as necessary before initiating the restart simulation. This facility permits selective "repair" of certain data (e.g., thalwegs) before continuing. However, it is not possible to make any topological changes to a model during a restart.

An additional collateral benefit of the restart procedure is that the restart file can also be used for off-line results processing, graphical or printed, with the PLIAL5 code. This permits detailed analysis of a simulation without the need to re-run all or part of a simulation in order to obtain detailed results in an area or period of particular interest.

III.7 Program Structure

CHARIMA comprises a MAIN program and 32 subroutines, organized as shown on the schematic flow chart of Fig. III.1. This structure makes extensive use of multiple entries to subroutines, for two reasons:
Figure III.1. Schematic flow chart of CHARIMA.
Figure III.1 cont
* to group in one subroutine procedures which are closely related but executed at
different times;

* to obviate the need to pass long argument lists in repetitive calls, thus achieving
some CPU time economy.

This latter justification, more fully described in Section III.3, relies on the feature of the
IBM FORTRAN vs compiler which allows a subroutine to "remember" the addresses of
arrays initially passed in an argument list when subsequent argument-free calls are made to
its multiple entry points. Use of CHARIMA with compilers which do not have this feature
requires some repetition of argument lists, rendering some of the present initial calls
unnecessary.

The structure and role of CHARIMA's individual routines are outlined in Section
III.8 below.

III.8 Annotated Review of Subprograms

III.8.1. Introduction. The purpose of this chapter is to provide some guidance
for a programmer or analyst desiring to understand the programmed implementation of the
theoretical procedures laid out in Chapters II and the additional code features described in
Sections III.2 - III.7. While it is not feasible to document every program instruction in a
report such as this one, detailed study of the code itself, in conjunction with study of this
section, should permit a full understanding of all details. However, it is also obvious that a
still-maturing code like CHARIMA is being modified and refined even as this is written,
and will continue to change as it is used for new studies. Therefore the authors beg the
reader's indulgence in the inevitable obsolensence of some of the descriptions in the
remainder of this section.

A detailed catalog of all important program variables is contained in Appendix A. Input
data records referred to herein are described in Appendix B.

III.8.2. MAIN Program. The sole function of the MAIN is to perform the
dynamic memory allocation of Section III.3. Input records 1 and 2 are read; the first
simply to allow printing of the run title, the second to permit computation of all array sizes for the dynamic allocation.

Prior to the dynamic allocation, the TLTM coefficients in Eqs. (II.21) and (II.23) are loaded in constants TLTM1- TLTM9; the values shown are for the Susitna River. Any re-calibration of TLTM for other rivers would result in modification of these constants in MAIN.

The variables I1- I are the "pointers" in the single array T, delineating the boundaries of all dynamically-allocated arrays. The calls to PILOT (immediate return) and PILOT1 (return at the end of the simulation) activate the dynamic allocation by establishing the addresses in T of all dummy arrays.

Any change in the size of array T involves recompilation of MAIN to change both the dimension of T and the scalar MEMO; these must have the same value for proper memory management.

III.8.3. Subroutine PILOT (entry PILOT1). PILOT (or, more properly, PILOT1) manages all data-preparation and computation operations. PILOT has an immediate return to MAIN, its purpose being simply to establish some of the array addresses. The second call from MAIN to PILOT1 establishes the remaining array addresses (two calls needed to avoid an excessively long argument list).

Input records 3,4,5,6 are read, default value loaded, and printed. Then the title and array-dimension data are written to the results file, NROUT, as results records 1 and 2. The remainder of this section is written for the case of a restart calculation (NRIN > 0) and an active results file (NROUT > 0); however, both are optional.

Statement 5 and the following one are dummy reads on the restart file NRIN, their purpose being simply to skip restart records 1 and 2. This skipping emphasizes the implicit requirement that the topological structure of the model be identical to that of the model on the restart file.

The standard sediment sizes, DS, are read on input record 8; however, if a restart is used, these values are immediately replaced by the ones read from record 3 of NRIN; indeed, it is not possible to change the sediment sizes implicitly incorporated in the many sediment arrays subsequently to be loaded from NRIN. The adopted sizes, whether taken from the restart file or from the input data, are then written onto NROUT, record 3. These
sizes (in mm) are then printed, then converted to feet in the DO 10 loop. The geometric mean sizes DSG are simultaneously computed.

Prior to the call to TOPOLO, record 4 of NRIN is skipped through a dummy read. Indeed, subroutine TOPOLO takes all topological data from input records 8 and 9; once again, it is implicit that the input topological structure is identical to the structure represented on NRIN. Upon return from TOPOLO, the topological data are transferred to the results file, record 4 of NROUT. At this point in the preparation, the complete topological structure of the model has been defined and checked in TOPOLO.

The instructions from statement 11 up to, but not including, statement 14 execute the task of loading the initial condition from the restart file NRIN (they are skipped if NRIN ≤ 0). This loading involves reading of former results for successive time steps until the results for the desired restart time ITREST are located. By convention, all restart-file results prior to the restart time are transferred to the results file NROUT if NROUT > 0 and if the restart time ITREST is identical to the simulation start time, ITBEG. In other words, the situation ITREST=ITBEG is interpreted to mean that the present simulation is in the real sense a continuation of the former one, implying the need for a results file containing all results, both prior to and after the restart.

The restart search operations in the implicit loop between statements 11 and 13 are self-explanatory; see Appendix D for description of the restart records 5, 6, and 7 which are successively processed. The loop DO 12 and the two instructions immediately preceding it transfer certain arrays to their "previous" counterparts in anticipation of the next results sequence being the restart one. If an end-of-file is encountered before reaching ITREST, control is sent to statement 998 (fatal error 21).

The restart loading, if activated, is followed by the call to subroutine POINTS, in which type 11 input records are read, checked, and loaded. If a restart is active, (NRIN > 0), then the data read in POINTS selectively modify the initial condition loaded from NRIN. If NRIN=0, then the entire initial condition is loaded in POINTS. In either case, upon return from POINTS the loop DO 15 computes and stores all computational reach lengths from the river miles associated with points.

The call to SEDINP (which is an entry in POINTS) provokes reading of input records 12 defining the "generic" initial sediment size distributions for each point. If a
restart is active, these distributions are ignored in favor of the actual distributions loaded from NRIN.

The loop DO 20, which is not executed if a restart is active, assign median bed-material sizes to reaches based on adjacent point values, and temporarily sets armoring factors to zero.

The call to SEXION provokes reading, verification, and loading of all type 15, 16, 17 input records defining the "generic" sections of the model. These input data replace all section data taken from the restart file.

The instructions following the call to SEXION through statement 18 comprise checking and verification operations for physical data. The individual checks can be understood by referring to Appendix C; in calls to ERRWAR, the first argument is 1 for a warning, 2 for an error, and 3 for an immediate fatal error. The second argument is the warning or error number, as appropriate. Null values of friction factor or median bed-material size indicate they were never loaded; negative values of section number indicate the requested section was never defined. The maximum-minimum variable serve to detect an obvious scale (or format) error in important physical parameters of the model.

Following the physical data checks, the lists of printed output data (at least one is required) and time step changes (if no specified) are read and printed, input records 18, 19. The parameter IDELT of input record 3 is normally used to begin the simulation, but it can be replaced immediately or subsequently by a change as desired.

The loop DO 40 loads a list of standard temperatures and converts the standard relative viscosities initially loaded by a DATA statement to absolute viscosities.

The twenty-three calls to subroutines DOLINK, SLINKS, DONODE, FRICT, TLTM, ACKERS, EXNER, USTLTM, GAUJOR, LODMAT, DAARMO, DAHYSO, NODSD, ENHAN, USENHA, COEFF, DASHIE, CRITER, FLOCA, TMCHG, DSBC, DOWFCT, and USPOW serve primarily to transfer dummy array addresses to the working routines of the simulation; each call is followed by an immediate or almost immediate return. These "dummy" calls constitute the final step in the dynamic allocation process.

The dummy calls complete the preparatory phase of a simulation. The program proceeds to execute the simulation only if no errors were encountered during the preparation operations.
The remainder of PILOT is devoted to execution and control of the actual simulation. Statement 45 marks the beginning of the time-step loop, and statement 500 marks the end of it. Within this time loop, statements 48 and 215 mark the beginning and end of the global iteration loop within each time step.

At the beginning of each time interval, the time step IDELT is first modified if appropriate. When either the simulation time exceeds ITEND or the number of time steps exceeds ITMAX, the simulation is ended by sending control to statement 500. The first time step (IT=1) serves only to permit printing of the initial condition, with control sent directly to the print sequence at statement 420.

The justification for the global iteration loop beginning at statement 48 is described in Section II.2, and its mechanics are outlined in Section II.4.5. The call to FLOCA1 (an entry of FLOCA) executes the water-flow simulation and manages the iteration loops. Upon return from FLOCA1, the parameter DETER=0.0 indicates the impossibility of inverting a matrix; control is sent to statement 425 for printing of the state of the model, followed by an abnormal end to the simulation. If no matrix-inversion anomalies are encountered, the loop DO 50 searches for and loads the appropriate temperature-dependent viscosity for subsequent use in sediment operations. At this point the hydraulic (backwater) computation, comprising all the operations of Section II.2, has been completed for the present iteration.

By convention in CHARIMA, negative times are taken to represent periods of simulation devoted solely to hydraulic stabilization, with all sediment operations suppressed. Therefore control is passed directly to the print cycle if ITIME < 0. If time is positive, then the various optional sediment operations are activated according to the option chosen for each. In the case of new subroutines written expressly for BRALLUVIAL and CHARIMA (TLTMQS, EXNER1, EXNER2), the loops on links and points are contained within the routines themselves. In the case of existing subroutines adopted from IALLUVIAL (HYSORT, ARMOR) the link-point loops are external to the routines, i.e., contained in PILOT.

Following the call to FLOCA1, for ITIME > 0, and if the appropriate option is active, the sediment operations are successively activated. The calls to TLTMQS, ENHAN1, POWFQS, ACKQS, etc. provoke computation of sediment discharge by size fraction at all points, Eq. (II.21, II.22, etc.). The function of loop DO 65 is to smooth the computed
transport capacities longitudinally. The call to EXNER1 (an entry in EXNER), provokes computation of the amount of each size fraction removed from each computational reach, Eq. (II.103). The loop DO 70 provokes the computation of sediment sorting in each computational reach through calls to HYSORT (an entry in DAHYSO), executing the procedures of Section II.6. The sorting (and armoring) procedures are suspended for any link which is not fluvial, declared dry (see Section III.5) or carrying a small discharge less than DRYQ.

If bed-level changes are not computed, there is no need to compute the upstream-boundary bed-level changes. Otherwise, the loop DO 75 identifies upstream-boundary links, then calls USTLT1, USENH1, USPOW1 to execute the computation of Section II.5.3. Once again, this operation is suspended if the boundary link is dry or carries only a small discharge.

The call to EXNER2 (another entry in EXNER) provokes finalization of the bed-level-change computation for each reach, taking into account any limitations detected in HYSORT. This procedures also includes allocation of reach-changes to adjacent points, whose thalweg elevations are appropriately modified.

The loop DO 80 executes the armoring computation for all reaches, through calls to ARMOR (an entry in DAARMO).

The loop DO 300 updates the median bed material size for each reach, then allocates reach values of median bed material size and armoring factor to adjacent points.

At this point all operations of Sections II.2 - II.7 are completed for one global iteration of one time step. The tests of statement 215 send control back to statement 48 for a new iteration if none of the iteration-termination criteria are satisfied.

Statement 420 begins the output cycle. The list of printed output dates (ITOUT) is first consulted to determine whether or not the present time step is to be printed. Statement 425 begins the actual output cycle. A time header is written to the results file (record 5 of NROUT), and a summary time header (format 2012) is printed if no general results printing is called for. The loops DO 450 access results for each point, writing records 6 and 7 to NROUT, and printing one line for each point if appropriate. Line numbers are tracked for spacing of new-page headers. Finally, "previous" values of variables CDEP, TALWEG, PT, ARM and QS are loaded by direct transfer.
The volume computations below statement 450 are not presently applicable, being remnants of IALLUVIAL. The only remaining statement of significance is the STOP 1984 in case of a matrix-inversion problem detected earlier following the call to NODES1.

III.8.4. Subroutine TOPOLO. The general purpose of TOPOLO is to read, check, and assemble topological data during the preparatory phase of a simulation. Throughout TOPOLO, the options IPLINK and IPNODE allow printing of topological data but have no effect on the actual operations.

The instructions beginning with statement 10 and ending before statement 30 comprise a loop for reading the link-definition input data records, type 9. Since the end of link-definition data is signalled by a negative link name, this last one is reset positive before the ERROR 6 check of coherence between LINKS and the number of link-definition records actually read.

The call to RAZ initializes to zero the number of nodes in each node group, NGSIZE; these values are subsequently counted automatically. The instructions beginning with statement 40 and ending before statement 50 comprise a loop for reading the node-definition input data records, type 10. This loop includes both counting of the number of nodes in each node group and noting of the largest water-sediment inflow sequence number (NINQ or NINQS). Other error checks contained in the loop are self-explanatory. As for the link-definition data, the negative node name signalling the end of the node data is reset positive, and then coherence between the number of nodes read and NODES is checked (ERROR 7).

The remainder of TOPOLO is devoted to verification of the topological coherency outlined in Section III.2. The loop DO 60 performs a topological check on all links; the operations are self-explanatory if one consults the appropriate error codes of Appendix C. The loop DO 70 performs a topological check on all nodes; these operations are also self-explanatory.

The loops DO 150 and DO 200 perform the final operation of Section III.2, namely, replacing all cross-references to link and node names by references to their respective sequence numbers. From this point onward, node and link names are used only for identification and checking purposes.
III.8.5. Subroutine POINTS (entries SEDINP, SEDTRB). The purpose of POINTS is to read and check all physical data associated with computation points. Like TOPOLO, POINTS is called from PILOT only once, during the preparation phase of a simulation. The array E is temporarily used to store the sediment type NSED for the POINTs and SEDINP operations. It should be remembered that if no restart is in progress (NRIN=0), POINTS must load all physical data, whereas in the case of a restart (NRIN > 0) POINTS loads only modifications, if any, to the restart initial condition. The parameter IPOINT simply switches on or off the printing of read data, with no effect on actual operations.

In NRIN=0, the call to RAZ sets to zero all friction factors, permitting a subsequent check, in PILOT, that all points were loaded by verifying non-zero friction factors.

The instructions from statement 5 to statement 70, inclusive, comprise a loop for reading the point-definition input data records, type 11. In statement 5, each record is read into scalars rather than directly into the appropriate arrays, to avoid possible array overflow for a linkname -9999 record. Normally the end of point data is signaled by a negative linkname; however, if no modifications are made to a restart initial condition, a single record carrying a fictitious linkname of -9999 signals the end of data. Thus control is sent directly to statement 999, provoking a return to PILOT, if -9999 is encountered.

The DO 50 loop verifies that the linkname being processed was also defined topologically (ERROR 8). If not, no action is taken other than signaling the error. If the linkname is valid, control is passed to statement 60 with the index L denoting the sequence number of the linkname.

The instructions from statement 60 to 70 load the scalar data into the appropriate arrays according to the valid link sequence number L and the point number I read on the input record (note that I is not checked for validity, i.e., 1 ≤ I ≤ II(L)). If a restart is active, modifications to the water level, discharge, and friction factor are prohibited. Moreover, the initial thalweg TALWGI (initial denoting here the beginning of the period of simulation) is loaded only for the no-start case. Default values of friction factor, velocity coefficient, and energy-slope weighting are loaded if the user furnished values of zero (or blank) for these parameters.

In the instruction preceding statement 70, the section number is set negative for subsequent use in checking that the requested section was indeed furnished. In statement
70, control is sent back to statement 5 for processing of the next record; however, if the current link name is negative, indicating the end of point data, control is sent to statement 999 for immediate return to PILOT. It is not necessary to set this last linkname positive, as it is strictly a local scalar. Loop DO 350 processes certain topological information at nodes. Loop DO 305 signals a warning 4 if the user assigns an inconsistent initial water surface elevation to any of the points attached to a node. Loop DO 310 assigns the average initial elevation to all points attached to the node. Instructions between statements 310 and 350 detect inconsistent section types for the two points attached to a simple node.

The purpose of SEDINP is to read the generic bed-sediment distributions, convert the cdf to pdf, compute the median size, and attribute the distribution to those computation points (actually to the reaches associated with those points) requesting its use. This attribution consists in simply identifying any point whose requested NSED is the same as the current NSED, then transferring the current generic pdf and median size to the appropriate PT and D50R arrays. Thus the null values of D50R are replaced by valid values for all points whose NSED corresponds to a furnished generic distribution.

In statement 220, the reading/processing loop is terminated if the current generic sediment distribution type is negative.

The purpose of SEDTRB is to read the bed-sediment distributions for tributary inflows to nodes, if any. SEDTRB is called from PILOT1 only once. Statement 600 reads the input data record 13. If NODNM = -9999 is encountered, this marks the end of record 13, so control is sent directly to statement 999 provoking a return to PILOT. Loop DO 500 to statement 510 computes D50 from the given CDF. Loop DO 520 then converts the CDF to a PDF. Loop DO 530 detects an inexistent node in input data record 13, if any, then signals an error 24. Before using loop DO 550 to store the PDF by the sequence numbers of nodes, an error 26 is signaled if a tributary sediment distribution was given for a node which was defined as not having tributary inflow. The variable NODSED(M) is changed from 0 to the name of node M to indicate that a sediment size distribution was furnished for the time-dependent sediment inflow to the node.

III.8.6. Subroutine SEXION (entry SECPRO). The role of SEXION and SECPRO is to manage all operations involving cross-section geometric data, following the principles of Section III.4. The option IPSECT serves only to provoke printing of section data, having no effect on actual operations. The section processing operations require use of a working memory zone TWORK; it can be seen by tracing arguments through the
dynamic allocation that TWORK is simply the unused space between the last word of the last dummy array in T, and the last word of T itself, T(MEMO). The length of this working zone is MEMO-IMLAST words. The arrays SEGEOM and ISEGEO are equivalent, sharing exactly the same locations in T. This double-definition facilitates storing both floating-point and integer information in the same array.

The loop DO 100 reads and processes all generic sections defined by input data records 15, 16, 17. This loop is explicit, thus input data errors will surely occur if the number of sections furnished is not exactly equal to the number specified in the dynamic allocation, NSECS.

The record 15 read statement (FORMAT 1000) notes the section "name" NUMSEC, the number of levels in the regular-grid table NLEVEL, the vertical interval in this table DH, and a 60-character TITLE which is used strictly for informational purposes. The call to RAZ sets to zero the entire working zone TWORK, for later use in checking for the end of data through recognition of a zero. The index IWORK is used to mark positions on TWORK as it is filled to a variable length from one section to another.

The fatal error check in statement 21 (ERROR 3) prevents overflow of array T if the raw section data pairs exhaust the available space in TWORK. This check is done for each record, not for each data pair. If space is available, the statement READ (5,1001) loads an input data record, type 16, into the working zone. If the first elevation on the record is negative, this signals the end of (elevation, width) data for the current section, sending control to statement 30. Otherwise, the index IWORK is incremented by 8 words (4 data pairs on one record) and control is sent to statement 20 to read the next record 16 for the current section NS into the working zone.

When control is passed to statement 30 for the current section NS, all the irregular (elevation, width) pairs have been stored in the working zone. The next task is to project these irregular pairs onto a regular grid through linear interpolation. Since the grid is regular, there is no need to store elevations; the vertical interval DH suffices. The interpolated widths are to be temporarily stored in the regular grid zone ultimately reserved for areas. Figure III.2 shows the structure of the block of SEGEOM allocated to each generic section.

At statement 30, the address in SEGEOM of the data block for the current section NS is noted and stored in ISECAD(NS). Then the section "name", number of levels, and

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Figure III.2
vertical interval are stored in the first 3 words of the data block. The remaining instructions through statement 40 constitute the filling of the area zone with interpolated widths at vertical intervals DH. This operation is essentially self-explanatory in conjunction with the following remarks. Although the first area $A_1$ is always zero (Eq. (III.1)) and thus need not be stored, the first width (at the thalweg) $B_1$ is stored in the area zone. Moreover, to obviate dry-bed problems associated with small conveyances, the width is forcibly limited to a minimum value of the order of 50 feet through the AMAX1 function applied to BHI. (This minimum width will ultimately be parameterized and made accessible through the input data.) The effect is to prohibit a triangular section and its associated low conveyances at small depths. Another feature incorporated in the interpolation is adoption of a constant width equal to the largest width furnished if the highest elevation furnished is lower than the vertical extent of the regular-grid table. Exhaustion of (elevation-width) pairs in TWORK is signalled by encountering a zero elevation. This arms the constant-width flag BCONST.

Following the DO 40 LOOP, the regular-grid table of widths is completed and stored in the area zone for section NS. The next task is to perform the trapezoidal integrations and computations of Eqs. (III.2 - III.5), replacing the widths by areas and loading the unit-friction-factor conveyance and hydraulic radius zones. This is accomplished in the loop DO 50, which is self-explanatory. Then the block index ISECA is incremented by the total length of the block for the current section NS, in preparation for treatment of the next section.

The final task is to attribute the current section's block address (in SEGEOM) to each computational point which requests use of this section. Thus the loop DO 60 identifies any and all points whose previously-stored value of NSEC (set negative) is the same as the current section's positive sequence number NS. If a point requests a section which is never defined, its NSEC will remain negative, provoking ERROR 17 in the DO 18 loop of PILOT.

After processing of NSECS sections, SEXION transfers control to statement 999 for immediate return to PILOT1. At this point all regular-grid section data have been prepared and stored, and all point-section cross-referencing has been resolved.

The SECPRO procedures in the subroutine SEXION are executed by multiple calls from COEFF1, USPOW1, USTLT1, USENH1, and LINKS2 during the actual
simulation. The task of SECPRO is to respond to the call by consulting the geometric tables for the requested section, computing the area, conveyance, width, hydraulic radius, and conveyance derivative, and returning control to the origin of the request.

At the time of the request, the arguments L and I identify the link and point for which data are required. The appropriate block in SEGEOM is first identified by noting the point's section sequence number stored in NSEC, then noting the block address stored in ISECAD. The NLEVEL and DH variables for this section are taken from the head of the block, and the thalweg depth is computed from the Y and TALWEG arrays. The regular-grid index \( i \ell \) of Eq. (III.6) is computed, with the constant 0.001 added to avoid round-off truncation to the next smaller integer if the depth is an exact multiple of DH.

Normally \( 1 \leq i \ell < \text{NLEVEL} \), and control is sent to statement 520 for processing. But if \( i \ell < 1 \), a dry-bed situation is indicated. The DRYBED flag for the link containing the point is armed; and the depth is arbitrarily set to DH, according to the procedures of Section III.5. If \( i \ell \geq \text{NLEVEL} \), the depth is greater than that anticipated in the choice of DH and NLEVEL for this section. If time is negative and the depth is not excessive, the anomaly is assumed to be a transitory one during hydraulic stabilization, so no warning is issued. If on the other hand time is positive or the depth is excessive, WARNING 6 is issued to alert the user to the anomaly. Moreover, if the depth is excessive (parameter DEPMAX, currently set to 500 feet), fatal ERROR 22 is issued. If the anomaly is judged to be non-fatal, the index \( i \ell \) is positioned for extrapolation upwards from the top of the regular-grid table, by setting \( i \ell = \text{NLEVEL} - 1 \).

The remainder of SECPRO, i.e. from statements 520 to 999, executes the computations of Eqs. (III.7 - III.11). The only remark needed is that the index IL is changed from the regular-grid index \( i \ell \) to an absolute index in SEGEOM for direct access to data in the block. IL is advanced from area to conveyance to hydraulic radius by adding NLEVEL words each time. Statement 999 returns control to either COEFF1, USPOW1, USTLT1, USENH1, LINKS2, etc.

III.8.7. Subroutine DOLINK (entries LINKS1, LINKS2). The forward and return sweeps of Section II.4.5 are contained in DOLINK. There is only one call to DOLINK, coming from PILOT1 during the preparation phase. This call establishes the dummy array addresses, and initializes the node water levels by setting them equal to the initial levels at associated computational points. This procedure, contained in the loop DO 10, implicitly assumes equality among the water levels at all points associated with a given
node. After execution of the DO 10 loop, control is sent to statement 999 for immediate return to PILOT1.

LINKS1 is called from FLOCA1 at every iteration of every time step. Its task is to calculate the E,F,H of Eq. (II.57) for each link, through the loop DO 90 on all computational points of the link. The coefficients $A_o, B_o, C_o, D_o, G_0, A'_o, B'_o, C'_o, D'_o,$ and $G'_o$ of the linearized flow equation are obtained in one of two ways. For a non-fluvial link (typically a weir), they are obtained through a call to SLINK1 (see Section III.8.8), which returns control directly to statement 15. For fluvial links, $A_o, B_o, C_o, D_o,$... are calculated by a call to COEFF1 (see Section III.8.23). At statement 15, the linearized coefficients are known for reach $i-1 \rightarrow i$, either from the fluvial calculation or from the weir calculation in SLINK1. For reaches beyond the first one ($i > 2$), control is sent to statement 50, where the recursive relations of Eqs. (II.58-60, 66-68) are executed. For the first reach ($i=2$), the initialization relations of Eqs. (II.61-63, 69-71) are executed. For a weir-type reach, on which there are only two points by definition, control is immediately transferred to the end of the link loop, statement 100. For fluvial reaches, control passes to statement 90 for possible continuation of the point loop. When all links have been treated, control passes to statement 999 for immediate return to FLOCA1. At this point the $E,F,H$ coefficients of Eq. (II.57) have been computed and stored for all links of the model, completing the link forward sweep.

LINKS2 is called from FLOCA1 at every iteration of every time step. Its task is to execute the links return sweep of Section II.4.5. The parameter DQMAX is first set to zero; it is subsequently used in FLOCA1 to check maximum discharge corrections as a criterion for iteration convergence.

The loop DO 200 executes the return sweep link by link. In preliminary operations for each link, the $\Delta y_1$ and $\Delta y_i$ of Eqs. (II.64 and II.72) are taken from the node-level correction at both ends of each link, associated with point $i=1$ (DY1) and $i=I$ (DYI), then $\Delta Q_1 = DQ1$ is calculated from Eq. (II.64) and $\Delta Q_i = DQI$ is calculated from Eq. (II.72). Then $y_{I,1}^{n+1}, Q_{I,1}^{n+1}, y_{I,1}^{n+1}$ and $Q_{I,1}^{n+1}$ are computed immediately.

The dry-bed flag for the current link is disarmed prior to the point-by-point return sweep, in which it may be rearmed if dry-bed conditions are encountered. If there are more than two points in the link, loop DO 155 executes the return sweep, which progresses from
point \( i = 1 \) to \( i = 11 \). For \( i = 1 \), \( y_{i,1}^{n+1} \) and \( Q_{i,1}^{n+1} \) have already been loaded, so control passes directly to statement 155. For other points, \( \Delta y_{i,2} = D Y \) is computed from Eq. (II.53), and \( \Delta Q_{i,2} \) is computed from Eq. (II.57). Then at point \( i \) in the link \( 2 \) water surface elevation \( y_{i,2}^{n+1} \) and discharge \( Q_{i,2}^{n+1} \) are updated immediately prior to statement 155.

Following statement 160, SECPRO is called for all fluvial reaches so as to rearm the dry-bed flag if necessary and to acquire the section geometric properties for use in calculating velocity for results output.

Upon return from LINKS2, the water routine computation is complete for the current iteration of the current time step.

III.8.8. Subroutine SLINKS (entry SLINK1). The purpose of SLINK is to compute the reach coefficients \( A_0, B_0, C_0, D_0, G_0, A'_0, B'_0, C'_0, D'_0 \), and \( G'_0 \) of Eq. (II.42-43) for a rectangular weir. The procedures follow those set forth in Section II.4.7. SLINKS is called once only from PILOT1 during the preparation phase. This call establishes the addresses of the dynamically allocated arrays, and provokes the loading of a few constant weir parameters before direct return to PILOT1.

SLINK1 is called from LINKS1 whenever the link forward sweep encounters a weir. It is anticipated that SLINKS will eventually contain routines for other special hydraulic features, as indicated by the value of LTYPE and the branching on \( I \). Presently only the weir is defined, with control passing always to statement 100.

The computations of SLINK1 are self-explanatory, following the equations in Section II.4.7. Suffice it to note that the RETURN 1 at statement 999 sends control directly back to statement 15 of LINKS1.

III.8.9. Subroutine DONODE (entry NODES1). DONODE is called once only from PILOT1, to establish dummy array dimensions and load a few constants. Control is then passed to statement 999 for immediate return to PILOT1.

NODES1 is called from FLOCA1 at each iteration of each time step. Its purpose is to manage the loading of the matrices and vector of Eq. (II.76) and the matrix double-sweep operations of Section II.4.6. The call to INFLOW provokes the interpolation and loading
of all time-dependent external water and sediment inflows to the model, as well as the downstream water level and water temperature.

The loop DO 100 executes the matrix forward sweep of Section II.4.6. The indices MBEG, MEND are the sequence numbers of the first and last nodes in each node group NG. The variables NGL, NGC, NGR are the number of nodes in the left (previous), central, and right (following) node groups, used for variable dimensioning of node-group matrices in subsequent operations.

The call to RAZ sets to zero the entire \( R \), \( S \), \( T \), and \( V \) arrays in anticipation of subsequent accumulation operations. Then for the first node group, which always contains the downstream boundary node 1, \( S \) and \( V \) are loaded so as to impose the downstream water-level correction directly, Eq. (II.74). In other words, for node \( m=1 \) the usual continuity equation is replaced by Eq. (II.74). For all nodes of the current group, the call to LDMAX1 at statement 20 provokes the loading of \( R \), \( S \), \( T \), \( V \) with the elements of the continuity equation for each node in the current (central) group. Upon return from LDMAX1, \( R \), \( S \), \( T \) and \( V \) are fully loaded for the current node group.

The remainder of NODES1 follows closely the matrix double sweep algorithm of Section II.4.6. For node groups other than the first one, control is passed to statement 30. For the first group, the \( S \) matrix is inverted through the call to INVERT, and the result left in SMAT; if the argument DETER is set to zero upon return from INVERT, this signals a singular or nearly singular matrix. In such a case, control is sent to statement 400 for special output. The call to MATMLT computes the matrix produce \( S^{-1}T \) of Eq. (II.82), and leave the product in the \( E \) matrix. Then the call to SCAMAT changes the sign of the previous product, completing the initialization of \( E \) by Eq. (II.82). The next call to MATVEC computes the scalar product \( \{ S^{-1}V \} \) of Eq. (II.83), and leaves the product in \( \{ F \} \) according to Eq. (II.83). \( E \) and \( F \) are now initialized; control is then sent to statement 100 for continuation of the loop on node groups.

After the call to LDMAX1 for subsequent node groups, control is passed to statement 30. The call to MATMLT at statement 30 computes the matrix product \( R_{ng}E_{ng-1} \) of Eq. (II.79), and stores the result in \( E_{ng} \). The call to MATADD adds \( S_{ng} \) to \( R_{ng}E_{ng-1} \) as in Eq. (II.79), and stores the result in \( S_{ng} \). Then the call to INVERT inverts this latter sum and leaves the result in \( S_{ng} \). For all node groups except the last one, the call to MATMLT takes the product of \( T_{ng} \) with the latter inversion, and puts the result back in
The computation of \([E]_{ng}\) in Eq. (II.79) is then completed by changing its sign through the call to SCAMAT.

The computation of \((F)_{ng}\) begins with the call to MATVEC to compute the scalar product \([R]_{ng} \ (F)_{ng-1}\), leaving the result in \((F)_{ng}\). The scalar \((V)_{ng}\) is then subtracted from this product through the call to MATSUB, and the result left in \((V)_{ng}\). The call to MATVEC multiplies this scalar factor of Eq. (II.80) by the matrix factor, still available in \([S]_{ng}\) from the earlier computations for \([E]_{ng}\), and leaves the result in \((F)_{ng}\). Finally, the call to SCAVEC changes the sign of \((F)_{ng}\) to compensate for the earlier reversed order of subtraction in the call to MATSUB. This completes the computation of \((F)_{ng}\), and control is sent back to the beginning of the loop for treatment of the next node group.

Upon completion of the DO 100 loop, the node-group matrices \([E]\) and vector \((F)\) are known and stored for all groups completing the matrix forward sweep. The loop DO 200 executes the matrix return sweep of Section II.2.6. This loop proceeds from \(ng = NG-1, ..., 1\); indeed, \((\Delta Y)_{ng}\) is already known and stored in \((F)_{NG}\) by virtue of Eq. (II.46). Throughout the return sweep, the \((\Delta Y)_{ng}\) vectors continue to be stored in the \((F)_{ng}\) vectors. The call to MATVEC computes the product \([E]_{ng} \ (\Delta Y)_{ng+1}\) of Eq. (II.78), with the result temporarily stored in \((V)_{1}\). (Note that \((F)_{ng+1}\) is actually \((\Delta Y)_{ng+1}\) at this stage.) The call to MATADD simply adds \((F)_{ng}\) to the previous product, and stores the results in \((F)_{ng}\), (actually \((\Delta Y)_{ng}\), completing Eq. (II.78) for the current node group. At the completion of the DO 200 loop, the nodal water-level change vectors \((\Delta Y)_{ng}\) have been computed for all node groups, and stored in the \((F)_{ng}\) vectors in the order of the declared positions (MPOS(m)) in the node-definition topological data.

The final operation of NODES1 involves transfer of node-group water-level correction vectors to the simple nodal array of level changes, DYN. In the loop DO 300, this transfer is accomplished in the first instruction, where each node's group number and relative group position are used to access the appropriate \((F)\) value. The next statement limits any node-level change to a maximum value of DELYM, which is a parameter of the order of one foot. The idea is to prevent global-iteration divergence by prohibiting any transient but excessive iterative level correction from initiating a divergence from the overall node-level solution. Any such arbitrary capping of \(\Delta Y\) temporarily causes continuity to be violated at the node in question.

The node-levels \(Y\) are updated by adding \(\Delta Y\), then the maximum correction is noted for later use in iteration management in PILOT1. Transfer is then sent to statement 999 for
return to FLOCA1. The array \((\Delta Y)_m, m=1,\) NODES is now loaded and available for the link return sweep.

III.8.10. Subroutine LODMAT (entry LODMA1). The general purpose of LODMAT is to load the \([R], [S], [T]\) matrices and \([V]\) vector of Eq. (II.76) for a node group. LODMAT is called once from PILOT1 during the preparatory phase of the simulation. This call serves simply to transfer the addresses of dummy arrays and load constants before direct return to PILOT1. LODMA1 is called from NODES1 once for each node group in each global iteration of each time step. In contrast to most entries in CHARIMA, LODMA1 has a rather long argument list. The reason is that the \([R], [S], [T]\), and \([V]\) arrays have varying dimensions from one node group to another. The other arguments, all loaded in DONODE, are the numbers of nodes in the previous (left), central, and following (right) node groups \((NGL, NGC, NGR)\); the node sequence numbers of the first and last nodes in the central group \((MBEG, MEND)\), and the group number of the current (central) group, \(NG\).

The loop DO 100 considers each of the nodes in the current (central) group, loading the appropriate matrices by \(E,F,H,E',F',H'\) coefficients and boundary conditions to constitute the continuity equation for each node, Eq. (II.41) as expressed in Eq. (II.76). In this loop, the index \(M\) is the sequence number of the current node, i.e. the key to accessing any required topological data for this node. MR is the relative position of node \(M\) in its node group, and KKK is the number of links attached to node \(M\).

By convention, a negative node sequence number \(NINQ\) indicates that the node is an imposed water level boundary. Therefore the instructions preceding statement 300 replace the usual continuity equation for the node with direct imposition of the water level, Eq. (II.74). The call to DSBC1 provokes loading of the appropriate member of QTR with an automatically determined water-surface elevation (quasi-uniform flow) if so requested by the input variable IDSBC. Control is then sent to statement 100 for treatment of the next node. For all nodes, MR denotes the node's relative position in its group, i.e. MR is the appropriate row index in the node-group continuity equation for the current node group, Eq. (II.76). If the current node has been designated as having an external water inflow (possible for any node, internal or boundary, indicated by \(NINQ>0\)), then in statement 300 the appropriate member of the vector \([V]\) is initialized by QTR, the value of the external inflow previously loaded when NODES1 called INFLOW.
Following this initial loading, the loop DO 90 incorporates the discharge contribution of each link connected to node M to that node's continuity equation. This operation involves a rather delicate establishment of correspondences among node-sequence addresses and node-group matrix addresses, and proper accounting of discharge sign conventions. The variable RLSIGN is set to + 1.0 for a link L whose positive discharge leaves node M, and to -1.0 for a link whose positive discharge enters node M.

The node sequence number of the node to which node M is connected by link L is identified as MCON, and then the relative position of MCON in its node group is identified and denoted MCONR; this can be thought of as a column index for the matrix-loading operations.

If the network comprises only one ("central") node group, then control is sent directly to statement 30. Otherwise, node MCON may be in the same, previous, or following node group, and the matrix loading operations are different for each case. Thus the test in statement 10 sends control to either statements 20 (link with previous group), 30 (link with same (central) group) or 40 (link with following group.) For all three cases, one end of the link is at node M, and the other at MCON; RLSIGN serves to distinguish which end is which, and thus correctly to allocate $E_1$, $H_1$, $D_1$, or $H_1$ to the correct element of [R], [S] or [T] with the proper sign reflecting inflow or outflow to the node, following Eq. (II.41). In the procedure for the central group beginning at statement 30, the column indices ICOLE and ICOLH are used to facilitate this matrix-loading juggling act. It is left to the reader to verify the correctness of these operations with the aid of the comments in the code.

All three node-group situations terminate with control transfer to statement 50, where the coefficients $F_1$ or $F_1^T$ and the previous discharges $Q$ are loaded into the free vector $V$ with a sign correction given by RLSIGN, again following Eq. (II.41). This terminates the treatment of one link.

To summarize, the loop DO 100 corresponds to the existence of one Eq. (II.41) for each node in a node group, and the loop DO 90 corresponds to the summations in Eq. (II.41).

III.8.11. Subroutine MATMLT (entries MATADD, MATSUB, MATVEC, SCAVEC, SCAMAT, VECVEC, VECMAT, MATEQ, VECLLEN, VECEQ, TRNSPZ). This subroutine comprises numerous linear algebra operations
called from DONODE during the matrix forward and return sweeps. The routine was taken virtually unchanged from Carnahan et al. (1969), Example 4.1; a complete description of the operations can be found therein. It should be noted that the two-dimensional matrix and one-dimensional vector arrays in MATMLT often correspond to particular constant-last-dimension zones of three-dimensional and two-dimensional arrays, respectively, in the calling program. It should also be noted that not all of the operations (entries) in MATMLT are used in CHARIMA.

III.8.12. Subroutine GAUJOR (entry INVERT). The matrix inversions of Section II.4.6 are performed using a Gauss-Jordan routine with maximum-pivot strategy. This algorithm was taken directly from Carnahan et al. (1969), Example 5.1.

GAUJOR is called once from PILOT1 during the preparation phase, to transfer dummy array addresses and load constants. Control is then sent to statement 999 for immediate return to PILOT1.

INVERT is called by NODES1 for each node group in each global iteration of each time step. Arguments A and N (square matrix A, dimension N*N) has variable size from one call to another, and thus must be passed as arguments. The parameter EPS is used to detect a dangerously small pivot coefficient in one row, signalling a possible singular matrix. If such a pivot smaller than EPS in absolute value is detected, the parameter DETER is set to zero as a flag and control is sent to statement 999 for return to NODES1, where the anomaly will be detected through DETER.

Detailed description of the inversion procedure can be found in Carnahan et al (1969).

III.8.13. Subroutine INFLOW. The task of reading and interpolating all time-dependent data is assigned to INFLOW; a virtually identical procedure is used in the IALLUVIAL program. INFLOW is called by NODES1 once in each global iteration of each time step. In the common/SCALR/, the scalar "input" ITIME contains the integer date (in days) for which time dependent data is to be loaded. In the argument list, the scalars YDOWNS and TEMPF, as well as the array QTR, are the "output" variables returned to NODES1. QTRIB is a dynamically-allocated working array, used only locally.

The instructions preceding statement 100 serve to read input data records of type 22 and assure that the latest one read is associated with the first input data time ITDAT which is larger than the current time ITIME. In subsequent interpolation operations, the
interpolation is always between the latest read values (TFREAD, YREAD, QTRIB) and the most recent values sent back to NODES1 (TEMPF, YDOWNS, QTR). The DO 30 loop and following three instructions temporarily load the latest read values into the output arrays in anticipation of reading a new data record. The implication is that any time ITIME advances beyond the latest read time, a new record is read and the interpolation will be between the latest two read records. Then as the time advances toward the latest read record, the previous one is no longer used. The DO 200 loop checks both NINQS and NINQ for each node M. If there is water discharge inflow (NINQ>0) and the power-law option is selected (NINQS≤O), then Q_s is computed by the power law \( q_s = a Q^b \) and loaded in QTR.

Control is passed to statement 100 as soon as data are correctly loaded for interpolation. The actual interpolation occurring between statements 100 and 999 is self-explanatory. The instructions at and below statement 900 signal exhaustion of the time-dependent data records.

It should be noted that the procedures in INFLOW allow the time-dependent data to be furnished independently of the time-step variations used for the simulation. It should also be noted that multiple calls to INFLOW for global iterations beyond the first one of a given time step provoke exactly the same redundant operations.

III.8.14. Subroutine TLTM (entry TLTMQS). The purpose of TLTM is to calculate the fractional and total sediment capacity loads at each computational point, according to the procedure set forth in Section II.3.1. TLTM is called only once from PILOT1 during the preparatory phase of a simulation, to transfer dummy array addresses and load constants; control is then sent to statement 999 for immediate return to PILOT1.

TLTMQS is called from PILOT1 for each global iteration of each time step. The loop DO 105 considers each link of the model; by convention, sediment loads are set to zero (call to RAZ) in links which are declared dry, or non-fluvial. The loop DO 100 considers each computational point of a link. If for some reason the velocity is strictly zero, or discharge is less than DRYQ, the sediment load is summarily left at zero through direct transfer to statement 100. In order to avoid excessively high sediment loads due to a transitory high energy slope, the latter is arbitrarily limited to 0.01 insofar as the sediment computation is concerned. The operation limiting B1 to a maximum of 70.0 is to avoid an exponentiation overflow in Eq. (V.3), again during a transitory anomaly of excessively
large hydraulic radius. It should be said that such anomalous situations do not occur once a model data set has been debugged.

The second loop DO 100 considers each size fraction at each point of each link, applying Eq. (II.21) and Eq. (II.22) with the weighting factor \( W \) in Eq. (II.22) taken from Eq. (V.2) (see Section V.3) for the Susitna model. If ISHEAR in input record 2 is not equal to zero, Shield's parameter SHIPAR is computed by Iwagaki's curve. The call to SHIELD with the Reynolds number as an argument (through COMMON) provokes computation and loading of the Shield's parameter SHIPAR, used to find the critical shear velocity USTARC. If the actual shear velocity is less than some fraction of the critical shear velocity for the current size fraction, the contribution of this fraction to the total load is taken to be zero through direct transfer of control to statement 100.

The four instructions preceding statement 40 are necessary to avoid a possible anomalous rapid increase in sediment load as flow conditions become quiescent. This possible anomaly is due to the strong nonlinearity of Eq. (II.21), by which a small velocity and a shear velocity just above the critical could cause both \( V_1 \) and \( V_3 \) of Eq. (II.21) (called V1 and V6 in the code) to be less than unity. Then the product of their logarithms would be positive, causing a potentially large contribution to the sediment capacity for the current size fraction. This anomaly, caused by the inapplicability of Eq. (II.21) for quiescent conditions, is avoided by suppressing the contribution of the third term on the right side of Eq. (II.21) whenever both \( V_1 \) and \( V_6 \) are less than unity. Statement 40 is Eq. (II.21).

The call to ERRWAR signalling warning 11 is provided to flag an anomalous excessive sediment transport. Normally the warning is skipped, control passing directly to statement 60 where the full-width uncorrected load for the current size fraction is computed from the left side of Eq. (II.21). Then, following an attribution of the next-to-last sediment pdf value to the last point if necessary, Eq. (II.22) is used with Eq. (V.2) to complete the computation of the corrected full-width capacity for the current size fraction, with the sign of the capacity set equal to that of the water discharge. This contribution is finally added to the total load QSTOT.

It should be emphasized that the treatments of possible computational anomalies in TLTMQS serve only to permit a shaky simulation to continue. Under normal conditions these treatments are never activated.
Upon return to PILOT1, the fractional and total sediment loads are computed and loaded for each computational point, for subsequent use in sediment-continuity, sorting, and armoring operations.

III.8.15. Subroutine FRICT (entry FRICT1). The purpose of FRICT is to compute the friction factor according to the methodology of Section II.3.3. FRICT is called once only from PILOT1 during the preparatory phase, to transfer addresses of dummy arrays and load constants. Control is then passed to statement 999 for immediate return to PILOT1.

FRICT1 is called from PILOT1 at each global iteration of each time step. The loop DO 200 considers each link of the model which is non-dry, fluvial, and has non-zero flow (this latter case leads to a singularity in the friction-factor computation.) The loop DO 100 then considers each computational point on the link, applying Eq. (II.34) to compute the energy slope; the coefficients $c_0$, $c_1$, and $c_2$ are those calibrated for the Susitna data, see Section V.2. The instruction preceding statement 100 extracts the friction factor itself from the Darcy-Weisbach relation,

$$S = \frac{f}{4R_h} \frac{u^2}{2g} \quad (\text{III.13})$$

Upon return to PILOT1, the friction factor has been updated for each fluvial computational point of the model, in preparation for the next backwater computation.

III.8.16. Subroutine EXNER (entries EXNER1, EXNER2). The EXNER routines execute the sediment continuity computation in fluvial reaches, Section II.5.1. EXNER is called once only by PILOT1 during the preparatory phase of a simulation, to transfer dummy array addresses and load constants. Control is then returned directly to PILOT1.

EXNER1 is called by PILOT1 for each global iteration of each time step. Its purpose is to compute the equivalent depths of bed-level change in each reach and for each size fraction, Eq. (II.103). The loop DO 100 considers all fluvial links which are non-dry and have discharge greater than some minimum DRYQ. By convention, no sediment operations are performed for dry or low-flow links.
The loop DO 95 considers each computational reach of the current link. The loop DO 90 considers each size fraction. If the direction of flow (as reflected in the signs of the present and previous fractional loads) has changed sign from the previous time step to the present one, then the weighting coefficient $\theta$ of Eq. (II.103) is set to 1.0 as a temporary precautionary measure (fully implicit weighting).

In anticipation of a "normal" computation, QSDP and QSD are loaded with the net outflow of the size class from the reach, at the previous and current time steps, respectively. If the computational reach is indeed "normal" in the sense that it is not connected to a sediment-inflow node, then control is sent to statement 111. The remaining instructions prior to statement 111 treat the case of a reach whose upstream computational point is a sediment-inflow node (upstream boundary or unmodelled tributary). Normally, the sediment inflow to the reach is then taken to be the user-furnished inflow as found in QTR and distributed to size classes by PTRIB. However, if the shear stress is less than the critical shear stress at the node (determined on the basis of either the Shields or the Iwagaki approach), then the user-imposed sediment inflow is suppressed (presumption that flow cannot carry the imposed load). Beginning at statement 111, TDELD (I,J,L), which is $\delta_{i,j}$ in Eq. (II.103), is computed by Eq. (II.103) for any reach; it should be noted that TDELD is positive for degradation, negative for aggradation.

The instructions between statements 110 and 90 comprise further adjustments to the Exner-computed bed-level change for the current size class. If the reach is not subject to bank erosion, control is sent directly to statement 112. Otherwise, the computed bed-level change TDELD is decreased (i.e. modified toward deposition) by the imposed bank-erosion sediment inflow, provided that the water discharge exceeds the specified minimum QMIN.

Beginning at statement 112, two procedures developed by Karim are implemented to further adjust TDELD under certain conditions. If a deposition tendency exists (TDELD<0) but the shear velocity exceeds the fall velocity, the deposition is reduced by the ratio of bed to total load as determined in CRIT2. If a degradation tendency exists (TDELD>0), it is suppressed if the bed shear velocity is less than the critical value for initiation of motion. These procedures, developed in the IALLUVIAL code, were found to be necessary for the Missouri River simulations.
Prior to the end of the DO 90 size-class loop, the individual size-class contributions to bed-level change are totalled up in VOLOUT for subsequent use. The sum of degradation/aggradation depths for all size fractions is accumulated in the variable DELD for subsequent use in controlling excessive bed-level changes.

The instructions following statement 90 constitute a check for, and control of, excessive bed-level changes. If |DELD| is less than the permissible vertical change VOLMAX, the situation is normal and control is sent to statement 95 for continuation of the loop on computational reaches. Otherwise, warning 10 is signalled through the call to ERRWAR, and the fractional loads are proportionally adjusted so that their sum will be strictly VOLMAX. This procedure is admittedly ad hoc, but has proven to be useful in controlling excessive bed-level changes during transitory anomalous hydraulic situations in early global iterations.

Upon completion of the loop DO 100, control is returned to PILOT1. At this point all fractional bed-level changes have been computed and loaded for subsequent use in sorting and armoring operations.

EXNER2 is called by PILOT1 in every global iteration of every time step, following the sorting computations. Its purpose is to perform final bed-level accounting operations following the possible adjustment of fractional bed-level changes in HYSORT.

The loop DO 300 considers all links of the model which are fluvial, and non-dry. The loop DO 200 considers all "normal" computational reaches on the current link. The loop DO 150 accumulates the total sorting-adjusted bed-level change in the reach in TOTAL; this quantity is immediately checked for excessive change (WARNING 10) and limited to VOLMAX; it also is summarily rounded off to zero if it is less than one thousandth of a foot.

The armoring depth CDEP is updated by TOTAL added to its previous value, and another armoring depth DARM is set equal to CDEP.

At the end of the DO 200 loop, the current bed-level change, VOLOUT, and the cumulative depths of degradation CDEP and DARM, have been computed for all computational reaches. If the current link has only one computational reach, control is sent to statement 270. Otherwise, the loop DO 250 computes the new thalweg at all interior computational points by applying a reach-weighted average of bed-level changes.
(VOLOUT) in adjacent reaches, Eq. (II.104). Following the DO 250 loop, the new thalweg at the first point is computed by simple attribution of the reach thalweg change. If the link is an upstream boundary link with no sediment inflow, control is sent to the end of the DO 300 link loop. If, on the other hand, the link is an interior one, the new thalweg at the last point is computed by simple attribution of the reach thalweg change, and control is sent to statement 300.

Statement 270 is a special calculation of the new thalweg at the first and last points of a link having only one reach; the reach changes are summarily attributed to the adjacent points.

At the completion of the DO 300 loop, new thalweg elevations have been computed at all computational points. It should be noted that the thalwegs at all link end points will subsequently be re-computed by the nodal sediment continuity procedure in PILOT1 except at the most upstream and downstream nodes of the model, Section II.5.4.

III.8.17. Subroutine USTLT (entry USTLT1). The purpose of USTLT is to compute the thalweg elevation at upstream boundaries of a model, according to the procedures of Section II.5.3. USTLT is called only once from PILOT1 during the preparatory phase of the simulation, to transfer addresses of dummy arrays and load constants, followed by immediate return to PILOT1. USTLT1 is called from PILOT1 for each upstream boundary point in each global iteration of each time step. In the argument list, the variable M is the sequence number of the node associated with the upstream boundary point, and the logical variable FIRCAL indicates whether or not this is the first time step of the simulation. Parameter C is the assumed bed-wave celerity in feet/day, L is the boundary link being processed, and I is the boundary point itself. If either the discharge of reach i or the discharge of reach i-1 is smaller than DRYQ, control is sent to statement 999 for return to PILOT1. If for some reason the boundary point is fully armored, control is sent to statement 999 for return to PILOT1 with no change to the point or reach bed elevation. (This procedure should eventually be generalized to allow for deposition on a fully armored bed.)

Normal execution resumes at statement 710, where iteration-loop preparation is begun. BUFF is the parameter $\beta_h$ in Eq. (II.105, 108); if the computed value of BUFF is greater than 0.5, it is replaced by 0.5. ITBC is an iteration counter; VAR1 is the denominator of $V_1$ in Eq. (II.21), and DEP is the current thalweg depth $d^n_I$. The actual
Newton-Raphson iteration loop for determination of the required bed elevation to satisfy Eq. (II.105) begins at statement 720 with a call to SECPRO to obtain current hydraulic conditions. If it is determined in SECPRO that the point is dry, WARNING 9 is signalled through a call to ERRWAR, the thalweg is put at its previous elevation, the reach degradation is set to zero, and control is sent to statement 999 for return to PILOT1. This abnormal procedure simply reflects the fact that it makes no sense to have a boundary link which is declared dry.

Normal execution resumes in statement 730; the Newton-Raphson computation referred to Section II.5.3. involves solving the following non-linear equation for depth \( d \):

\[
f(d) = \log \left[ \frac{\frac{\bar{Q}_s^{n+1}}{B_1(\exp(-2.99573 ACF_I))} - \frac{\beta_o \Delta x}{\Delta \tau} \frac{(1-p)}{\exp(-2.99573 ACF_I)} (y_1^{n+1}-d-z_1^n)}{\sqrt{g(s-1) D_{50}^3}} \right] - a_o - a_1 \log V_1 - a_2 \log V_1 \log V_3 - a_3 \log V_2 \log V_3 = 0 \quad \text{(III.14)}
\]

in which the last four terms are as defined in Section II.3.1. In the code, the following FORTRAN variables correspond to those of Eq. (III.14):

- \( \bar{Q}_s^{n+1} \)  
  \( \text{FD} = f(d) \)

- \( Q_{SIMP} = \frac{\bar{Q}_s^{n+1}}{B_1(\exp(-2.99573 ACF_I))} \)

- \( \text{BUFF} = \beta_b = c \Delta t / \Delta x \)

- \( \text{REACH(I-1,L)} = \Delta x \)

- \( \text{IDELT*TCONST} = \Delta t \) (sec)

- \( \text{POROS} = p \)

- \( \text{ACF(I,L)} = ACF_I \)

- \( \text{Y(I,L)} = y_1^{n+1} \)
DEP = d, 

\[ TALWGP(I,L) = \frac{x^n}{l} \]

\[ \text{VAR1} \ast D5OP(I,L) = \sqrt{g(s-1)D_{50}^3} \]

\( V8 = \) argument of first logarithm in Eq. (III.14).

It should be noted that in the loading of V8, the anomaly treatments used in TLTM (see Section III.8.14) are again employed, and the correspondences between program variables V1, V2 etc. and their counterparts in Eq. (II.21) are also the same as in TLTM. It should be noted that a boundary singularity is avoided by requiring that the armor-corrected QSIMP be at least 0.0001 ft²/sec. If \( V8 \leq 0 \), an anomaly exists; control is sent to statement 9.

The variable FDP is the derivative of FD with respect to d or R, the implicit assumption being that \( \Delta \text{DEP} = \Delta p \approx \Delta R \), and the statement DELD = - FD/FDP is the Newton-Raphson correction to the depth. Following loading of "previous" values V8P etc., control is sent to statement 12. Statement 9 handles the anomalous situation of "******" which indicates that conditions are outside of the normal range of Eq. (II.21). In this case, variables are reset to previous values in anticipation of \( V8 > 0 \) in the next global iteration (DELD = 0.0 will provoke exit from the iteration loop.)

Normal execution resumes at statement 12, where the depth and thalweg are corrected. Control is sent back to statement 720 for another iteration if the correction is greater than 0.1% of the depth and the maximum of 50 iterations has not been reached. If iterations are terminated for either reason, the usual WARNING 10 check is made for excessive bed-level change.

At this point the bed elevation at boundary point I has been computed. The remaining task is to compute the reach bed-level change as described in the last paragraph of Section II.5.3. This computation is essentially the same as the solution of Eq. (II.103) as coded in EXNER1 (Section III.8.16). The "previous" values are initialized if FIRCAL (first time step) is armed and the current call is for the first global iteration. The resulting VOLOUT depth of degradation is the bed-level change in the boundary reach, to be used in a subsequent call to EXNER2 from PILOT1. If the imposed sediment load QSTR(M) is equal to (or less than) zero but deposition occurs, control is sent to statement 20 to impose VOLOUT = 0. If VOLOUT is larger than or equal to VOLMAX, WARNING 10 is
signalled for excessive bed-level change. Then, the absolute value of VOLOUT is replaced by VOLMAX.

Statement 999 returns control to PILOT1.

III.8.18. Subroutine DAHYSO (entry HYSORT). The bed-sediment sorting operations of Section II.6 are computed in DAHYSO. The procedures are quite complicated, but are identical to those incorporated in the subroutine of the same name in IALLUVIAL. Therefore no attempt is made herein to provide detailed annotation of the code especially since such annotation is currently being prepared for IALLUVIAL.

DAHYSO is called once from PILOT1 to transfer dummy array addresses and load constants, with control sent immediately back to PILOT1. HYSORT is called from PILOT1 for each computational reach of each link in each global iteration of each time step; however reaches which are dry, non-fluvial, or carrying very low flow are bypassed. In subsequent development of CHARIMA, use of the link index in HYSORT should be eliminated, as L changes only from one call to the next.

III.8.19. Subroutine DAARMO (entry ARMOR). The bed-armoring operations of Section II.7 are computed in DAARMO. The complicated procedures are identical to those incorporated in the subroutine of the same name in IALLUVIAL. Since detailed documentation of these procedures is currently being prepared for IALLULVIAL, no attempt is made herein to duplicate this effort.

DAARMO is called once from PILOT1 during the preparatory phase of a simulation, to transfer dummy array addresses, load constants, and read all armoring data, input record 20. (Note that the user instructions in Appendix B do not describe the rarely-used reading of fractional armoring factors in the loop DO 2010.) ARMOR is called from PILOT1 for each computational reach of each link in each global iteration of each time step. However, all dry, non-fluvial, and low flow reaches are bypassed. As for HYSORT, subsequent development should include elimination of the static link index L in ARMOR, to achieve some reduction in CPU time.

III.8.20. Subroutine DASHIE (entry SHIELD). The purpose of DASHIE is to compute the Shield's parameter for a given Reynold's number by consulting a parameterization of Shield's curve. The basic parameterization procedure is presented in the report by Holly et al. (1984), Section III.B.
DASHIE is called once by PILOT1 during the preparatory phase of a simulation. This call provokes the loading of the local arrays SHP1 and SHP2 using a segmented power-law parameterization of Shield's curve, for subsequent consultation in repetitive calls to SHIELD. These arrays contain the Shields parameter for 50 Reynolds' numbers from 0.1 to 5.0, and for 496 Reynolds' numbers from 5 to 500. Once the arrays have been loaded, control is sent directly back to PILOT1.

SHIELD is called from USTLT1, TLTMQS, POWFQS, ENHAN1, EXNER1, CRITER, HYSORT, and ARMOR at the level of the most embedded loops, usually on size fractions, for each global iteration of each time step, and for each Newton-Raphson iteration in USTLTM. Thus SHIELD is called an extremely large number of times in one simulation. At the time of calling, the Reynolds number REYN is the working argument contained in COMMON/SHD/. If REYN < 5, the fine-grid array SHP1 (Reynolds number intervals of 0.1) is consulted; otherwise the coarse-grid array SHP2 (intervals of 1.0) is consulted. In both cases, the appropriate address in SHP1 or SHP2 is found by simple conversion of REYN to an integer, with truncation. The maximum and minimum operations assure that an excessively small or large Reynolds number cannot lead to an address outside the range of the tables. No attempt is made to interpolate in the tables. This would add considerably to the cost of the consultation, and result in no improvement in accuracy given the already approximate nature of the power-law parameterization of the curve.

III.8.21. Subroutine RAZ. The function of RAZ is simply to set to zero the entire zones of arrays, eliminating the need to code loops for this purpose in the calling programs. When RAZ is called, the argument TABLE is aligned with the array zone to be set to zero, and LENGTH is the number of words in the zone. The locally one-dimensional TABLE is frequently a multi-dimensional array in the calling program.

III.8.22. Subroutine ERRWAR. The function of ERRWAR is simply to print warning and error messages in a uniform format. At the time of calling, the arguments are: IEW = 1 for warning, 2 for error, 3 for fatal error; NO = warning or error code number; IT = number of current time step; L, I = integer parameters; PARAM = floating-point parameter. The operations are self-explanatory. The COMMON variables IERR and IWAR accumulate the number of errors and warnings for use in PILOT1 in deciding whether or not to proceed to simulation following the preparation phase.
III.8.23. Subroutine COEFF (entry COEFF1). The purpose of COEFF is to calculate the coefficients of the linearized de St. Venant equations, Eqs. (II.44-II.52). COEFF is called only once from PILOT to transfer array addresses.

COEFF1 is called for each computational reach I of each link L at each iteration of the workflow computation. The call comes from FLOCA1, either in the steady-flow or unsteady-flow operations.

The working time step DELTS is computed from the base time step DELTB; DELTB is always in minutes for quasi-steady flow computation (IUNST=0 or ITIME<0), and may be in any units for unsteady computations. The two calls to SECPRO provoke the loading of all channel section properties for points I and I+1 flanking reach I. This is followed by a transfer of array values to local scalar values, simply to facilitate the coding of the linearized coefficients.

ALPI is the value of the kinetic-energy correction coefficient ALPHA in the dynamic equation. As described in Section II.4.8., it is useful to suppress the kinetic-energy term for the early iterations of the quasi-steady flow computation. Therefore, ALPI is set to zero in such cases for subsequent use in the calculation of coefficients. Similarly, the local scalar BET is the value of the energy-slope weighting coefficient BETA adjusted to the local direction of water flow. BET is used subsequently in the coefficient calculation.

The remainder of the subroutine simply calculates the coefficients A,B,C,D,G',A',B',C',D', and G, as given in Section II.4.3., Eqs. (II.44-II.52).

III.8.24. Subroutine DSBC (entry DSBC1). The purpose of DSBC is to generate a quasi-uniform-flow downstream water-level boundary condition when option IDSBC (see data input record 3) is set to 1. DSBC is called once from PILOT to establish array addresses. DSBC1 is called from LDMAT in each global iteration of each time step, for any and all boundary nodes M designated as being of the imposed-water-level type, when IDSBC = 1.

In SEDICOUPL, a boundary point having an imposed water level must always be connected to only one link. Thus this link is simply connected, and coefficient H of Eq. (II.63) is always zero.
The uniform-flow downstream-boundary condition is expressed as:

\[ Q_1 = K\sqrt{S_o} \]

where \( K(y_0) \) = section conveyance and \( S_o \) = energy slope imposed (and constant) on input data record 7 as parameter \( S_o \). The objective of DSBC is, then, to determine the required correction to the water-level \( y_1 \) which results in the uniform-flow law above being satisfied at the downstream point 1.

The forward sweep down to the boundary point yields

\[ \Delta Q_1 = E_1 \Delta y_1 + F_1 \]

with \( E_1, F_1 \) known from the computations managed by DOLINK. Alternately, the required discharge correction to satisfy the uniform-flow law is

\[ Q_1(y_1^{m+1}) - Q_1^m \]

or

\[ Q_1(y_1^m) + \frac{\partial Q_1}{\partial y_1} \Delta y_1 - Q_1^m \]

or

\[ K(y_1^m)\sqrt{S_o} + \frac{\partial}{\partial y_1}[K(y_1^m)\sqrt{S_o}]\Delta y_1 - Q_1^m \]

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where superscript $m$ denotes the latest iterative estimate. When this expression is set equal to the previous forward-sweep expression and the result is solved for $\Delta y_1$, the result is the FORTRAN statement for DYN($M$) in DSBC. Then the corresponding corrected nodal water level $YN(M) + DYN(M)$ is loaded into the time-dependent data array QTR to be subsequently retrieved in LODMAT and treated as if it were a simple imposed time-dependent water level. The RETURN sends control back to LODMAT for this operation.

III.8.25. Subroutine FLOCA (entry FLOCA1). The purpose of FLOCA is to manage the flow computations for both the quasi-steady and unsteady flow cases. FLOCA is called once only from PILOT, to transfer array addresses and initialize certain iteration counters.

FLOCA1 is called from PILOT once in each global iteration of each time step. For a fully unsteady flow computation (IUNST=1), the working time step DELTB is set equal to the user's given step, IDELT.

In the remainder of the subroutine, there are two major sections, managing unsteady and steady flow, respectively. Although the heart of the computation is the same in both cases for one iteration, the iteration management imperatives and techniques are quite different in the two cases. A distinct separation of the two kinds of computation renders them more clearly understood and modified.

In the unsteady flow computation, ITER is the counter of Newton-Raphson iterations for the de St. Venant flow equations. Statement 300 is the beginning of the Newton-Raphson iteration loop for unsteady flow. The call to LINKS1 provokes execution of the link forward sweep. The call to NODES1 then provokes computation of the nodal water-level corrections. If DETER=0, this indicates that there was a problem in matrix inversion for the nodal-matrix operations, and control is sent back to PILOT to terminate the computation in this case. Otherwise, the link return sweep is executed by calling LINKS2. At this point, all nodal water-surfaces, and all computational-point water surfaces and discharges, have been corrected for the current iteration. Control is returned to statement 300 for the next iteration if the number of Newton-Raphson iterations has not exceeded ITERMX and neither the water-level criterion EPSHYD nor the discharge criterion IPSQIT for convergence have been satisfied.
Once the Newton-Raphson iteration is declared to be convergent, the loop DO 350 determines the maximum water-level and discharge corrections occurring since the last global iteration, for subsequent use in global-iteration management in PILOT. The loop DO 150 then loads certain variables into the corresponding "preceding" arrays for subsequent use, and updates the energy slope for fluvial links.

The steady-flow stabilization procedure begins with initializing the total equivalent stabilization time STBTIM, and the primary time-step cycle counter ICYCLE, to zero. At statement 50, which is the beginning of the overall loop on equivalent time steps, the constant-time-step interval counter IDT is incremented. Then, if IDT is larger than the programmed limit IDTMX, the secondary counter IDTT is also incremented. The call to TMCHG1 provokes selection of the appropriate time step DELTB and convergence criterion EPSHY for the current value of IDT or IDTT.

Statement 250 is the beginning of the time-step iteration loop for a given constant-time-step cycle; ITGLOB is the counter of time steps executed for a given constant time step. The calls to LINKS1, NODES1, and LINKS2 execute the forward sweep, nodal matrix solution, and backward sweep, respectively, exactly as for the unsteady computation described above.

The loops DO 450 and DO 550 determine the maximum water-surface and discharge corrections occurring in the model, and transfer certain current array values to "previous" value arrays. After an accounting of the total equivalent stabilization time, the friction factors are updated through a call to FRICT1 if the user options so specify. If the number of iterations within the current constant-time-step-cycle is still less than ITGLMX, and the maximum water-level change is still greater than the criterion EPSY, then control is sent back to statement 250 to perform another time step using the same time step as before. Otherwise, it is necessary to determine whether or not to proceed to the next higher constant time step in the stabilization procedure. If either the last constant-time-step interval has been reached or the maximum water level and discharge changes are less than the maximum criteria EPSHYD and EPSQ then control is sent back to statement 50 to advance to the next constant-time-step interval. In addition, control is sent back to statement 50 if the secondary counter IDTT is less than its maximum allowable value.

At the end of the steady-flow stabilization procedure, FRICT1 is called to definitely update the friction factors; then control is returned to PILOT.
II.8.26. Subroutine ACKERS (entry ACKQS). The purpose of ACKERS is to calculate the fractional and total bed-material load capacities at each computational point. According to the Ackers-White procedure set forth in Section II.3.1., ACKERS is called once from PILOT1 during the preparatory phase of a simulation, to transfer dummy array address and load constants; control is then sent to statement 999 for immediate return to PILOT1.

Entry ACKQS is called from PILOT1 for each global iteration of each time step. The loop DO 105 considers each link of the model; by convention, sediment loads are set to zero (call to RAZ) in links which are declared dry or non-fluvial. The loop DO 100 considers each computational point of a link. If the velocity is strictly zero, or discharge is less than DRYQ, the sediment load is immediately left at zero through direct transfer to statement 100. Shear velocity $u_\tau$, water depth, and mean particle size $D_{50}$ of this point are either calculated or transferred to a scalar variable for subsequent use. The second loop DO 100 considers each size fraction at each point of each link, applying Eqs. (II.24), (II.25), (II.26), (II.27), (II.28), (II.29) and (II.30). The concentration $C_T$ for each size fraction is computed, then transformed to sediment discharge. Equation (II.22) and the armoring factor $ACF_1$ are used to complete the computation of the corrected full-width capacity for the current size fraction, with the sign of the capacity set equal to that of the flow direction. This contribution is finally added to the total load QSTOT.

Upon return to PILOT1, the fractional and total sediment loads are computed and loaded for each computational point, for subsequent use in sediment-continuity and armoring operations.

III.8.27. Subroutine ENHAN (entry ENHAN1). The purpose of ENHAN is to calculate the fractional and total bed-material load capacities at each computational point, according to the Engelund-Hansen procedure set forth in section II.3.1. ENHAN is called once from PILOT1 during the preparatory phase of a simulation, to transfer dummy array address and load constants; control is then sent to statement 999 for immediate return to PILOT1.

Entry ENHAN1 is called from PILOT1 for each global iteration of each time step. The loop DO 200 considers each link of the model. The total sediment load QSTOT for each point is set to zero by a call to RAZ in links which are declared dry or non-fluvial. The loop DO 150 considers each computational point of a link. If the discharge is less than
DRYQ, the sediment load is left at zero through direct transfer to statement 100. The square of velocity, shear velocity $u_\infty$, and bed shear stress $\tau_0$ of this point are calculated and stored in scalar variables for subsequent use. The coefficient $B_1$ of the sediment weighting factor is computed with Eq. (V.4) but restricted to a maximum of 70.0 to avoid an exponentiation overflow in Eq. (V.3) during a transitory anomaly of excessively large hydraulic radius.

The second loop DO 100 considers each size fraction at each point of each link, applying Eq. (II-3/A) with the weighting (hiding) factor $W_K$ in Eq. (II.22) taken from Eq. (V.2). $W_K$, then, is restricted to a maximum of 1.0. Eq. (II.22) and the armoring factor $ACF_1$ are used to complete the computation of the corrected full-width capacity for the current size fraction, with the sign of the capacity set equal to that of the flow direction. This contribution is finally added to the total load QSTOT.

Upon return to PILOT1, the fractional and total sediment loads have been computed and loaded for each computational point, for subsequent use in sediment continuity and armoring operations.

**II.8.28. Subroutine POWFCT (entry POWFQS).** The purpose of POWFCT, like TLTM, is to calculate the fractional and total sediment capacity loads at each computational point, according to the power-law procedure set forth in Section II.3.1. POWFCT is called once from PILOT1 during the preparatory phase of a simulation, to transfer dummy array addresses as well as to load constants; and to define the two empirical power-law constants A and B; control is then sent to statement 999 for immediate return to PILOT1.

Entry POWFQS is called from PILOT1 for each global iteration of each time step. The loop DO 200 considers each link of the model; by convention, sediment loads are not set to zero (call to RAZ) in links which are declared dry or non-fluvial. The loop DO 150 considers each computational point of a link. The shear velocity $u_\infty$ and bed shear stress $\tau_0$ of the point are computed. The coefficient $B_1$ of the sediment weighting factor is computed based on Eq. (V.4), but restricted to a maximum of 70.0 to avoid an exponentiation overflow in Eq. (V.3) during a transitory anomaly of excessively large hydraulic radius.

The loop DO 100 considers each size fraction at each point of each link, applying Eq. (II.31c) and Eq. (V.2) to calculate the critical velocity $U_C$ and the sediment hiding factor $W_K$, respectively; then $W_K$ is restricted to a maximum of 1.0.
The full-width uncorrected load for the current size fraction is computed by the empirical power-law relation Eq. (II.31B). Then, Eq. (II.22) and the armoring factor ACFT are used to compute the computation of the corrected full-width capacity for the current size fraction, with the sign of the capacity set equal to that of the flow direction. This contribution is finally added to the total load QSTOT.

Upon return to PILOT1, the fractional and total sediment loads have been computed and loaded for each computational point, for subsequent use in sediment-continuity and armoring operations.

II.8.29. Subroutine USPOW (entry USPOW1). The purpose of USPOW, like USTLTM, is to compute the thalweg elevation at the upstream boundaries of a model (when sediment load capacities are computed by POWFCT), according to the procedures of Section II.5.3. USPOW is called only once from PILOT1 during the preparatory phase of the simulation, to transfer addresses of dummy arrays and load constants, followed by immediate return to PILOT1.

Entry USPOW1 is called from PILOT1 for each upstream boundary point in each global iteration of each time step. In the argument list, the variable M is the sequence number of the node associated with the upstream boundary point, and the logical variable FIRCAL indicates whether or not this is the first time step of the simulation. THETAS is the time weighting parameter in Eq. (II.103). Parameter C is the assumed bed-wave celerity in feet/day. L is the boundary link being processed, and I is the boundary point itself. The critical velocity Uc for incipient motion is calculated based on Eq. (II.31C). If the discharge of either reach I or reach I-1 is smaller than DRYQ, control is sent to statement 999 for return to PILOT1, with no change to the boundary thalweg elevation. If the boundary point is fully armored, control is again sent to statement 999 for return to PILOT1 with no change to the point or reach bed elevation.

Normal execution resumes at statement 710, where iteration-loop preparation is begun. BETA1 is the parameter \( \beta_b \) in Eq. (II.105, 108). If the computed value of BETA1 is greater than 0.5, it is restricted to 0.5. ITBC is an iteration counter; and DEP is the current thalweg depth \( d_T^{n+1} \). The actual Newton-Raphson iteration loop for determination of the required bed elevation to satisfy Eq. (II.125) begins at statement 720 with a call to SECPRO to obtain current hydraulic conditions. If it is determined in SECPRO that the point is dry, WARNING 9 is signaled through a call to ERRWAR, the thalweg is set to its
previous elevation, the reach degradation is set to zero, and control is sent to statement 999
for return to PILOT1. This abnormal procedure simply reflects the fact that it makes no
sense to have a boundary link which is declared dry.

Normal execution resumes at statement 730; the Newton-Raphson computation
described in Section II.5.3. involves solving the following non-linear equation for average
depth \( d \):

\[
f(d) = \frac{\tilde{Q}_s^{n+1}}{B_I[\exp(-2.99 ACF_I)]} - \frac{\beta_b \Delta x}{\Delta t} \frac{(1-p)(y_I^{n+1} - d - Z_I^n)}{\exp(-2.99 ACF_I)} - a(U-U_c)^b
\]

(III.15)

in which the last term is defined in Section II.3.1. (Power-law method). In the code, the
following FORTRAN variables correspond to those of Eq. (III.15):

\[
\tilde{Q}_s^{n+1}
\]

\( FD = f(d) \) \hspace{2cm} \( QSIMP = \frac{\tilde{Q}_s^{n+1}}{B_I \exp(-2.996 ACF_I)} \)

\( BETA1 = \beta_b = C \Delta t / \Delta x \) \hspace{2cm} \( \text{REACH}(I-1,L) = \Delta x \)

\( \text{IDELT}*\text{TCONST} = \Delta t (\text{sec}) \) \hspace{2cm} \( \text{POROS} = \rho \)

\( ACF(I,L) = ACF_I \) \hspace{2cm} \( Y(I,L) = y_I^{n+1} \)

\( \text{DEP} = d = d_I^{n+1} \) \hspace{2cm} \( \text{TALWGP}(I,L) = z_I^n \)

\( \text{DELTZ} = \Delta z_I = y_I^{n+1} - d - Z_I^n \) \hspace{2cm} \( \text{WIDTH}(I,L) = B_I \)
The variable FDP is the derivative of FD with respect to d, and the statement DELD = -FD/FDP is the Newton-Raphson correction to the depth. After the depth and thalweg are corrected, control is sent back to statement 720 for another iteration if the correction is greater than 0.01% of the depth and the maximum of 50 iterations has not been reached. If iterations are terminated for either reason, the usual WARNING 10 is made for excessive bed-level change. The current thalweg is changed by the amount VOLMAX.

At this point, the bed elevation at boundary point I has been computed. The remaining task is to compute the reach bed-level change using Eq. (II.103) and applying to (1-β_b)Δx, as described in the last paragraph of Section II.5.3. The "previous" values are initialized if FIRCAL (first time step) is armed and the current call is for the first global iteration. The resulting VOLOUT (depth of degradation) is the bed-level change in the boundary reach, to be used in a subsequent call to EXNER2 from PILOT1.

If the imposed sediment load QSTR(M) is equal to (or less than) zero but deposition occurs, control is sent to statement 20 to impose VOLOUT = 0. If VOLOUT is larger than or equal to VOLMAX, WARNING 10 is signalled for excessive bed-level change. Then, the absolute value of VOLOUT is replaced by VOLMAX.

Statement 999 returns control to PILOT1.

III.8.30. Subroutine TMCHG (entry TMCHG1). The purpose of TMCHG is to manage the automatic time-step variations of the steady-flow stabilization procedure described in II.4.8. Although it is presently unnecessary (no argument list), TMCHG is called once from PILOT during preparatory operations. TMCHG1 is called from FLOCA within the automatic time-step change sequence. Recall that IDT is the counter of time-step increases in the first stabilization phase (kinetic-energy terms suppressed), and IDTT is the counter in the second phase (full equations).

The initial test of IDT compared to IDTMX simply sets up a branching based on IDT or IDTT as appropriate. Control is sent to one of statements 1 through 20 according to the status of the stabilization. At each of these statements, the working time step DELTB is taken as a multiple or fraction of the base value FDELTB, and the iteration convergence criterion EPSY is taken as a multiple of the base value EPSYB, according to Table II.2. Both FDELTB and EPSYB are set by the user an input data record 5. Control is then sent back to FLOCA for one or more time-step computations using DELTB.
III.8.31. Subroutine USENHA (entry USENH1). The purpose of USENHA is to compute the thalweg elevation at the upstream boundaries of a model (when the sediment load capacities are computed by ENHAN), according to the procedure of Section II.5.3. USENHA is called only once from PILOT1 during the preparatory phase of the simulation, to transfer addresses of dummy arrays and load constants, followed by immediate return to PILOT1.

Entry USENH1 is called from PILOT1 for each upstream boundary point in each global iteration of each time step. In the argument list, the variable M is the sequence number of the node associated with the upstream boundary point, and the logical variable FIRCAL indicates whether or not this is the first time step of the simulation. THETAS is the time weighting parameter in Eq. (II.103). Parameter C is the assumed bed-wave celerity in feet/day. L is the boundary link being processed, and I is the boundary point itself. If the discharge of either reach I or reach I-1 is smaller than DRYQ, control is sent to statement 999 for return to PILOT1, with no change in thalweg elevation. If the boundary point is fully armored, control is sent to statement 999 for return to PILOT1 with no change to the point or reach bed elevation.

Normal execution resumes at statement 710, where iteration-loop preparation is begun. BETA1 is the parameter $\beta_b$ in Eq. (II.105, 108); if the computed value of BETA1 is greater than 0.5, it is restricted to 0.5. ITBC is an iteration counter; DEP is the current thalweg depth; and TALWGP (I,L) is the bed elevation in the previous time step, $z^n_l$. The actual Newton-Raphson iteration loop for determination of the required bed elevation to satisfy Eq. (II.105) begins at statement 720 with a call to SECPRO to obtain current hydraulic conditions. If it is determined in SECPRO that the point is dry, WARNING 9 is signalled through a call to ERRWAR, the thalweg is set to its previous elevation, the reach degradation is set to zero, and control is sent to statement 999 for return to PILOT1. This abnormal procedure simply reflects the fact that it makes no sense to have a boundary link which is declared dry.

Normal execution resumes in statement 730; the Newton-Raphson computation referred to in Section II.5.3. involves solving the following non-linear equation for depth $d$:  

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\[
f(d) = \frac{Q_s^{n+1}}{B_I[\exp(-2.996ACF_I)]} - \frac{\beta_b \Delta x}{\Delta t} \frac{(1-p)(y_I^{n+1} - d - z_I^{n})}{\exp(-2.996ACF_I)}
\]

\[
- 0.05V^2 \left[ \frac{D_{s0}}{g(s-1)} \right]^{3/2} \left[ \frac{\tau_o}{(\gamma_{s} - \gamma)D_{s0}} \right]^{3/2}
\]

(III.16)

in which the last term is defined in Section II.3.1. (Engelund-Hansen Method). In the code, the following FORTRAN variables correspond to those of Eq. (III.16):

\[Q_s^{n+1}\]

\[
FS = f(d) \quad QSIMP = \frac{B_I\exp(-2.996ACF_I)}{B_I[\exp(-2.996ACF_I)]}
\]

\[BETA1 = \beta_b = C\Delta t/\Delta x (sec) \quad \text{REACH} (I-1,L) = \Delta x
\]

\[IDELT*TCONST = \Delta t (sec) \quad \text{POROS} = p
\]

\[ACF(I,L) = ACF_I \quad Y(I,L) = y_I^{n+1}
\]

\[DEP = d = d_I^{n+1} \quad \text{TALWGP}(I,L) = z_I^{n}
\]

\[DELTZ = DZ_I = y_I^{n+1} - d - z_I^{n} \quad \text{WIDTH}(I,L) = B_I
\]

\[SF(I,L) = S_f
\]

The variable FDP is the derivative of FD with respect to average-depth d, and the statement DELD = -FD/FDP is the Newton-Raphson correction to the average depth. After
the depth and thalweg are corrected, control is sent back to statement 720 for another iteration if the correction is greater than 0.01% of the depth and the maximum of 50 iterations has not been reached. If iterations are terminated for either reason, the WARNING 10 is made for an excessive bed-level change. The current thalweg, then, is replaced by the amount VOLMAX.

At this point, the bed elevation at boundary point I has been computed. The remaining task is to compute the reach bed-level change using Eq. (II.103) and apply it to the reach length \((1 - \beta_b)\Delta x\), as described in the last paragraph of Section II.5.3. The "previous" values are initialized if FIRCAL (first time step) is armed and the current call is for the first global iteration. The resulting VOLOUT (depth of degradation) is the bed-level change in the boundary reach, to be used in a subsequent call to EXNER2 from PILOT1.

If the imposed sediment load QSTR(M) is equal to (or less than) zero but deposition occurs, control is sent to statement 20 to impose VOLOUT = 0. If VOLOUT is larger than or equal to VOLMAX, WARNING 10 is signalled for excessive bed-level change. Then, the absolute value of VOLOUT is replaced by VOLMAX.

Statement 999 returns control to PILOT1.

III.8.32. Subroutine IWAGAK. The purpose of subroutine IWAGAK is to compute the critical shear stress TAUC according to Iwayaki's incipient-motion relation, Section II.3.2. IWAGAK is called from various locations, with the Reynolds number REYSTA loaded in COMMON/SHEAR/prior to each call. The tests on REYSTA activate the appropriate segmental power-law representation of Iwagaki's curve, loading TAUC in COMMON/SHEAR/ for subsequent use in the calling routine.

III.8.33. Subroutine NODSD (entries NODSD1, NODSD2, NODSD3). The general role of the procedures in NODSD is to treat sediment continuity processes at nodes, as outlined in Section II.5.4. NODSD is called once from PILOT to transfer array addresses and load constants. The procedures in NODSD1 represent an earlier conception of nodal sediment formulations, and are presently (3/88) not in use. They are retained in the code for possible future reference. Entries NODSD2 and NODSD3 deal, respectively, with nodal bed-level changes and sediment-transport distribution among channels, and nodal sediment sorting and armoring processes.

Entry NODSD2 is called from PILOT in each iteration of each time step, immediately following execution of the sediment-continuity procedures for reaches in EXNER1. The
loop DO 600 considers all nodes in turn; KKK is the number of links attached to the node.
QINF is the sum of inflow discharges to the node, and QOUTF is the sum of outflows. If
the node is a boundary node (only one link attached) KKK = 1, and the node is bypassed
as its sediment-continuity processes are treated in boundary-condition routines. The calls
to RAZ initialize to zero the working arrays CDF and QSOUTF.

The loop DO 602 loads, for a node M which has a sediment-inflow boundary
condition (NINQS>0), the imposed inflow sediment load into the temporary storage array
CDF for each size class J. Note that QTR is the total load, and PTRIB is the (constant)
fractional allocation of this total load to each size class.

The loop DO 610 considers all fluvial (LTYPE = 0), flowing(DRYBED = F) links
attached to the node, and notes cumulative water and sediment inflows to the node. L is the
sequence number of the link; I is set to either the first or last point on the link, depending
on which end of the link is attached to the node. By convention, if the water discharge at
this point is less than the parameter DRYQ, the link is given no further consideration.

The test IF(Q(I,L)*LL(M,K).GT.0.0) determines whether point I of link L is an
inflow to or outflow from node M. (Recall that by convention if LL(M,K)<0, a positive
discharge is an inflow to node M.) For an inflow point, the instructions immediately
following the test accumulate the water inflow in QINF, and accumulate the sediment
inflow by size class in CDF. The outflow case is treated from statement 611, with water
outflow accumulated in QOUTF. The index IO notes the next-downstream computational
point adjacent to the outflow point on link L. In loop DO 630, the unadjusted unit-width
sediment-discharge capacity QSCAP is accumulated in the temporary array QSOUTF for
subsequent use.

The loop DO 650, comprising the remainder of NODSD2, executes the sediment-
continuity computation for the outflow computational reaches adjacent to the node. As
usual, the procedure is unnecessary and skipped if the link L is nonfluvial, dry, or has a
discharge less than DRYQ. The instructions through statement 665 identify the position of
the reach connected to the node. When statement 665 is reached, I = number of
computational point adjacent to the node; I1 = IO = number of the computational point
adjacent to I; and BAVG = average channel width for the reach. If the reach is an outflow
reach, control is sent to statement 670; otherwise control is sent to the end of the loop for
consideration of the next attached reach.
The loop DO 690 performs the sediment-continuity computation for each size class J. For the normal case in which at least one of the outflow reaches has a finite sediment-transport capacity, control is sent to statement 691 where the net sediment-transport outflow from the reach (QSD) is taken as the difference between the computed capacity at the adjacent point IO, and the transport coming from the node. This latter is taken as the total sediment inflow to the node (CDF) allocated to each outflow reach by the ratio of its unadjusted unit-width capacity QSCAP to the total such outflow capacity, QSOUTF. If the total outflow capacity is strictly zero, then the net outflow QSD is taken as the total inflow CDF allocated to each outflow reach by the ratio of its water discharge Q to the total water outflow QSOUTF.

In either case, statement 692 loads the outflow reach degradation TDELD for each size class using the usual Exner equation. Following the call to CRIT2 (which causes USTWJ, USTC, and QBQT to be loaded in COMMON/TLTENH/), the TDELD component is adjusted as in EXNER, viz: aggradation is reduced by the ratio of bedload to total load (QBQT) if the ratio of shear stress to fall velocity (USTWJ) exceeds unity; and degradation is disallowed if the ratio of actual to critical shear stress is less than unity (USTC<1). This completes the bed-level sediment-continuity treatment for a node M. After all nodes have been treated, control is sent back to PILOT.

Entry NODSD3 is called once in each iteration of each time step from PILOT, after all other operations have been completed. The loop DO 400 considers each node in turn, although boundary nodes are skipped (KKK = 1). The loop DO 430 considers each fluvial reach attached to the node, accumulating the reach-weighted degradation in DZSUM and the total represented reach length in DXSUM. Then the reach-weighted average degradation DZANG is computed.

The loop DO 440 attributes the nodal degradation DZAVS to each fluvial point attached to the node, essentially overriding any previous thalweg computation in EXNER. This terminates the procedures for any "true" node having three or more reaches attached, control being sent to statement 400 for continuation of the loop on the nodes.

If KKK = 2, then node M is simply an in-line node, having no particular topological significance (such nodes are often used in anticipation of subsequent topological additions). If either of the attached links L1, L2 are non-fluvial, no further action is taken, control being sent to statement 400. If both links are fluvial, then I1 and I2 are loaded as the
numbers of the appropriate computational points attached to the node. Beginning with statement 410, the average values (i.e. average of the two attached points) of armoring factor, friction factor, and bed-material size distribution are computed and assigned equally to the two points. The effect is to require that a simple in-line, fluvial node be "transparent".

**III.8.34. Subroutine CRITER (entry CRIT2).** The purpose of CRITER is to furnish indications of the suspension potential, erodibility, and ratio of bedload to total load for use in overriding sediment continuity considerations in EXNER and NODSD. CRITER is called once from PILOT to transfer array addresses during the preparatory phase of the computation. CRIT2 is called from EXNER for each sediment size class \( J = J_1 \) in each reach \( I = I_1 \) of each link, \( L = L_1 \), and from NODSD for each size class of each node, in each global iteration of each time step.

The instructions through statement 162 permit computation of the critical shear velocity for incipient motion, USTARC, using either the Iwagaki or Shields procedures. USTC is then the ratio of the actual to the critical shear velocity, made available to EXNER or NODSD through the COMMON/TLTENH/. Then the particle fall velocity is computed by Rubey's equation, and the ratio of shear velocity to fall velocity, USTWJ, is computed and made available for use in EXNER or NODSD through its appearance in COMMON/TLTENH/.

The following sequence of operations results in the computation of the total load QSTL by the TLTM expression, Eq. (II.21). Then the bedload QB is computed by Karim's bed-load predictor presented in Karim and Kennedy (1981). Finally, the bed-to-total load ratio QBQT is computed and made available to EXNER or NODSD through COMMON/TLTENH/. Control is then returned to EXNER or NODSD.

**III.8.35. Subroutine USACK (entry USACK1).** The purpose of USACK, like USTLTM, is to compute the thalweg elevation at the upstream boundaries of a model (when sediment load capacities are computed by ACKERS), according to the procedures of Section II.5.3. USACK is called only once from PILOT1 during the preparatory phase of the simulation, to transfer addresses of dummy arrays and load constants, followed by immediate return to PILOT1.

Entry USACK1 is called from PILOT1 for each upstream boundary point in each global iteration of each time step. In the argument list, the variable M is the sequence
number of the node associated with the upstream boundary point, and the logical variable FIRCAL indicates whether or not this is the first time step of the simulation. THETAS is the time weighting parameter in Eq. (II.103). Parameter C is the assumed bed-wave celerity in feet/day. L is the boundary link being processed, and I is the boundary point itself. If the discharge of either reach I or reach I-1 is smaller than DRYQ, control is sent to statement 999 for return to PILOT1, with no change to the boundary thalweg elevation. If the boundary point is fully armored, control is again sent to statement 999 for return to PILOT1 with no change to the point or reach bed elevation.

Normal execution resumes at statement 710, where iteration-loop preparation is begun. BETA1 is the parameter βb in Eqs. (II.105, 108). If the computed value of BETA1 is greater than 0.5, it is restricted to 0.5. ITBC is an iteration counter; and DEP is the current thalweg depth dI n+1. The actual Newton-Raphson iteration loop for determination of the required bed elevation to satisfy Eq. (II.125) begins at statement 720 with a call to SECPRO to obtain current hydraulic conditions. If it is determined in SECPRO that the point is dry, WARNING 9 is signaled through a call to ERRWAR, the thalweg is set to its previous elevation, the reach degradation is set to zero, and control is sent to statement 999 for return to PILOT1. This abnormal procedure simply reflects the fact that it makes no sense to have a boundary link which is declared dry.

Normal execution resumes at statement 730; the Newton-Raphson computation described in Section II.5.3 involves solving the following non-linear equation for average depth d:

$$f(d) = \frac{Q^n_s}{B_l[\exp(-2.99ACF_l)]} \cdot \frac{\beta_b \Delta x}{\Delta t} \cdot \left(1-p\right) \left(y^n_{I} - d - z^n_{I}\right) \cdot \frac{C_2D_g \left(\frac{F_o}{C_3} - 1\right) C_4}{\frac{C_1}{u^*}} U^{1+C_1}$$

(III.17)

in which the last term is defined in Section II.3.1 (Modified Ackers-White Method). In the code, the following FORTRAN variables correspond to those of Eq. (III.1):
FD = f(d) \quad \text{QSIMP} = \frac{Q_{s}^{n+1}}{B_{i} \exp(-2.99ACF_{i})}

BETA = \beta_{b} = C\Delta t/\Delta x \quad \text{REACH}(I-1,L) = \Delta x

\text{IDELT} \times \text{TCOST} = \Delta t (\text{sec}) \quad \text{POROS} = \rho

ACF(I,L) = ACF_{i} \quad Y(I,L) = y_{I}^{n+1}

\text{DEP} = d = d_{I}^{n+1} \quad \text{TALWGP}(I,L)F = z_{I}^{n}

\text{DELTZ} = \Delta z = y_{I}^{n+1} - d - z_{I}^{n} \quad \text{WIDTH}(I,L) = B_{I}

The variable FDP is the derivative of FD with respect to d, and the statement DELD = -FD/FDP is the Newton-Raphson correction to the depth. After the depth and thalweg are corrected, control is sent back to statement 720 for another iteration if the correction is greater than 0.01% of the depth and the maximum of 50 iterations has not been reached. If iterations are terminated for either reason, the usual WARNING 10 is made for excessive bed-level change. The current thalweg is changed by the amount VOLMAX.

At this point, the bed elevation at boundary point I has been computed. The remaining task is to compute the reach bed-level change using Eq. (II.103) and applying to (1-\beta_{b})\Delta x, as described in the last paragraph of Section II.5.3. The "previous" values are initialized if FIRCAL (first time step) is armed and the current call is for the first global iteration. The resulting VOLOUT (depth of degradation) is the bed-level change in the boundary reach, to be used in a subsequent call to EXNER2 from PILOT1.

If the imposed sediment load QSTR(M) is equal to (or less than) zero but deposition occurs, control is sent to statement 20 to impose VOLOUT = 0. If VOLOUT is larger than or equal to VOLMAX, WARNING 10 is signalled for excessive bed-level change. Then, the absolute value of VOLOUT is replaced by VOLMAX.
Statement 999 returns control to PILOT1.

III.8.36. Subroutine HYSOR2

HYSOR2 is a revised version of the HYSOR1 sorting routine of IALLUVIAL and earlier versions of CHARIMA. As in the SEDICOUPT code, HYSOR2 simply enforces sediment continuity for each size class within the mixing layer of each reach. However, one major difference from sorting implementation in SEDICOUPT is that in CHARIMA, the mixed-layer composition for a reach is a property of that reach, whereas in SEDICOUPT it is expressed as an average of the composition at the computational points at the extremities of the reach.

If the input variable ISORT is set equal to 2, then HYSOR2 is called from PILOT1 for each computational reach of each link in each global iteration of each time step. (HYSOR1 is called if ISORT = 1). The link dimension of arrays is stripped in calls to HYSOR2, to save run-time addressing effort.

If the armoring factor ACF is greater than 0.98, Warning 8 is issued and the armoring factor is reset to 0.98 to avoid a singularity.

When the degradation depth VOLOUT calculated in EXNER is not zero, the "mixing layer thickness for the current reach is calculated using Allen's formula (Eq. (II.35)) based on the average flow conditions in the reach. This thickness is then adjusted by the armoring factor, and then increased if necessary to ensure availability of all scoured material.

The remainder of the subroutine follows closely the descriptions of section II.6.3. Note that two different equations (Eq. II.112 b and c)) are used for the two cases of rising and descending mixed-layer floor, respectively.

III.9. Memory and Time Requirements

A dynamic allocation procedure, designed to eliminate the need to dimension arrays and optimize memory use, is employed as described in Section III.3. The procedure involves the use of just one working array, called T. All working arrays are stored inside T, and dimensioned automatically at execution time according to the specific size of the
problem being solved (number of points, number of links, number of nodes, etc.). The details of this procedure have been described by Holly et al. (1985).

The required size of the working array $T$ is set by the dimensions of the particular model data set being processed. The formula for computing the required memory size for CHARIMA is given in Table III.3. It is readily seen that the number of links LINKS, the maximum number of nodes NODES, the maximum number of links per node KMAX, and the number of size fractions N1 are the principal factors determining required memory size. The object codes themselves, exclusive of the array $T$, occupy about 425,000 bytes on the IBM 4381 computer with the FORTRAN VS 77 compiler.

The CPU time required is highly dependent on the structure of the model data set and the type of computer and compiler being used. The Susitna model, which has 306 links, 249 nodes, and 918 points required about 5 ms/point/iteration for all water and sediment routing operations on the University of Iowa's IBM 3033.
Table III.3
MEMORY REQUIREMENTS FOR WORKING ARRAY T

| MEMO | = LINKS \[57*IMAX - 3\] + NODES \[16 + N1 + KMAX\] + MAXG \[5 + 3*MAXG + NGROUP*(1+MAXG)\] + N1 \[8 + 19*IMAX*LINKS - 1*LINKS\] + NSECS \[4 + 3*NLEVMAX\] + NGROUP + NITOUT + NBDT \[2\] + 4 |

The symbols used in this table are:

- **LINKS** = Exact number of links;
- **IMAX** = Maximum number of computational points on one link;
- **N1** = Exact number of sediment size intervals;
- **MAXG** = Maximum number of nodes in a node gorup;
- **NGROUP** = Exact number of node groups;
- **NSECS** = Exact number of section-types;
- **NLEVMAX** = Maximum number of levels in cross-section data table;
- **NITOUT** = Exact number of printed output dates;
- **NBDT** = Number of time-step changes.
IV. USER INSTRUCTIONS

IV.1. Introduction

In order to apply CHARIMA properly, the user should read Appendices B, C, and D carefully. The purpose of this section is to give users general instructions and information supplementary to that contained in Appendices B, C, and D. After study of this section, the user should be able to prepare and construct the data set for any specific model by following Appendix B, and also be able to resolve basic operational problems.

IV.2. Data Preparation

IV.2.1. General Data Requirements. An input data set including topological, boundary, and geometrical data, as well as computational parameters and control variables, is required in order to apply CHARIMA to a specific problem. The input data structure of CHARIMA is given in Appendix B. To construct the data set, the user should first acquire the following information:

Geometry: In principle, geometric data which is as detailed as possible is required to obtain sufficient accuracy of the simulation results. Nevertheless, in reality, for a complex system such as that shown in Figure I.1, it is almost impossible to proceed with a comprehensive field survey due to the high expense involved. Based on whatever data is available, the following information and procedures are recommended for geometric data preparation:

- Aerial photographs corresponding to several representative flow conditions, such as floods and low flows, should be assembled.

- On the basis of the above photos, a schematic topological layout such as Figure I.1 should be laid out.

- Based on the topological layout, link and node topology, including node-group assignments, should be established.
- From the topological layout, aerial photos, and whatever measured cross-section data is available, the point properties of each link should be determined by inspection and comparison.

**Sediment:**

- Best possible estimates of sediment-size distribution at all computational points of the model.

**Hydrology/Hydraulics:** The following hydrology and hydraulic data are required:

- Inflow hydrographs of water and sediment discharges at upstream boundaries;
- Inflow hydrographs for tributaries not modelled within the interior part of the model;
- Outflow hydrographs to distributaries not modelled;
- Water level variations at the downstream boundary;
- Water level and/or discharges at a number of control points inside the model domain (for calibration).

**IV.2.2. Guidance for Choice of Numerical Parameters.**

- The numerical parameters mentioned herein are those found on input data records type 1 to 7 of Appendix B.
- No variables can be omitted.
In record type 2, NODES, LINKS, N1, NGROUP, NSECS, NITOUT must be the exact number corresponding to the topology of the model.

In record type 3, ITBEG and ITEND are the time counters of the simulation process. ITMAX is another time controller. Usually the time counted from ITMAX (IDELT*ITMAX) is set somewhat larger than the difference between ITBEG and ITEND.

If a restart results input file is used, i.e. when NRIN (in record 3) is not zero, the initial condition assigned for ITBEG is extracted from the results at time ITREST in file NRIN, subject to possible modification by subsequent type 11 records. ITREST is not necessarily equal to ITBEG, though ITBEG = ITREST implies that the present calculation is a simple continuation of a previous one.

It is always useful for reference to print out all of the link topology, node topology, point properties and cross-section data in the first run (i.e. IPLINK, IPNODE, IPOINT, IPSECT in record type 3 are set greater than zero).

The use of iterations can improve the accuracy of the results. However, for a long-term simulation, excessive iterations can require a significant increase in CPU time, yet may not give a significant improvement in the results. Therefore the maximum number of iterations MITMAT in record type 4 is usually determined intuitively based on experience gained through several test runs.

The nodal water surface change EPSHYD (ft) and the discharge change EPSQ(cfs) in record type 5 are also used as a criterion to terminate iterations. The values of EPSHYD and EPSQ have to be intelligently determined, although no exact standard exists. It is logical to adopt values of EPSQ and EPSHYD which are consistent with the energy equation.

The value of THETA in record type 6 has been discussed in Section II.2: THETA = 0.55 is the normal choice.

ADJRE in record type 6 is discussed in Section II.5.3. In a physical sense it represents the sediment wave celerity in miles/month.
IV.2.3. Link and Node Topology, Point Properties and Cross-Section Data Input.

- Link topology and node topology data input are described for record types 9 and 10 respectively.

- LNKNAM in record 9 can be any number, without following a numeric sequence. At the end of the data set of record 9, a negative LNKNAM is required to signal the end.

- II in record 9 must be the exact number of computational points on the specific link.

- NODNAM in record type 10 can be any number without following a numeric sequence in the data set. However, the nodes must be furnished following the node group sequence. At the end of the data set, a negative NODNAM is required.

- NINQ and NINQS in record type 10 must be consistent with the list QTR in record type 22.

- Cross-section data input as described in record types 15, 16, 17 is determined by inspecting the topographic maps and the given cross-section data. Various major cross-section types which may be used to represent the model should be established as thoroughly as possible.

- Point properties data input is described in record type 11.

- For a node joining only two links, the section type NSEC and the sediment type NSED for the two points attached to the node should be the same. In other words, a discontinuity of cross-sections and sediment distributions at a simple node is not advised.

- Thalweg TALWEG for points attached to the same node should normally be the same.
Point properties data input can be suppressed by substituting -9999 in the first five columns of the one and only record 11, if a restart file is used (NRIN > 0).

If a restart file is used and modification of some point properties is required, only the modified point data are furnished in the data set.

**IV.3. Monitoring of Computation**

**IV.3.1. Suggested Execution Sequences.** CHARIMA is written in such a way that at least two runs are generally required to implement water and sediment routing for a model. The first run performs the steady or unsteady computations required to generate a range of required initial conditions. The computation results are stored in a results file. Subsequent runs take the appropriate results from the results file to be the initial condition and then perform the mobile-bed computations.

In addition to the normal procedures mentioned above, during the test run stage, an execution sequence which is always needed for the purpose of correcting data input is given as follows:

- Preliminary runs to verify the data input and determine the stabilization period needed.

- Test runs of water routing for a short time period to examine the hydraulic behavior. From convergence behavior, the warning and error messages, and simulation results output, possible corrections to the data input (mainly point properties) can be determined.

- An extended period run of water routing.

- Test runs with water and sediment operations for a short time period.

- Final extended water and sediment routing.
IV.3.2. Data-Error Detection. During the preparatory operations, there are many possible error messages warning messages; these are all described in Appendix C. The error messages will stop the program execution at the end of the preparatory phase.

There is no need to repeat the details of these preparatory phase messages herein. If the messages appear in the printed results, the user should be able to follow Appendix C very easily for guidance in correcting the data input.

IV.3.3. Hydraulic Anomalies. Generally speaking, warning numbers 6 and 9, and error numbers 2 and 22, are associated with hydraulic anomalies during the simulation. Warning number 6 indicates that the depth at the computation point (ID2 of link ID1) is greater than the maximum depth (NLEVEL*DH) for the section allocated to the point. The areas, conveyances, hydraulic radius, and widths are extrapolated upwards. However, if the depth reaches a limiting value (a constant assigned directly in subroutine SECPRO), then error numbers 22 (fatal warning no. 6) is called, and the execution is stopped. Warning 6 and Error 22 are called in subroutine SECPRO which is called from subroutines LINKS1, LINKS2, AND QSUSBC. It is difficult to determine explicitly the causes inducing the excessive depth. Several reasons may be suspected, such as divergence of the nodal matrix solution, inappropriate cross-section type used, etc., in fact such causes may be correlated, and thus cannot always be expressed separately.

Error no. 2 indicates that a singular matrix was detected. This is a severe problem, whose resolution may require consultation with the authors if no hydraulic anomalies are apparent.

IV.3.4. Sedimentation Anomalies. Warning numbers 1, 8, 10, and 11 are associated with sediment operation problems. Warning no. 1 is used in the nodal thalweg averaging procedure to indicate an excessive nodal bed-level change. Warning no. 10 indicates an excessive bed-level change at a point, detected in EXNER2 or one of the subroutines for treatment of the upstream boundary condition. These messages will not cause disasters as long as the hydraulic computation does not diverge. Warning no. 8, which is called in subroutine HYSORT, is informational in nature.

Warning no. 11 is called from one of the sediment-bed subroutines or its upstream-boundary counterpart. Again, many possible causes for this problem exist. Usually an unreasonable large sediment load is due to use of the sediment load formula outside its normal range of parameters. For example, the TLTM formula involves products of
logarithms and may not be a single-value function. Warning no. 11 usually will not appear as long as the hydraulic computation is converging without any problem. However, the user should realize that an unreasonable degradation or aggradation depth may appear in the results due to the excessive bed-level change caused by the excessive sediment load.

**IV.4. Results Interpretation**

**IV.4.1. Preparatory Operations.** During the preparatory operations, the numerical parameters, bed material sizes, restart file NRIN and time, sediment type, physical data checks, link topology, node topology, point properties, cross-section data, printed output dates, time step changes, and total number of error-warning messages are written in the printed output. The user should carefully check these printed results to verify correct data input.

The minimum and maximum values of thalweg, friction factor, particle median size, armoring factor, reach length, weir crest level and width are printed in the physical data check table, so that the user can detect any order-of-magnitude error in data input.

**IV.4.2. Simulation Output.** During the simulation process, warning and error messages may be printed. In addition, for those time steps whose simulation results are not requested, one line of information is printed comprising:

- IT (time step), ITIME (real time), ITHYD (number of iterations), DYNMAX (maximum difference of water level between last two iterations), DQNMAX (maximum difference of discharge between last two iterations), OUTFLOW (total discharge at node 1).

The complete simulation results output includes LNKNAM (LINK), section number (PT), river mile (STATION, miles), stage (STAGE, ft), discharge (DISCHG, cfs), velocity (VEL, ft/sec), hydraulic radius (RH, ft), width (WEDTH, ft), thalweg (THALWEG, ft), sediment load (SED LOAD, cfs), friction factor (FFACT), total cumulative deg./aggr. depth (DEG, ft), armoring factor (ARM), median size of mixed-layer particles (D50, mm), energy slope (SF), current incremental depth-equivalent volume change in a reach (VOLOUT, ft), and Froude number squared (FR2). (Degradations are taken as positive).

- ITHYD, DYNMAX, DQMAX are the variables which indicate the hydraulic convergence status. The ideal case for each time step is ITHYD < MITHYD, DYNMAX < EPSHYD, DQMAX < EPSQ.

- If the above-mentioned conditions are not satisfied, the user should then check the error-warning messages described in Section IV.3.3.

- Check water continuity equation at nodes.

- Check dry bed links, to assure that the water flows in the direction of the fall in water surface.

- Check for excessive Froude numbers, generally indicating near-dry conditions.

- Check the energy slope, which should normally be a small value except for dry-bed links.


- Check the total deg./aggr. depth; unexpectedly excessive values may indicate sedimentation anomalies.

- Excessive bed-level changes usually indicate that the topographical/geometrical initial conditions do not represent a sediment-equilibrium condition.

IV.4.5. Graphical Analysis of Simulation Results. Although the printed output furnished by CHARIMA is sufficient for spot-checking of simulation results, detailed analysis, especially for long-term simulations, is greatly facilitated by use of graphical results processing. As described in Section III.8.3 and Appendix D, all simulation results for all time steps can be stored on the file NROUT for restart of a subsequent simulation or offline graphical results processing. The FORTRAN code PLIALS, presented in Appendix G, provides the user with a relatively straightforward
means of accessing computed functions of time or distance, as well as certain input data, on this results file. As contained herein, PLIAL5 generates graphical output using the DISSPLA graphics software system, and would need to be modified for adaptation to other graphics systems. However PLIAL5 always generates printed data pairs (time or distance functions) which can easily be re-read by the user’s own graphics routines for installation-specific plotting. The portions of PLIAL5 which permit access to the results file should not need to be changed from one installation to another.

IV.5. Summary

There are no specific rules for evaluation of a computation. There is no substitute for the user’s conscientious delving into the details of results and computation methods in search of a full understanding of water and sediment dynamics in his model. In particular, the user should be wary of focussing his attention on particular warning messages or odd computational results. These are usually only the symptoms of a deeper problem which can be ascertained only through serious study and analysis.
V. EXAMPLE APPLICATIONS

V.1. Missouri River

V.1.1. Introduction. The objective of this chapter is to describe use of CHARIMA to simulate long-term bed evolution under quasi-steady flow conditions in the Missouri River. The river reach studied is between Gavins Point Dam (G.P.D., RM. 811.0) and the Rulo Bridge (RM.498.1), Rulo, Nebraska, along with twelve tributaries, the most important of which is the Platte River. Figure V.1 shows the location of the study reach within the river basin.

As discussed by Sayre and Kennedy (1978), the reach between G.P.D. and Blair, Nebraska has experienced severe degradation between the time the G.P.D. began operation (1950) and 1980, in contrast to the downstream reaches below Omaha, Nebraska which have undergone very little change in bed elevations during the same period. In order to predict the future trend of morphological change, numerical-model simulation studies have been performed in recent years. The reach from G.P.D. to the Iowa-Missouri border has been studied by Holly and Karim (1983); the extended reach from G.P.D. to Rulo Bridge has been studied by Holly et al. (1986). Both of these studies used the IALLUVIAL code (Karim and Kennedy, 1982). However, in the original version of IALLUVIAL, tributary inflow can only be treated as a point source. Therefore, the simulation is very sensitive to errors in the imposed sediment inflow hydrographs, including the sediment discharge and its size distribution. This drawback has been discussed by Holly et al. (1986).

This shortcoming can be avoided with the use of the CHARIMA code, which accepts any level of branched or looped topology. However, in contrast to IALLUVIAL, CHARIMA is based on an uncoupling of the friction factor from the sediment transport and uses strict separation of sediment transport in different size classes as described earlier. In order to verify the validity of the code for both simple channels with point sources and for a branched system, two different schematic layouts were adopted for this study. The simple-channel schematic layout is shown in Figure V.2. In order to demonstrate the capability of applying the looped-channel formulation to a simple branched-channel system and to examine the validity and advantages of the proposed nodal sediment-continuity routine, a second layout was adopted as shown in Figure V.3 to treat the Platte River as a modelled tributary.
Figure V.2. Schematic diagram of the Missouri River from RM 811 to RM 498.1 (Model I).
Figure V.3. Schematic diagram of the Missouri River from RM 811 to RM 498.1 (Model II).
V.1.2. **Data Set.** The basic geometric, sediment, and hydrologic data are extracted from the report by Holly et al. (1986). Details concerning the data preparation and calibration can be found in the report by Holly et al. (1986).

The two schematic models shown in Figures V.2 and V.3 are denoted as Model I and II hereafter. In Model II, the Platte River is considered as a modelled tributary, whereas the rest of the tributaries remain unmodelled. Little geometric data is available for these tributaries and their influence on mainstem evolution is minimal. The data set described in the sequel is for Model II, since Model I is just a special case of it.

In accordance with the topological structure established in CHARIMA, the mainstem of Missouri River is divided into eleven links. Each link is bounded by nodes where the tributary inflows enter or by the upstream- and downstream-most nodes. In this arrangement, the Monona-Harrison Ditch, Little Sioux River, and Soldier River have been combined together since they are only 5 miles apart and their sediment properties are almost the same. The Platte River is denoted as link 11 and divided into 4 computational points. The computational points considered in each link of the main stem and their corresponding location are listed in Table V.1.

For each computational point, the following data are required:

* cross-sectional data consisting of channel width and bed level;

* bed-sediment data: bed-material size distribution.

Cross-sectional data and initial bed-material size distribution for computational points in the mainstem are basically taken from the 1963 Hydrographic Survey (U.S. Army Corps of Engineers, 1963), as reported by Holly et al. (1986). The initial bed material size distribution in the Platte River is given herein as shown in Table V.2; the data for the rest of points in the model are the same as those reported by Holly et al. (1986).

The sediment inflows for the tributaries and bank erosion, the imposed water-discharge hydrograph, and the water rating curve at downstream boundary (i.e., Rulo Bridge) are identical to those used by Holly et al. (1986).
Table V.1.

List of computational points for Misssour-River model.

<table>
<thead>
<tr>
<th>Link Name</th>
<th>Point No.</th>
<th>River Mile (1960)</th>
<th>1960 Smoothed Thalweg Elevation (ft)</th>
<th>Section Type</th>
<th>Approximate Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>498.1</td>
<td>834.16</td>
<td>Rect.</td>
<td>Rulo Bridge</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>502.0</td>
<td>838.16</td>
<td>&quot;</td>
<td>Upper Rush Bottom Bend</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>507.0</td>
<td>843.30</td>
<td>&quot;</td>
<td>Lower Cottier Bend</td>
</tr>
<tr>
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<td>1</td>
<td>507.0</td>
<td>843.30</td>
<td>&quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>512.0</td>
<td>848.44</td>
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<td></td>
</tr>
<tr>
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<td>854.61</td>
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<tr>
<td></td>
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</tr>
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<td>1</td>
<td>528.0</td>
<td>864.88</td>
<td>&quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
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<td>870.02</td>
<td>&quot;</td>
<td>Lower Brownville Bend</td>
</tr>
<tr>
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<td>875.16</td>
<td>&quot;</td>
<td>Upper Sonora Bend</td>
</tr>
<tr>
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<td>4</td>
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<td>880.29</td>
<td>&quot;</td>
<td>Nishnabotna Bend</td>
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<td>1</td>
<td>543.0</td>
<td>880.29</td>
<td>&quot;</td>
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</tr>
<tr>
<td></td>
<td>2</td>
<td>548.0</td>
<td>885.56</td>
<td>&quot;</td>
<td>Lower Barney Bend</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>553.0</td>
<td>890.82</td>
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<td>Hamburg Bend</td>
</tr>
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<td>4</td>
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<td>899.44</td>
<td>&quot;</td>
<td>Nebraska City</td>
</tr>
<tr>
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<td>566.0</td>
<td>904.82</td>
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<tr>
<td></td>
<td>6</td>
<td>571.6</td>
<td>910.86</td>
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<td>915.27</td>
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<td>Van Horn's Bend</td>
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<td>920.66</td>
<td>&quot;</td>
<td>Calumet Bartlett Bend</td>
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<td>9</td>
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<td>926.37</td>
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<td>Lower Bellevue Reach</td>
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<td>598.0</td>
<td>939.30</td>
<td>&quot;</td>
<td></td>
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<tr>
<td></td>
<td>4</td>
<td>604.5</td>
<td>945.45</td>
<td>&quot;</td>
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<tr>
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<td>5</td>
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<td>951.31</td>
<td>&quot;</td>
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<tr>
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<td>954.79</td>
<td>&quot;</td>
<td>Omaha Gauge</td>
</tr>
<tr>
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<td>7</td>
<td>620.0</td>
<td>958.83</td>
<td>&quot;</td>
<td>Narrows (appy Field)</td>
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<td>8</td>
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<td>962.87</td>
<td>&quot;</td>
<td>Florence Bend</td>
</tr>
<tr>
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<td>629.1</td>
<td>966.19</td>
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<td>Lower Pigeon Creek Bend</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>635.8</td>
<td>971.60</td>
<td>&quot;</td>
<td>Boyer Bend</td>
</tr>
<tr>
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<td>1</td>
<td>635.8</td>
<td>971.60</td>
<td>&quot;</td>
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<tr>
<td></td>
<td>2</td>
<td>641.3</td>
<td>976.49</td>
<td>&quot;</td>
<td>Upper Calhoun Bend</td>
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<td>646.0</td>
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<td>&quot;</td>
<td>Desota Bend</td>
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<tr>
<td></td>
<td>4</td>
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<td>982.82</td>
<td>&quot;</td>
<td>Blair Highway Bridge</td>
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<td>651.9</td>
<td>986.45</td>
<td>&quot;</td>
<td>Tysons Bend</td>
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<tr>
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<td>6</td>
<td>655.0</td>
<td>989.49</td>
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<td>993.91</td>
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<td>Peterson Cutoff</td>
</tr>
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Table V.2.

Cumulative size distribution of bed material in Platte River.

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<th>0.590</th>
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</table>

V.1.3. Test Conditions  Four runs were performed for the purpose of examining the validity of the procedures and code developed herein. The modified TLTM method sediment-discharge predictor is used for RUN1, RUN2, and RUN3. The fourth run uses the modified Ackers-White method to compute the sediment discharge. The primary numerical parameters used for these test runs are:

\[ \Delta t = 10 \text{ days} \]

\[ \Delta x = 11,600 \text{ to } 42,200 \text{ feet} \]

\[ \alpha = 1.0 \]

\[ \phi = 0.5 \]

\[ \theta = 1.0 \]

\[ \beta = 0.5 \]

Iteration number = 0

The conditions of each run are as follows:
RUN1

A 20-year simulation, from 1960 to 1980, was performed for Model I. This run is identical to that performed by Holly et al. (1986) using IALLUVIAL. The purpose of this run is to demonstrate the validity and applicability of CHARIMA for simulating nonuniform sediment transport in a simple channel with point sources entering the mainstem under quasi-steady flow conditions.

RUN2

This run is performed to simulate bed-evolution in Model II from 1960 to 1980. The sediment inflow at the upstream boundary of the Platte River is arbitrarily assumed to be the rating curve used for the point source at Platte confluence in Model I. The purpose of this run is to show the validity of the looped-channel algorithm applied to a simple branched system.

RUN3

This run is the same as RUN2, but instead of Allen's dune-height relation used in RUN1 and RUN2 Yalin's relation is used. This run is to investigate the applicability of both dune-height formulations to bed evolution in the Missouri River.

RUN4

This run is the same as RUN2, but the modified Ackers-White method is used to compute the sediment-transport capacity. The purpose of this run is to show the applicability of the modified Ackers-White method to the Missouri-River model.
V.1.4. Analysis of Results

RUN1

Figure V.4 shows the evolution of the longitudinal thalweg (Z0 profile), from 1960 to 1980, computed by the BRALLUVIAL code with a time step of 10 days. The result shows that the upstream reach from RM 770 to RM 650 suffers serious degradation whereas the downstream reach tends toward stabilization. This tendency is the same as that obtained by Holly et al. (1986) with the IALLUVIAL code.

The dashed line in Figure V.5 shows the bed-level change (DZ) along the study reach after a 20-year simulation. Degradation occurs in the reach from the upstream end down to the vicinity of Omaha. The maximum degradation depth is about 8 feet near RM 680 and RM 730. The reach between the Platte confluence and the Rulo Bridge has slightly degraded. The measured data, shown as a solid line in Figure V.5, was constructed on the basis of U.S. Army Corps of Engineers Hydrographic surveys. No bed-elevation data is available for the reach between RM 740 and G.P.D. in 1980. Therefore, instead of the bed-level change, the water-surface-level change for this subreach is shown in the figure.

From Figure V.5, it can be observed that the computed bed-level changes are qualitatively and quantitively similar to the measured ones. The large deviation appearing in the upstream reach between RM 770 and G.P.D. may be caused by the uncertain bank-erosion sediment supply and some other factors, such as the geometric data and bed-material composition. Also, it should be noted that the water-surface-level change in general is not exactly equivalent to the bed-level change. Hence, one has to recognize that some degree of error exists in the so-called measured data. The maximum difference between the computed and measured bed-level change is about 2.5 feet. For the numerical simulation of nonuniform sediment transport this error probably can be considered as reasonable.

RUN2

The change in bed-level along the study reach for this run is shown in Figure V.6. Solid and diashed lines represent the measured and the computed results respectively, for

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Figure V.4. Longitudinal thalweg profile in Missouri River.
Figure V.5. Bed-level changes in Missouri River for RUN1.
the main channel not including the Platte River. The dotted line represents the result for RUN1. The computed result for this run is similar to that for RUN1, but fits the measured data better. The upstream boundary of the Platte River, which is not plotted here, has two feet of aggradation. No measured data are available for the Platte River; hence, no analysis can be conducted to verify the computed bed-level change in the Platte River.

RUN3

The computed bed-level change along the study reach after 20-year simulation in identical to that in RUN2; the results are shown in Figure V.7. At present, it can only be concluded that Yalin's dune-height predictor functions in the same way as Allen's relation during the simulation for the Missouri River model.

RUN4

The bed-evolution result for this run is almost the same as that for RUN2 as shown in Figure V.8. Some small differences exist; the maximum deviation is about 1 foot near the upstream boundary. This difference is not unexpected since each sediment predictor has its own characteristics and limitations. It may be concluded that the modified Ackers-White method is also applicable for the Missouri-River-model study.

V.1.5. Conclusions. It has to be stressed here that while the Missouri River model is based on the best available data, it is still a schematic one-dimensional simplification of a complicated 3-D process. The looped-channel algorithm used to model the tributary as a branching system instead of as a point source can only avoid some uncertainty caused by the tributary sediment inflow. If the model is to be used for predictions, the simulation results should not be interpreted as definitive, quantitative forecasts of future bed levels. The prognosis runs given above are mainly used to examine the validity and applicability of the code developed herein and to show the advantage and capability of this newly developed code.
Figure V.8. Bed-level changes in Missouri River for RUN4.
On the basis of the results discussed above, a few conclusions can be reached:

1) The newly developed code has the same capability as other 1-D codes, such as IALLUVIAL, to simulate bed evolution for gradually varied flow in an alluvial channel with nonuniform bed material and to adopt the tributary as a point source if the point-source sediment inflow data are correct.

2) The morphological change of an alluvial channel can be predicted with some degree of accuracy by the use of numerical modelling. However, sediment transport in a natural river is a complex process which comprises many controlling factors and is not yet fully understood. Hence, the simulation results can be subject to considerable uncertainty. Therefore, numerical simulation should be properly be considered only to predict the trend of variation, and should not be considered as furnishing definitive conclusions.
3) The looped-channel formulation developed herein can also be used for simple branched systems.

4) Mixed-layer thickness plays an important role in the bed-evolution problem as discussed in Section II.6. From RUN2 and RUN3, it can be concluded that the two proposed mixed-layer prediction methods (Yalin's and Allens' relations) function equally well for the Missouri River model.

5) For bed-evolution simulation in the Missouri River, both sediment-discharge predictors (i.e., the modified TLTM and the modified Ackers'White methods) give almost identical results.

V.2. Cho-Shui River

V.2.1. Introduction. The Cho-Shui River in western Taiwan is very wide. Its channel width at some places exceeds 13,000 feet. The channel bed slope varies from 1/10 upstream to less than 1/1,000 downstream near the river mouth. The average base-flow discharge at the mouth is no more than 5,000 cfs during the wet season (June to September), and only about 1,000 cfs during the rest of the year. The lowest historical flow is about 500 cfs. However, the Cho-Shui floods two or three times each year. The flood discharge can rise to 400,000 cfs within a few hours. A tremendous amount of sediment is carried down to the downstream reach and deposited after the flood. From 1913 to 1954, the bed level in the downstream reaches of the channel has aggraded about 7 feet. The main channel of the stream has shifted constantly and formed a braided channel system as shown in Figure V.9, which is based on a 1968 aerial photograph. Following levee construction along most of the river, the channel bed has been quite stable. However, during floods severe degradation has been observed.

One of the purposes of this study is to simulate short-term bed evolution during the flood period using the code CHARIMA. Two typhoons, Fabian in 1970 and Elsie in 1969, were studied. They were chosen for this study for the following reasons:

* The measured geometrical data provided by the Taiwan Water Conservancy Bureau (TWCB) is for 1968. These two typhoons occurred close to this time. Therefore, the possible error caused by uncertain geometrical data should be minimized.
* According to the historical record, the Fabian typhoon is the most severe one ever recorded; the peak discharge was about 400,000 cfs.

The study reach extends from Hsi-Lo Bridge to the river mouth as shown in Figure V.9; the total length is about 13.3 miles. The reason that only this downstream reach is selected for this study is:

* This reach suffers the most serious sedimentation problems caused by floods according to the Taiwan Water Conservancy Bureau's observations and study.

* Only this reach has measured bed-level change data during floods.

* The bed slope in the upstream reach is very steep; it is expected that supercritical flow and hydraulic jumps occur. The CHARIMA code is not designed to handle such flow conditions.

In this study, the modified TLTM method is used for computing the sediment discharge.

V.2.2 Data Set.

Topology

The main channel in the Cho-Shui River shifts constantly during the flood period; no stable channel pattern can be identified. Figure V.9 shows the flow path of the main channel measured in 1954 and 1968. However, the Taiwan Water Conservancy studies (1972) concluded that the main channel has remained quite stable since 1968. Therefore, the topology adopted for the downstream study reach as shown in Figure V.10 (based on Figure V.9) should be reasonable for studying the Fabian typhoon in 1970 and Elsie typhoon in 1969. The approximate locations of computational points corresponding to the TWCB cross-section number shown in Figure V.9 are given in Table V.3. The same computational point numbers in links 1 and 2 are located at the same river mile from the mouth.
Figure V.9. Flow path of main channel in Cho-Shui River.
Figure V.10. Schematic topological diagram of Choi-Shui River.
Geometric Data

The location of computational points was determined through careful review of the location of available cross sectional data. Links 1 and 2 are divided into 18 computational points; link 3 is divided into 28 points. The cross-sectional data and bed elevation for each point were taken from the measured cross-section geometry supplied by the Taiwan Water Conservancy Bureau. The channel along the study reach has a very wide flood plain. The channel can be considered as approximately rectangular. However, in order to simulate low-flow conditions, the cross-section geometry has been carefully taken from the measured data to include a small drainage ditch to represent the main flow path. A summary of the geometric data is given in Table V.3.

Bed Material Composition

A complete set of bed-material composition data has been collected by the Taiwan Water Conservancy Bureau in 1968. Along the study reach, there are 11 measuring stations, for which the cumulative size distributions are summarized in Table V.4. Since only eleven stations are available, the data required for the remaining computational points were assumed to be the same as those of neighboring stations.

The measured bed-material composition as shown in Table V.4 is used as the parent-bed material for both typhoon flood simulations.

Boundary Conditions

Two upstream boundary conditions and one downstream condition are required. The upstream boundary conditions consist of water and sediment inflow hydrographs. The water hydrographs for both floods are given in Figure V.11. The sediment-inflow hydrograph was based on the total-load rating curve. According to the Taiwan Water Conservancy Bureau study, only 10% of the measured suspended load is supplied from the bed material. Therefore, the measured total sediment discharge is taken as the sum of 10% measured suspended load and total bed load. Several trials have been carried out to calibrate the coefficients $b_1$ and $b_2$ appearing in Eq. (II.23) needed for computing the sediment discharge from the modified TLTM method. It was found that $b_1 = 1$ and $b_2 = 1$
Table V.3.

Summary of cross-section data for Cho-Shui River.

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<td>66.04</td>
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</tr>
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<td>&quot;</td>
<td>19</td>
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<td>&quot;</td>
</tr>
<tr>
<td></td>
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<td>11.863</td>
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<td>&quot;</td>
</tr>
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<td>21</td>
<td>12.321</td>
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<td>&quot;</td>
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</table>
Table V.3 (continued).

<p>| | | | |</p>
<table>
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</tr>
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<td>&quot;</td>
</tr>
<tr>
<td>25</td>
<td>13.628</td>
<td>83.53</td>
<td>&quot;</td>
</tr>
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<td>26</td>
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<td>85.89</td>
<td>&quot;</td>
</tr>
<tr>
<td>27</td>
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<td>&quot;</td>
</tr>
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<td>28</td>
<td>14.503</td>
<td>90.74</td>
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Table V.4.
Cumulative size distribution of bed material
in Cho-Shui River.

<table>
<thead>
<tr>
<th>Link Name</th>
<th>Point No.</th>
<th>D50 (mm)</th>
<th>0.062</th>
<th>0.149</th>
<th>0.297</th>
<th>0.590</th>
<th>1.190</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1, 2, 3, 4, 5</td>
<td>0.328</td>
<td>0.000</td>
<td>0.140</td>
<td>0.460</td>
<td>0.840</td>
<td>0.965</td>
</tr>
<tr>
<td>1</td>
<td>6, 7, 8, 9, 10</td>
<td>0.337</td>
<td>0.000</td>
<td>0.100</td>
<td>0.440</td>
<td>0.880</td>
<td>0.970</td>
</tr>
<tr>
<td>1</td>
<td>11, 12, 13, 14, 15</td>
<td>0.370</td>
<td>0.000</td>
<td>0.110</td>
<td>0.400</td>
<td>0.800</td>
<td>0.950</td>
</tr>
<tr>
<td>1</td>
<td>16, 17, 18</td>
<td>0.395</td>
<td>0.000</td>
<td>0.090</td>
<td>0.380</td>
<td>0.740</td>
<td>0.950</td>
</tr>
<tr>
<td>1</td>
<td>16, 17, 18</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>3</td>
<td>4, 5, 6, 7, 8</td>
<td>0.376</td>
<td>0.000</td>
<td>0.120</td>
<td>0.360</td>
<td>0.880</td>
<td>0.960</td>
</tr>
<tr>
<td>3</td>
<td>9, 10, 11, 12, 13, 14, 15, 16, 17, 18</td>
<td>0.443</td>
<td>0.000</td>
<td>0.090</td>
<td>0.360</td>
<td>0.640</td>
<td>0.860</td>
</tr>
<tr>
<td>3</td>
<td>19, 20, 21, 22, 23</td>
<td>0.409</td>
<td>0.000</td>
<td>0.100</td>
<td>0.340</td>
<td>0.760</td>
<td>0.900</td>
</tr>
<tr>
<td>3</td>
<td>24, 25, 26, 27</td>
<td>0.356</td>
<td>0.000</td>
<td>0.100</td>
<td>0.450</td>
<td>0.700</td>
<td>0.870</td>
</tr>
<tr>
<td>3</td>
<td>28</td>
<td>0.657</td>
<td>0.000</td>
<td>0.060</td>
<td>0.190</td>
<td>0.475</td>
<td>0.700</td>
</tr>
</tbody>
</table>
Table V.4. (continued)

<table>
<thead>
<tr>
<th>2.380</th>
<th>4.760</th>
<th>9.520</th>
<th>19.10</th>
<th>38.10</th>
<th>76.20</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.990</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>0.985</td>
<td>0.990</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>0.985</td>
<td>0.980</td>
<td>0.985</td>
<td>0.990</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>0.975</td>
<td>0.980</td>
<td>0.990</td>
<td>0.995</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>0.980</td>
<td>0.990</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>0.940</td>
<td>0.960</td>
<td>0.970</td>
<td>0.980</td>
<td>0.990</td>
<td>1.000</td>
</tr>
<tr>
<td>0.940</td>
<td>0.960</td>
<td>0.965</td>
<td>0.980</td>
<td>0.990</td>
<td>1.000</td>
</tr>
<tr>
<td>0.930</td>
<td>0.945</td>
<td>0.950</td>
<td>0.960</td>
<td>0.980</td>
<td>1.000</td>
</tr>
<tr>
<td>0.845</td>
<td>0.880</td>
<td>0.910</td>
<td>0.940</td>
<td>0.975</td>
<td>1.000</td>
</tr>
</tbody>
</table>
Figure V.11. Hydrograph for Fabian and Elsie typhoons.
gives the best fit with the measured rating curve as shown in Figure V.12. The downstream boundary is the river mouth which is influenced by the tide. However, at the time of writing, the Taiwan Water Conservancy Bureau had not yet been able to furnish the measured tidal records. Thus, a water rating curve has been constructed on the basis of the assumption of uniform flow and a constant bed slope. This means that no tidal reverse flow is possible.

**V.2.3. Test Conditions.** Three simulations were conducted. The primary numerical parameters used for these runs are:

\[ \Delta t = 30 \text{ minutes} \]

\[ \Delta x = 528 \text{ to } 5280 \text{ feet} \]

\[ \alpha = 1.0 \]

\[ \phi = 0.5 \]

\[ \theta = 1.0 \]

\[ \beta = 0.9 \]

iteration number = 0

**RUN1**

This run simulates the Fabian typhoon. Sorting and armoring procedures were deactivated in this run.

**RUN2**

This run also simulates the Fabian typhoon but with the sorting and armoring procedures activated.
Figure V.12. Sediment-discharge rating curve at Hsi-Lo.
RUN3

This run simulates Elsie typhoon without sorting and armoring procedures.

V.2.4. Analysis of Results.

Run1

Figure V.13 shows the computed and measured stage hydrographs at Hsi-Lo gage station (i.e., the only section having a measured stage hydrograph along the study reach). The difference between the computed and measured values can be attributed to several factors, such as the uncertainty of schematized cross-section data, and incorrect bed elevations. The maximum deviation in the stage hydrograph is about 1.0 foot. No further calibration was performed to obtain a better agreement. The 1.0-foot difference in stage hydrograph occurs at the low flow, so the influence on sediment routing should be minimal. The goal is primarily one of studying sediment-transport phenomena. Therefore, the results as shown in Figure V.13 are considered to be acceptable for the bed-evolution study, although they may not represent a good low-flow calibration of the model. The computed bed elevations along the channels are shown in Figure V.14. Obviously, the simulation shows the channel bed has degraded during the flood. No detailed data for the bed-level change along the braided flow paths during the flood are available. Only the cross-sectional average degradation depth for some of the sections (denoted by geographic section number TWCB 6, 16, 29, 33, 37, 41, 45, and 49) are available. Therefore, the average value of the computed bed-level change for the corresponding computational points along links 1 and 2 is used to compare with the measured data. For example, the bed-level change for geographic section TWCB16 is the average of computational point 12 in links 1 and 2. Table V.5 shows the measured and computed bed-level changes along the study reach during the flood.

The results from the simulation are quite promising except for the downstream point. It is not unexpected that an inconsistency should occur at the downstream point since tidal effects are not considered in this simulation.
Figure V.13. Stage hydrograph at Hsi-Lo during Fabian typhoon.
Figure V.14. Longitudinal thalweg profile after Fibian typhoon.
Table V.5.

Bed-level change during Fabian typhoon.

<table>
<thead>
<tr>
<th>TWCB Section No.</th>
<th>Measured Degradation Depth (ft)</th>
<th>RUN1 Computed Degradation Depth (ft)</th>
<th>RUN2 Computed Degradation Depth (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>2.98</td>
<td>0.00</td>
<td>0.06</td>
</tr>
<tr>
<td>16</td>
<td>2.79</td>
<td>1.63</td>
<td>0.04</td>
</tr>
<tr>
<td>29</td>
<td>3.84</td>
<td>3.09</td>
<td>0.31</td>
</tr>
<tr>
<td>33</td>
<td>2.53</td>
<td>1.95</td>
<td>0.08</td>
</tr>
<tr>
<td>37</td>
<td>3.25</td>
<td>3.23</td>
<td>0.11</td>
</tr>
<tr>
<td>41</td>
<td>2.79</td>
<td>2.37</td>
<td>0.08</td>
</tr>
<tr>
<td>45</td>
<td>3.28</td>
<td>3.59</td>
<td>0.26</td>
</tr>
<tr>
<td>49</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

RUN2

Table V.5 shows the measured and computed degradation depths along the study reach during the flood. The simulation underpredicts the bed-level degradation during the flood. This is possibly caused by the tendency for the wave of bed-material composition change to propagate faster than the bed-level change as suggested by Vanoni and Dawdy (1986). During the flood simulation, the bed material has coarsened in a short time, and the transport capacity is reduced dramatically.

Figure V.15 shows the time history of bed-level change (DZ), median particle size (D50), and armoring factor (ACF) at the computation point TWCB45 (arbitrarily chosen) during the flood. From Figure V.15 (a), it can be seen that the bed-level change for this run is much less than that for RUN1. Figure V.15 (b) shows that the median particle size of the mixed layer and the armoring factor increase as the degradation depth increases. The maximum value of bed-level change, median particle size, and armoring factor occurs at the peak of flood and remains constant during the recession period of flood.
Figure V.15. Time history of bed-level change, $D_{50}$, and ACF at TWCB45 during Fabian typhoon.
Figure V.16. Longitudinal thalweg profile after Elsie typhoon.
This behavior may imply that the sorting and armoring processes can be neglected for the highly unsteady (peaky) flow.

RUN3

Figure V.16 shows the bed elevation after the flood. Again, as in the previous runs, the bed level degrades during the flood. The measured and computed degradation depths are given in Table V.6. The measured values shown here are the data collected after 4 typhoons during that year. The computed results are obtained only by simulating one typhoon (i.e., Elsie typhoon). Therefore, it is not unexpected that some difference exists between the computed results and the measured data.

V.2.5. Conclusions. 1) The code, CHARIMA, can be used to study unsteady flow and bed-evolution problems in a branched system with multiple downstream boundaries. For the Cho-Shui River, the simulation results are quite convincing of CHARIMA’s ability to predict the maximum degradation depth during a flood.

Table V.6.

<table>
<thead>
<tr>
<th>TWCB Section No.</th>
<th>Measured Degradation Depth (ft)</th>
<th>Run3 Computed Degradation Depth (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>2.65</td>
<td>0.00</td>
</tr>
<tr>
<td>16</td>
<td>2.59</td>
<td>0.30</td>
</tr>
<tr>
<td>29</td>
<td>2.92</td>
<td>1.67</td>
</tr>
<tr>
<td>33</td>
<td>0.00</td>
<td>1.06</td>
</tr>
<tr>
<td>37</td>
<td>2.07</td>
<td>2.00</td>
</tr>
<tr>
<td>41</td>
<td>0.00</td>
<td>1.07</td>
</tr>
<tr>
<td>45</td>
<td>3.11</td>
<td>1.83</td>
</tr>
<tr>
<td>49</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>
2) If the flow conditions change rapidly, the sorting and armoring procedures can be neglected.

3) In order to have a better simulation for the Cho-Shui River, the tidal effects at the downstream boundary should be taken into account when field data become available.

V.3. SUSITNA RIVER

V.3.1. Introduction. The BRALLUVIAL code (equivalent to CHARIMA for quasi-steady-state water flow) was developed in response to the need of Harza-Ebasco Susitna Joint Venture to conduct long-term water- and sediment-routing simulations in a highly braided fifteen-mile reach of the Susitna River, Alaska. The study reach extends from the Chulitna confluence (River Mile RM 98) past the Talkeetna confluence (RM 97) down to the Sunshine Bridge (RM 83). The general purpose of Harza-Ebasco's study was to analyze, in as detailed a manner as possible, the effect of upstream flow modulation (due to possible hydropower development) on quasi-two-dimensional aggradation patterns in the vicinity of the Chulitna/Talkeetna confluence. Indeed, the Susitna's sudden change from a single-channel to multiple braided channels at RM 98 is in response to the heavy sediment inflows of the Talkeetna and Chulitna.

The Susitna model was not only the immediate reason for development of BRALLUVIAL, but also the most challenging of a broad class of modelling situations which the code is designed to accommodate. The model is intensely looped (multiply-connected channels); has highly non-uniform sediment (medium sands to coarse gravels and cobbles); has many channels on supercritical slopes at low flow; has many perched channels which dry out at low flow; and has multiple (eleven) inflow points.

A complete description of the Susitna study and its results can be found in the companion report by Harza-Ebasco Susitna Joint Venture. The purpose of this chapter is to describe the calibration of sediment-discharge and friction-factor relations for the Susitna, outline assembly of the model data set, and briefly comment on some of the particular computational anomalies of the Susitna model.
V.3.2. Calibration of Sediment-Transport and Friction-Factor Relations.

Sediment Discharge Relation.

Bed sediments of the Susitna River are highly nonuniform, with particle sizes varying from sand size to as large as gravels and cobbles and median size \( (D_{50}) \) in the range of 40 mm to 50 mm. Because of this nonuniformity and large particle sizes, a single sediment size, like \( D_{50} \), can hardly represent the wide spectrum of sizes present in the Susitna River bed materials. It is, therefore, necessary to divide bed sediments into several representative size fractions and compute sediment discharge for each fraction, e.g., by Eq. (II.22). Application of Eq. (II.22) to the Susitna requires the determination of the coefficients \( a_0 \) to \( a_3 \) of Eq. (II.21) and the weighting factor \( W_k \) in Eq. (II.22) from an analysis of the Susitna River data. Because of the limited availability of sediment discharge data for the Susitna River (available record for 2 years, 1982-83), a regression analysis to determine the coefficients \( a_0 \) through \( a_3 \) of Eq. (II.21) is not justifiable. The approach utilized herein, therefore, is to adopt the values of the coefficients in Eq. (II.21) as

\[
\begin{align*}
    a_0 &= -2.278 \\
    a_1 &= 2.972 \\
    a_2 &= 1.06 \\
    a_3 &= 0.299
\end{align*}
\]  

(V.1)

which were obtained by Karim and Kennedy (1981) from an analysis of 615 flume and river flows; and then formulate a relation for \( W_k \) from an analysis of the Susitna River data. A further justification for utilizing the coefficients given in Eq. (V.1) is that these coefficients were obtained from flows with bed sediment sizes varying from sand size to gravels, as are typical for the Susitna bed materials.

Sediment discharge data of the Susitna River (1981-82 data) were utilized to formulate a relation for the weighting function \( W_k \), expressed as

181
\[ W_k = b_0 \left( \frac{D_k}{D_{50}} \right)^{b_1} \]  

(V.2)

where \( D_k \) = representative sediment size of kth fraction; \( D_{50} \) = median size; and \( b_0, b_1 \) are coefficients. The total sediment discharge for all size fractions, \( q_s \), was obtained from Eqs. (II.68) and (V.2):

\[ q_s = \sum_{k=1}^{K} q_s(D_k) \cdot P_k \cdot b_0 \left( \frac{D_k}{D_{50}} \right)^{b_1} \]  

(V.3)

where \( K \) = total number of size fractions. From the known values of \( q_s \) for the Susitna, a trail-and-error procedure was used to determine the best-fit values of \( b_0 \) and \( b_1 \) in Eq. (V.3).

Available records for four stations: Susitna near Talkeetna; Chulitna near Talkeetna; Talkeetna near Talkneetna; and Susitna at Sunshine--are utilized in the analysis to determine \( b_0 \) and \( b_1 \). Because of the difficult field conditions encountered at the three upstream stations (near Talkeetna) and the small number of samples taken, sediment-discharge data at these stations are less reliable than those at Sunshine; consequently, the data at Sunshine are given most weight in the present analysis. The best-fit values of \( b_0 \) and \( b_1 \) are:

\[ b_0 = 1.0 \]  

(V.4)

\[ b_1 = 0.26 \sqrt{d/D_{50}} \]
where \( d \) = mean flow depth. Average bed-material size distributions (average of all samples taken at each station during 1981-82) at the four stations are shown in Figure V.17. The size distribution for the Susitna near Talkeetna, with \( D_{50} = 92 \) mm (Figure V.17), is probably not representative of bed sediments of the whole section. These distributions have been used to compute total sediment discharges at each station by Eq. (V.3), along with Eqs. (V.1) and (V.4), and the computed values along with the measured quantities are presented in Tables V.7 through V.10. Measured suspended-sediment discharges are adjusted to exclude the fractions not represented on the bed. The fraction of measured suspended discharges excluded in computing bed-material discharges, as estimated from bed-material and suspended-sediment size distributions (1981-82 data), is 87% for Susitna near Talkeetna; the corresponding figures for the other three stations are 86%, 74%, and 88% for Chulitna near Talkeetna, Talkeetna near Talkeetna, and Susitna at Sunshine, respectively. It is seen from Tables V.7 through V.10 that the computed sediment discharges are in reasonable agreement with the measured values for the two stations of Susitna at Sunshine (Table V.10) and Chulitna near Talkeetna (Table V.8) while the agreements for the other two stations are less satisfactory. In view of the uncertainties in the measured values of bed-material size distributions, the paractical difficulties in field measurements, and the variability in sediment and geometric properties across the sections (or among different subchannels of a highly braided river like the Susitna), such deviations are not surprising. A similar comparison of the computed and measured sediment discharges for 1982-83 data indicates good agreement for the Susitna at Sunshine but less satisfactory for other three stations. A plot of the measured and computed sediment discharge of the Susitna at Sunshine for both 1981-82 and 1982-83 data is shown in Figure V.18. It is encouraging to note good agreement in results at Sunshine, because this is the only station with well-defined channel section and therefore, measured values are more reliable.

Friction factor relation.

The friction factor relation given by Eq. (II.34), with the coefficients obtained from Karim and Kennedy's (1981) data analysis,
Figure V.17. Bed-material size distribution in Susitna River.
Figure V.18. Computed and measured sediment discharges of the Susitna River at Sunshine.
Table V.7.

Summary of measured and computed quantities for the Susitna River near Talkeetna (1981-82)

<table>
<thead>
<tr>
<th>No</th>
<th>Date</th>
<th>Q</th>
<th>Depth (ft)</th>
<th>Vel. (ft/sec)</th>
<th>Energy Slope x10^3</th>
<th>f</th>
<th>q_s** (tons/d/ft)</th>
<th>Depth (ft)</th>
<th>Vel. (ft/sec)</th>
<th>f</th>
<th>q_s (tons/d/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>06/03/82</td>
<td>35,800</td>
<td>7.76</td>
<td>7.38</td>
<td>1.5*</td>
<td>.06</td>
<td>19.7</td>
<td>8.95</td>
<td>6.40</td>
<td>.08</td>
<td>2.1</td>
</tr>
<tr>
<td>2</td>
<td>06/08/82</td>
<td>44,400</td>
<td>8.25</td>
<td>8.15</td>
<td>1.4</td>
<td>.04</td>
<td>15.8</td>
<td>10.10</td>
<td>6.66</td>
<td>.08</td>
<td>2.0</td>
</tr>
<tr>
<td>3</td>
<td>06/15/82</td>
<td>24,200</td>
<td>5.27</td>
<td>7.42</td>
<td>1.4*</td>
<td>.03</td>
<td>3.8</td>
<td>7.18</td>
<td>5.44</td>
<td>.09</td>
<td>1.5</td>
</tr>
<tr>
<td>4</td>
<td>06/22/82</td>
<td>37,000</td>
<td>7.37</td>
<td>7.78</td>
<td>1.5</td>
<td>.05</td>
<td>10.2</td>
<td>8.96</td>
<td>6.40</td>
<td>.08</td>
<td>2.1</td>
</tr>
<tr>
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<td>06/30/82</td>
<td>30,200</td>
<td>6.52</td>
<td>7.44</td>
<td>1.8</td>
<td>.05</td>
<td>8.1</td>
<td>7.58</td>
<td>6.40</td>
<td>.09</td>
<td>2.6</td>
</tr>
<tr>
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<td>07/08/82</td>
<td>20,800</td>
<td>5.15</td>
<td>6.78</td>
<td>1.3</td>
<td>.04</td>
<td>2.3</td>
<td>6.85</td>
<td>5.09</td>
<td>.09</td>
<td>1.3</td>
</tr>
<tr>
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* estimated values

** excludes susp. sed. disch. not represented in bed (87%)

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### Table V.8.

Summary of measured and computed quantities for the Chulitna River near Talkeetna (1981-82)

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<td>5.16</td>
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<td>8.82</td>
<td>6.89</td>
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<table>
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<th>q_s (tons/d/ft)</th>
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</thead>
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<td>22,000</td>
<td>8.50</td>
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<td>17,900</td>
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<td>09/18/82</td>
<td>29,600</td>
<td>9.16</td>
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* estimated values
** excludes susp. sed. disch. not represented in bed (86%)

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### Table V.9.

Summary of measured and computed quantities for the Talkeetna River near Talkeetna (1981-82)

| No | Date    | Q (cfs) | Depth (ft) | Vel. (ft/sec) | Energy Slope x10³ | f | q_s (tons/d/ft) | | Depth (ft) | Vel. (ft/sec) | f | q_s (tons/d/ft) |
|----|---------|---------|------------|---------------|-------------------|---|----------------|---|----------------|---|----------------|---|----------------|
| 1  | 07/21/81| 16,800  | 8.63       | 5.54          | 1.00*             | .07| 23.4          |   | 8.78          | 5.44        | .08| 4.0           |   |                |
| 2  | 08/25/81| 9,900   | 5.19       | 5.69          | 1.00*             | .04| 9.8           |   | 6.49          | 4.54        | .08| 10.4          |   |                |
| 3  | 09/29/81| 2,910   | 3.07       | 3.05          | 1.00*             | .09| 0.7           |   | 3.15          | 2.97        | .09| 5.0           |   |                |
| 4  | 06/02/82| 19,100  | 7.11       | 7.52          | 1.00*             | .03| 15.3          |   | 9.42          | 5.67        | .08| 13.4          |   |                |
| 5  | 06/09/82| 14,000  | 6.03       | 6.64          | 0.96              | .03| 35.9          |   | 7.95          | 5.03        | .08| 11.8          |   |                |
| 6  | 06/16/82| 11,400  | 5.63       | 5.79          | 1.00*             | .04| 8.5           |   | 6.92          | 4.70        | .08| 9.6           |   |                |
| 7  | 06/23/82| 12,400  | 5.73       | 6.29          | 1.00*             | .04| 9.9           |   | 7.39          | 4.87        | .08| 11.7          |   |                |
| 8  | 06/29/82| 10,900  | 5.70       | 5.48          | 1.00*             | .05| 8.4           |   | 6.75          | 4.62        | .08| 8.1           |   |                |
| 9  | 07/07/82| 6,840   | 4.35       | 4.75          | 1.00*             | .05| 4.5           |   | 5.19          | 3.98        | .08| 8.3           |   |                |
| 10 | 07/13/82| 9,020   | 4.78       | 5.53          | 1.00*             | .04| 4.4           |   | 6.08          | 4.35        | .08| 10.8          |   |                |
| 11 | 07/20/82| 8,560   | 4.83       | 5.16          | 1.00*             | .05| 5.3           |   | 5.85          | 4.25        | .08| 8.9           |   |                |
| 12 | 07/28/82| 14,300  | 6.26       | 6.56          | 1.00*             | .04| 11.4          |   | 8.00          | 5.13        | .08| 11.4          |   |                |
| 13 | 08/03/82| 9,140   | 4.83       | 5.51          | 1.00*             | .04| 7.4           |   | 6.09          | 4.37        | .08| 10.6          |   |                |
| 14 | 08/10/82| 7,070   | 4.35       | 4.81          | 1.00*             | .05| 15.6          |   | 5.23          | 4.00        | .08| 8.6           |   |                |
| 15 | 08/17/82| 6,260   | 3.83       | 4.85          | 1.00*             | .04| 9.8           |   | 4.85          | 3.83        | .09| 10.2          |   |                |
| 16 | 08/24/82| 5,960   | 3.75       | 4.77          | 1.00*             | .04| 7.6           |   | 4.74          | 3.77        | .09| 10.0          |   |                |
| 17 | 08/31/82| 9,200   | 4.53       | 5.79          | 1.00*             | .03| 5.5           |   | 6.03          | 4.35        | .08| 13.2          |   |                |
| 18 | 09/20/82| 14,600  | 6.55       | 6.40          | 0.49              | .02| 16.7          |   | 10.11         | 4.14        | .07| 3.6           |   |                |

* estimated values
** excludes susp. sed. disch. not represented in bed (74%)
*** computed using measured depths and velocities
Table V.10.

Summary of measured and computed quantities for the Susitna River at Sunshine (1981-82)

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<th>Energy Slope x10³</th>
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<th>qs** (tons/d/ft)</th>
<th></th>
<th>COMPUTED Depth (ft)</th>
<th>Vel. (ft/sec)</th>
<th>f</th>
<th>qs (tons/d/ft)</th>
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<td>.07</td>
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* estimated values
** excludes susp. sed. disch. not represented in bed (88%)
\[ c_5 = 0.33 \]  
\[ c_6 = 0.376 \]  
\[ c_7 = 0.310 \]  

(V.5)

is adopted for the Susitna River. The coefficients in Eq. (V.5) were obtained from regression analysis of 615 flows, with sediments varying from sand to gravel sizes. Available measured hydraulic data at the four stations of the Susitna River have been utilized to check the accuracy of the predicted values of velocities (or friction factors). Mean velocities and friction factors computed by Eq. (II.70) with the coefficients given by Eq. (V.5) are presented in Tables V.7 through V.10 for the four stations. Mean normalized errors (MNE) defined (in percent) as the average of the ratios of absolute deviations between the measured and computed values to the measured values are computed for the predicted velocities given in Tables V.7 through V.10; these MNE's are 20.8\%, 3.9\%, 19.2\%, and 17.4\% for the predicted velocities given in Tables V.7 through V.10, respectively. Weighted MNE for all 69 flows in the four tables is 15.1\%. A similar comparison has also been made for the 1982-83 data, with the corresponding MNE's being 15.2\% (12 flows), 8.5\% (13 flows), 16.5\% (13 flows), and 0.9\% (13 flows). Overall MNE for all 120 flows (1981-82 and 1982-83) is 13.9\%. It is interesting to note that the predicted velocities of the Chulitna near Talkeetna gives the best agreement (MNE = 3.94\% for 1981-82; 8.5\% for 1982-83); this is not surprising because bed seiments at this station are generally less nonuniform than the other three stations (see Fig. V.18), and therefore, the use of a single representative sediment size, \( D_{50} \), is more appropriate. With increasing nonuniformity, the representativity of bed roughness by a single sediment size (like \( D_{50} \)) becomes less and less appropriate. In view of the uncertainties in field measurements and the complexities of the sediment and geometric characteristics of the Susitna River, an average MNE of about 15\% in predicting velocities is considered reasonable.

V.3.3. Data Set. The Susitna data set was assembled jointly by the authors and Dr. Jerry Lin or Harza-Ebasco. The four essential elements of the data set--topology, geometry/topography, bed material, boundary conditions--are described below, followed by a description of the actual coded data set included in Appendix E.
Topological Data.

The nodes and links of the model, shown in Figure I.1, were defined by the authors through analysis of aerial photographs in conjunction with cross-sectional surveys. The aerial photographs, furnished to IIHR by Dr. Khalid Jawed of Harza-Ebasco, were 1:2000 scale coverage of the reach from the Chulitna confluence to Sunshine Bridge. The photos were taken on the dates and for the flow conditions shown in Table V.11. The topological layout was made by tracing well-defined channels from low to high flow, placing supplementary nodes wherever it appeared that cross-bar weir-type links might be useful in later studies. Identification of perched channels, active only at high flow, was difficult and somewhat arbitrary in some cases. Wherever possible, the cross-sections described below were used to confirm or refine the topological layout. Once the layout was complete, topological input data were prepared by first assigning numbers to the nodes and links, then manually tabulating the node-link cross-references of input data records 9 and 10. Finally, node groups were identified by sketching division lines on the topological layout, following the principles of Section II.4.6. In the interest of minimizing computational costs, only two computational points were assigned to each link, one at each end.

Geometrical and Topographical Data.

Preparation of geometrical and topographical data consisted in assigning section-type numbers and thalweg elevations to each and every computational point of the model, and defining the section-types themselves. The data for the lower portion of the model, RM 87.7 to Sunshine Bridge, were assembled by the authors and subsequently slightly revised by Dr. Lin. The data upstream of RM 87.7 were assembled entirely by Dr. Lin.

The primary source of cross-section data was the R & M Consultants report by Ashton (1984). The report contains 28 sections, measured in 1982 and 1984, roughly but never exactly perpendicular to the flow direction in individual channels, and concentrated in the upstream portion of the study reach.

The longitudinal sparseness of measured cross sections compared to the need to model individual channels led to the need for considerable judgement in assigning thalweg elevations and section-types to computational points situated some distance from measured
Table V.11.

Key to aerial photos used for topological layout

<table>
<thead>
<tr>
<th>Date</th>
<th>Discharge at Sunshine Bridge (cfs)</th>
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</thead>
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<tr>
<td>10/25/83</td>
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<tr>
<td>09/16/83</td>
<td>22,000</td>
</tr>
<tr>
<td>09/06/83</td>
<td>37,500</td>
</tr>
<tr>
<td>08/27/83</td>
<td>56,500</td>
</tr>
<tr>
<td>08/27/84</td>
<td>75,000</td>
</tr>
</tbody>
</table>
sections. General interpolation of thalwegs based on streamwise distance was employed where possible, but the resulting elevations led to obvious main channel/minor channel anomalies at junctions of flow paths having significantly different lengths. The aerial photos were used to guide assignment of section-types to points located large distances from measured sections.

Section-types were defined through manual tabulation of (elevation/width) data pairs as scaled from the measured cross-sections. As many as ten section-types were located on a given measured transect, each corresponding to a distinct individual channel. Care was taken to ensure that at high flow, the individual sections touched their neighbors to the left and right, enabling computational representation of the full valley width when bars are submerged at high flow.

Although cross-bar weirs were anticipated in the original topological layout of the model and are fully operational in the code, they have not been included in the data set as of this writing. These weirs should improve the high-flow performance of the model by allowing transverse water exchange among parallel channels.

**Bed-Sediment Data.**

As is the case for cross-section data, bed-sediment data in the study reach is too sparse to permit representation of local variations in the model data set. After analysis of all available bed-sediment data, notably that contained in the reports by Ashton (1984) and Harza-Ebasco Susitna Joint Venture (1984), a single representative bed-material size distribution was identified and assigned to all computational points. This distribution, which is close to that measured near the Sunshine Bridge in 1983, is given in Table V.12. Although some local refinement of this distribution could be developed, the effect of this refinement on long-term simulation results would be minimal.

**Boundary Conditions.**

The downstream model boundary conditions consists of a water rating curve at Sunshine Bridge. This curve was taken from the R & M Consultants report by Bredthauer
Table V.12.
Representative bed-material size distribution (D50 = 50.6 mm)

<table>
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<tr>
<th>Size Fraction k</th>
<th>Diameter Dk, mm</th>
<th>% Finer</th>
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<td>1</td>
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<td>0</td>
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<td>3</td>
<td>1.0</td>
<td>3.6</td>
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<td>5.3</td>
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<td>7</td>
<td>128.0</td>
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</tbody>
</table>
and Drage (1982), Figure A.2, with gage zero set at 253 feet msl. There appears to be some uncertainty as to whether or not this datum is correct.

The upstream boundary conditions consist of water and sediment inflows at ten inflow points: node 322 (Talkeetna); node 348 (Susitna); and nodes 329, 330, 334, 337, 341, 342, 345, and 346 (Chulitna). The water hydrographs were developed by Dr. Lin on the basis of historical data and a photo-guided flow-dependent allocation of Chulitna inflow to its multiple channels. The sediment hydrographs were based on the total-load rating curves (or sum of suspended and bed load curves) taken from the report by Harza-Ebasco Susitna Joint Venture (1984), with wash load removed according to the percentages shown in Tables V.7-V.9.

**Coded Data Set.**

Appendix E contains a listing of the actual data set employed for a 1982-83 water year simulation. This data set excludes many of the minor channels above RM 87.7 which are judged not to be of primary importance for long-term simulation. A few of the links have been represented as weir-equivalent flows at locations where excessively steep thalweg slopes caused computational anomalies. A few additional links, not shown on Figure I.1, have been added to resolve local ambiguity as to cross-bar and channel flow near junctions (notably at nodes 215 and 2151). Section and type numbers are coded to represent the river mile and sub-section number; for example section 9661 is the first (left-bank) channel at the measured section of RM 96.6.

The initial conditions for water level and discharge are consistent with the hydraulic start-up time-dependent data for negativae times -55 to 0. This start-up consists of a 5-day increase of discharges from near zero to 75,000 cfs total inflow at a pooled water surface elevation of 340 feet msl, followed by a progressive 50-day lowering of the level at Sunshine Bridge to 263.7 feet, the rating-curve elevation for 75,000 cfs. The subsequent time-dependent data from day 0 to 55 is used to generate a range of stabilized states from 75,000 cfs to 5,000 cfs, for subsequent use as restart initial conditions. The data for day 127 to 272 represent the 1982-83 water year, as compiled by Dr. Lin. The time-dependent data include an artificial "leakage" inflow at certain nodes, found and to be useful in easing the transition to dry channels at low flow.
It should be noted that model verification efforts underway as of this writing involve modification of some of the data shown in Appendix E.

V.3.4. Results Analysis. Detailed analysis of simulation results can be found in the companion report by Harza-Ebasco. The purpose of this section is to comment on the basic "health" of the model as concerns computational anomalies.

The model is subject to occasional slow convergence—even possible divergence—of the hydraulic computational at low flows. This is evidenced by discharge corrections greater than about 500 cfs at the last iteration, and/or water-level corrections arbitrarily limited to 1.0 feet. In this latter case, a list of water-level corrections at all nodes is printed; analysis of the list generally shows that only a few nodes are subject to non-convergence, usually due to a data-related low-flow or dry-bed situation. It has been the authors' experience that as long as such non-convergence remains limited to only a few nodes, its effect on long-term bed-evolution simulation is minimal. However, any generalized non-convergence usually results in a gross discharge error at the downstream boundary, with a concomitant error in sediment-transport capacity. If such a divergence persists, the long-term simulation is probably not viable. If the divergence exists for only an occasional time step, the integrity of the long-term simulation is probably not compromised.

A second computational anomaly concerns excessive bed-level changes as manifested in WARNING 1 (at nodes) and 10 (in internal and boundary reaches). There are three causes of these anomalies:

1. In a boundary reach, the given section and thalweg slope may yield a sediment-transport capacity which is quite different from the estimated imposed load. As a result, the boundary section may have to aggrade or degrade quite rapidly to accommodate itself to the imposed load. This behavior is the inevitable consequence of uncertainty as to imposed loads and the local validity of the sediment-transport relation.
2. In an internal reach, excessive bed-level change results if there is a large disparity between sediment inflow and outflow due to, for example, a major difference in cross-sectional properties from one end of the reach to the other. In this sense, a WARNING 10 is a signal that all may not be well with the point and section data. Whenever a link is on the verge of being declared dry, rather high velocities can result, leading to a possibly high net sediment inflow and thus, to a WARNING 10. Such transitory anomalies are of no importance.

3. At a node, any assumed thalweg elevations (as well as the assumed important channels) may result in such a large net sediment inflow (positive or negative) that rapid thalweg adjustment must occur to achieve sediment equilibrium. When thalweg elevations have to be grossly estimated due to the sparseness of measured sections, WARNING 1 at a node suggests that the thalweg in the point data should probably be adjusted in the direction the model itself is trying to change it.

It is impossible to categorize and discuss all possible computational anomalies in the Susitna model. Analysis of computational results requires careful consideration of any warnings, with a willingness on the part of the analyst to plunge into the results in search of an understanding of what caused the anomaly - to identify the cause giving rise to the symptoms. This is not always easy, requiring familiarity with both the theoretical notions of Chapter II and their numerical implementation in Chapter III. Yet responsible use of the Susitna model demands such diligence.
VI. CONCLUSIONS AND SUGGESTIONS FOR FURTHER DEVELOPMENT

CHARIMA has been developed on the basis of the most recently developed mathematical formulations for water and nonuniform sediment transport in multiply connected river systems. The code is designed in such a way that as new knowledge becomes available in the field of sediment transport, it can be easily incorporated. It can be used either for fixed-bed channels or for mobile-bed channels.

The validity and limitations of the code were investigated through application to three natural river systems. The principal conclusions can be summarized as follows:

1) The mathematical formulations for nonuniform sediment transport used in the code, including sediment-discharge by size fraction, sorting, and armoring procedures, are satisfactory for gradually varied flow conditions. The application to the Missouri River, with its extensive database, is a convincing example.

2) For a complex channel system such as the Susitna River, involving channels with dry-bed situations, long-term bed evolution can be simulated only with careful adjustment of the geometric data and the input sediment data.

3) Bed-evolution under highly unsteady flow conditions can be simulated using the CHARIMA code. The maximum degradation depth during passage of a flood can be predicted with some degree of accuracy.

4) For the highly unsteady case, it is appropriate to deactivate the sorting and armoring procedures.

5) Both the proposed dune-height predictors by Allen (1978) and Yalin et al. (1979) for determining the mixed-layer thickness can work equally well for the Missouri River case study.

6) Both the modified TLTM and the modified Ackers-White sediment-discharge predictors are applicable for the Missouri-River model.

The experience of the present study, suggests the following recommendations for further research:
1) A great deal of uncertainty remains about transport of nonuniform sediment under unsteady flow conditions. It seems that the most important problem involved is the separate propagation (temporal lag) of changes of the bed-material composition and the bed-level. It is recommended that experiments be performed to obtain deeper insight into these physical processes. Numerically, the variation of the bed-material composition should be fully coupled with the change of the bed level in the continuity equation.

2) The nodal sediment-continuity procedures proposed herein are based strictly on a one-dimensional approach. This may bias the natural phenomenon, since in reality the secondary current associated with curvilinear flow may be the significant factor at nodes. In addition, as discussed in Sections 7.5 and 7.6, the solution stability for the looped-channel system is strongly dependent on the nodal sediment-routing processes. In order to minimize the possible error induced by the uncertain sediment distribution at nodes, it will be necessary to carry out experiments to establish some correction-factor relations to adjust the distribution of sediment at nodes for one-dimensional modelling.

3) When TLTM is used for computing sediment discharge by size fraction, one has to calibrate the correction factors, $b_1$ and $b_2$. It will be useful for numerical modelling, if a general correction-factor relation can be established.

4) The procedures proposed herein, for transport of nonuniform sediments, require computation of the sediment discharge for each size fraction and then application of Exner's equation to compute the bed evolution for each particle size. In fact, for the small size particles which belong to the category of suspended load, it may not be appropriate to use this approach. In particular, for streams with either predominantly suspended load or bed load, it may be necessary to simulate both loads separately, recognizing the fundamentally different physics and speed of bed-load and suspended-load transport.
REFERENCES AND BIBLIOGRAPHY


Little, W.C. and Mayer, P.G., 1972, "The Role of Sediment Gradation on Channel Armoring", School of Civil Engineering, Georgia Institute of Technology, Atlanta, Georgia, May.


Appendix A

List of Variables
In the tabulated list of variables, the following numerical codes are used to indicate in which routines dimensioned arrays are used:

1. MAIN Program
2. Subroutine PILOT (entry PILOT1)
3. Subroutine USTLTM (entry USTLT1)
4. Subroutine LODMAT (entry LODMA1)
5. Subroutine SEXION (entry SECPRO)
6. Subroutine TOPOLO
7. Subroutine TLTM (entry TLTMQS)
8. Subroutine POINTS (entries SEDINP, SEDTRB)
9. Subroutine DOLINK (entries LINKS1, LINKS2)
10. Subroutine INFLOW
11. Subroutine DAHYSO (entry HYSORT)
12. Subroutine ERRWAR
13. Subroutine EXNER (entries EXNER1, EXNER2)
14. Subroutine FRICT (entry FRICT1)
15. Subroutine GAUJOR (entry INVERT)
16. Subroutine SLINKS (entry SLINK1)
17. Subroutine DONODE (entry NODES1)
18. Subroutine DAARMO (entry ARMOR)
19. Subroutine DASHIE (entry SHIELD)
20. Subroutine RAZ
21. Subroutine MATMLT (entries MATADD, MATSUB, MATVEC, SCAVEC, SCAMAT, VECVEG, VECMAT, MATEQ, VECLEN, VECEQ, TRNSPZ)
22. Subroutine COEFF (entry COEFF1)
23. Subroutine DSBC (entry DSBC1)
24. Subroutine FLOCA (entry FLOCA1)
25. Subroutine ACKERS (entry ACKQS)
26. Subroutine ENHAN (entry ENHAN1)
27. Subroutine POWFCT (entry POWFQS)
28. Subroutine USPOW (entry USPOW1)
29. Subroutine TMCHG (entry TMCHG1)
30. Subroutine USEHNA (entry USEHNA1)
31. Subroutine IWAGAK
32. Subroutine NODSD (entries NODSD1, NODSD2, NODSD3)
33. Subroutine CRITER (entry CRIT2)
34. Subroutine USACK (entry USACK1)
35. Subroutine CROISS
36. Subroutine HYSOR2

Notes:
1) Only a selection of principal variables have been catalogued, although all dimensioned arrays are shown. Recent array additions may not be shown.

2) The "Dimensions" column is used only for arrays.

3) The "TI?" column gives the variables address in the dynamic-allocation array T of the first word of the dimensioned array, where applicable.

4) The columns "a", "b", "c", etc. give the numerical codes of routines in which dimensioned arrays are used.
<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Dimensions</th>
<th>TI?</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
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Appendix B

CHARIMA

Input Data Guide
## Appendix B

**CHARIMA**

**Input Data Guide (CARDIN.DAT)**

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<td>IMAX</td>
<td>I5 (16-20)</td>
<td>Maximum number of computational points on one link</td>
</tr>
<tr>
<td></td>
<td>N1</td>
<td>I5 (21-25)</td>
<td>Exact number of sediment size classes</td>
</tr>
<tr>
<td></td>
<td>MAXG</td>
<td>I5 (26-30)</td>
<td>Maximum number of nodes in a node group</td>
</tr>
<tr>
<td></td>
<td>NGROUP</td>
<td>I5 (31-35)</td>
<td>Exact number of node groups</td>
</tr>
<tr>
<td></td>
<td>NSECS</td>
<td>I5 (36-40)</td>
<td>Exact number of section types</td>
</tr>
<tr>
<td></td>
<td>NLEVMAX</td>
<td>I5 (41-45)</td>
<td>Maximum number of levels in any A-K-R table</td>
</tr>
<tr>
<td></td>
<td>NITOUT</td>
<td>I5 (46-50)</td>
<td>Exact number of printed output dates</td>
</tr>
<tr>
<td></td>
<td>NBDT</td>
<td>I5 (51-55)</td>
<td>Number of time step changes</td>
</tr>
<tr>
<td></td>
<td>ISHEAR</td>
<td>I5 (56-60)</td>
<td>0: Shields' diagram is used</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1: Iwagaki's curve is used</td>
</tr>
<tr>
<td></td>
<td>IYALIN</td>
<td>I5 (61-65)</td>
<td>0: Allen's mixed-layer thickness predictor used</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1: Yalin's mixed-layer thickness predictor used</td>
</tr>
<tr>
<td></td>
<td>MAXBED</td>
<td>I5 (66-70)</td>
<td>Maximum number of bed layers</td>
</tr>
<tr>
<td>Var</td>
<td>Type</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>N2</td>
<td>I5</td>
<td>Item 71-75</td>
<td></td>
</tr>
<tr>
<td>MZN</td>
<td>I5</td>
<td>Item 76-80</td>
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</table>

**SUBROUTINE PILOT**

<table>
<thead>
<tr>
<th>Var</th>
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<th>Description</th>
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</thead>
<tbody>
<tr>
<td>ITBEG</td>
<td>F5.0</td>
<td>Time units at beginning of simulation (see TCONST, record 7)</td>
</tr>
<tr>
<td>ITEND</td>
<td>F5.0</td>
<td>Time units at end of simulation (see TCONST, record 7)</td>
</tr>
<tr>
<td>IDELT</td>
<td>F5.5</td>
<td>Time step (see TCONST, record 7)</td>
</tr>
<tr>
<td>ITMAX</td>
<td>I5</td>
<td>Maximum number of time steps</td>
</tr>
<tr>
<td>ITREST</td>
<td>F5.0</td>
<td>Time of restart data on file NRIN (see TCONST, record 7)</td>
</tr>
<tr>
<td>IPLINK</td>
<td>I5</td>
<td>Option for printing link topology (0 = no print)</td>
</tr>
<tr>
<td>IPNODE</td>
<td>I5</td>
<td>Option for printing node topology (0 = no print)</td>
</tr>
<tr>
<td>IPOINT</td>
<td>I5</td>
<td>Option for printing point topology (0 = no print)</td>
</tr>
<tr>
<td>IPSECT</td>
<td>I5</td>
<td>Option for printing section data (0 = no print)</td>
</tr>
<tr>
<td>NRIN</td>
<td>I5</td>
<td>Results input file (FORTRAN reference number)</td>
</tr>
<tr>
<td>NROUT</td>
<td>I5</td>
<td>Results output file (FORTRAN reference number)</td>
</tr>
</tbody>
</table>
| IUNST | I5   | 0: steady-flow computation  
1: unsteady-flow computation |
| IBUG  | I5   | 1: for expanded screen debug output  
0: otherwise |
| IRADI | I5   | 1: RN computation active  
0: RN computation not active |
| IDSBC | I5   | Downstream boundary condition  
0: water level imposed  
1: uniform flow conditions imposed |
| IUSBC | I5   | Upstream boundary condition  
0: (Karim) normal condition  
(CALL EXNER only)  
1: Cunge boundary condition  
(CALL USTLTM etc.) |
<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>MITMAT</td>
<td>I5 (1-5)</td>
</tr>
<tr>
<td></td>
<td>NBIN</td>
<td>I5 (6-10)</td>
</tr>
</tbody>
</table>
|   | IFFACT | I5 (11-15) | 1: automatic computation of friction factor  
                         0: friction factor fixed by input data  
                         -1: Strickler coefficient fixed by input data |
|   | ISEDI | I5 (16-20) | 1: sediment bed loads calculated by TLTM  
                         2: sediment bed loads calculated by Engelund Hansen  
                         3: sediment bed loads calculated by Power law  
                         4: sediment bed loads calculated by Ackers-White  
                         0: sediment loads and operations not calculated |
|   | IEXNER | I5 (21-25) | 1: bed level evolution calculated  
                         0: bed level evolution not calculated |
|   | ISORT | I5 (26-30) | 0: bed material sorting not calculated  
                         1: bed material sorting calculated by HYSORT (not available)  
                         >1: bed material sorting calculated by HYSOR2 |
|   | IARM | I5 (31-35) | 1: bed armorng calculated  
                         0: bed armorng not calculated |
|   | ITERMX | I5 (36-40) | maximum number of Newton-Raphson iterations, de St. Venant equations |
|   | ITGLMX | I5 (41-45) | maximum number of steady-flow stabilization computations in each of several progressively increasing time steps |
|   | IDTMX | I5 (46-50) | (not used) |
|   | IDTTMX | I5 (51-55) | (not used) |
|   | ISL | I5 (56-60) | sediment-calculation option  
                         0: bed-load computation only  
                         1: bed-load + suspended-load computation |
|   | LBED | I5 (61-65) | 0: bed-layer model not active  
                         1: bed-layer model active |
|   | LCONS | I5 (66-70) | 0: bed consolidation not calculated  
                         1: bed consolidation calculated |
<p>|   | MDBED | I5 (71-75) | default initial number of bed layers |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>NBSED</td>
<td>I5 (76-80)</td>
<td>default name of sed. type for bed layers</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>EPSHYD [1]</td>
<td>F10.0 (1-10)</td>
<td>threshold value (ft) of nodal water-surface changes for terminating global iterations</td>
</tr>
<tr>
<td></td>
<td>EPSQ [1]</td>
<td>F10.0 (11-20)</td>
<td>threshold value (cfs) of discharge changes for terminating global iterations</td>
</tr>
<tr>
<td></td>
<td>DRYQ</td>
<td>F10.0 (21-30)</td>
<td>discharge below which no sediment operations are computed</td>
</tr>
<tr>
<td></td>
<td>EPS</td>
<td>F10.0 (31-40)</td>
<td>threshold value (ft) used to avoid the singularity for the weir-flow computation</td>
</tr>
<tr>
<td></td>
<td>EPSYB</td>
<td>F10.0 (41-50)</td>
<td>threshold value (ft) of water-surface level change corresponding to the specified time interval during the flow stabilization</td>
</tr>
<tr>
<td></td>
<td>FDELTB</td>
<td>F10.0 (51-60)</td>
<td>base time interval for steady flow stabilization procedure, min (Default = IDELT in minutes)</td>
</tr>
<tr>
<td></td>
<td>WKB0</td>
<td>F10.0 (61-70)</td>
<td>coefficient (b0) used in TLTM (usually is 1.0)</td>
</tr>
<tr>
<td></td>
<td>WKB1</td>
<td>F10.0 (71-80)</td>
<td>coefficient (b1) used in TLTM (usually is 1.0)</td>
</tr>
<tr>
<td>6</td>
<td>SGRAV</td>
<td>F10.0 (1-10)</td>
<td>specific gravity of bed sediment</td>
</tr>
<tr>
<td></td>
<td>POROS</td>
<td>F10.0 (11-20)</td>
<td>porosity of bed sediments</td>
</tr>
<tr>
<td></td>
<td>THETA [2]</td>
<td>F10.0 (21-30)</td>
<td>time-weighting parameter $\theta$ in de St. Venant's equation</td>
</tr>
<tr>
<td></td>
<td>ADJRE [3]</td>
<td>F10.0 (31-40)</td>
<td>buffer-reach parameter for upstream sediment boundary condition</td>
</tr>
<tr>
<td></td>
<td>PHI</td>
<td>F10.0 (41-50)</td>
<td>space weighting factor $\phi$ in de St. Venant equations</td>
</tr>
<tr>
<td></td>
<td>FFIMP</td>
<td>F10.0 (51-60)</td>
<td>default initial value of roughness</td>
</tr>
<tr>
<td></td>
<td>ALIMP</td>
<td>F10.0 (61-70)</td>
<td>default $\alpha$ value in de St. Venant equation.</td>
</tr>
<tr>
<td></td>
<td>BEIMP</td>
<td>F10.0 (71-80)</td>
<td>default $\beta$ value, energy slope weighting factor in the discritized de St. Venant equation.</td>
</tr>
<tr>
<td>7</td>
<td>THETAS</td>
<td>F10.0 (1-10)</td>
<td>time weighting parameter $\theta$ in Exner's equation</td>
</tr>
</tbody>
</table>
| TCONST [24] | F10.0 (11-20) | Conversion coefficient for time units. 
| | | If time unit is: 
| | | day, TCONST = 86400. 
| | | hour, TCONST = 3600. 
| | | minute, TCONST = 60. 
| | | second, TCONST = 1. 
| DTHBED | F10.0 (21-30) | default thickness of bed layers, ft 
| SO | F10.0 (31-40) | Constant value of energy slope imposed at downstream boundary. For $IDSBC = 1$ 
| CRIT | F10.0 (41-50) | threshold value of bed level change for terminating the global iteration. 
| QSDIF | F10.0 (51-60) | diffusion coefficient for QS smoothing, ft2/sec 
| SLDIF | F10.0 (61-70) | longitudinal diffusion coefficient for suspended-load, ft2/sec. 
| ZMAXD | F10.0 (71-80) | maximum thickness of a new deposit layer, ft 

| 8 | DS | 8F10.0 | * required only if NC > 0 
| | | | standard sediment sizes (mm) 
| | | | defining size intervals (N1 + 1) values 

| 8a | J | I5 (1-5) | size-class number 

| IENTR | I5 (6-10) | 0<=$IENTR<=$10 identifies a sediment size class 
| | | | 0: for non-cohesive sediment entrainment 
| | | | 1: for cohesive sediment entrainment by the Mehta method 
| | | | $IENTR=11$ identifies heat as a constituent 
| | | | $IENTER = 21$ identifies radionuclide constituent 

| IDEP | I5 (11-15) | 0: for non-cohesive deposition 
| | | | 1: for cohesive deposition by the Mehta method 
| | | | * if $IENTR = 11$ (= IHT) 
| | | | 0: diffusion + surface heat exchange 
| | | | 1: diffusion only 
| | | | -1: no heat computation 

| ICONS | I5 (16-20) | 0: for no consolidation 
| | | | 1: for cohesive consolidation by the Mehta method 

| IDUM | I5 (21-25) | (not used) 

<table>
<thead>
<tr>
<th>IDUM</th>
<th>I5 (26-30)</th>
<th>(not used)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDUM</td>
<td>I5 (31-35)</td>
<td>(not used)</td>
</tr>
<tr>
<td>SGRAVJ</td>
<td>F5.0 (36-40)</td>
<td>specific gravity for this class (default = SGRAV)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>* if IENTR = 11 standard longitudinal dispersion coefficient (DIFL), ft²/sec</td>
</tr>
<tr>
<td>POROSJ</td>
<td>F5.0 (41-45)</td>
<td>loose porosity for this class (default = POROS)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>* if IENTR = 11 standard wind reduction factor (WRFG)</td>
</tr>
<tr>
<td>PORODJ</td>
<td>F5.0 (46-50)</td>
<td>consolidated porosity for this class (default = POROS)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>* if IENTR = 11 standard areal reduction factor (ARFG)</td>
</tr>
<tr>
<td>8b</td>
<td>PENTR(1,J)</td>
<td>F10.0 (1-10)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>* if IENTR = 11 empirical conductivity constant (RNE) Kcal-mmHg/Kg/C (default = 278.7)</td>
</tr>
<tr>
<td></td>
<td>PENTR(2,J)</td>
<td>F10.0 (11-20)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>* if IENTR = 11 empirical evaporation constant a (EVPOA) m/day/mmHg (default = 0.0)</td>
</tr>
<tr>
<td></td>
<td>PENTR(3,J)</td>
<td>F10.0 (21-30)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>* if IENTR = 11 empirical evaporation constant b (EVPOB) sec/day/mmHg (default = 0.0001802)</td>
</tr>
<tr>
<td></td>
<td>PENTR(4,J)</td>
<td>F10.0 (31-40)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>* if IENTR = 11 specific heat of water (WCP), Kcal/Kg/C (default = 1.0)</td>
</tr>
<tr>
<td>PENTR(5,J)</td>
<td>F10.0 (41-50)</td>
<td>critical shear stress of bed for erosion, lb/ft²</td>
</tr>
<tr>
<td>-----------</td>
<td>---------------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>* if IENTR = 11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>atmospheric transmission coeff. (ATRANS)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(default = 0.9)</td>
</tr>
<tr>
<td>PENTR(6,J)</td>
<td>F10.0 (51-60)</td>
<td>(not used)</td>
</tr>
<tr>
<td>8c PDEP(1,J)</td>
<td>F10.0 (1-10)</td>
<td>maximum shear stress above which no deposition can occur (critical shear stress for deposition), lb/ft²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>* if IENTR = 11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>latitude (TLATIT), degrees</td>
</tr>
<tr>
<td>PDEP(2,J)</td>
<td>F10.0 (11-20)</td>
<td>threshold concentration for flocculation lb/ft³</td>
</tr>
<tr>
<td></td>
<td></td>
<td>* if IENTR = 11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>reference altitude above sea level (BALTIT), ft</td>
</tr>
<tr>
<td>PDEP(3,J)</td>
<td>F10.0 (21-30)</td>
<td>threshold concentration above which hindering effects may occur, lb/ft³</td>
</tr>
<tr>
<td></td>
<td></td>
<td>* if IENTR = 11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>decimal day of the year corresponding to simulation time 0.0 (FJDAY)</td>
</tr>
<tr>
<td>PDEP(4,J)</td>
<td>F10.0 (31-40)</td>
<td>(not used)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>* if IENTR = 11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>clock time at the beginning of simulation (FJCLOCK), hour</td>
</tr>
<tr>
<td>PDEP(5,J)</td>
<td>F10.0 (41-50)</td>
<td>(not used)</td>
</tr>
<tr>
<td>PDEP(6,J)</td>
<td>F10.0 (51-60)</td>
<td>(not used)</td>
</tr>
<tr>
<td>8d PCONS(1,J)</td>
<td>F10.0 (1-10)</td>
<td>(not used)</td>
</tr>
<tr>
<td>PCONS(2,J)</td>
<td>F10.0 (11-20)</td>
<td>(not used)</td>
</tr>
<tr>
<td>PCONS(3,J)</td>
<td>F10.0 (21-30)</td>
<td>(not used)</td>
</tr>
<tr>
<td>PCONS(4,J)</td>
<td>F10.0 (31-40)</td>
<td>(not used)</td>
</tr>
</tbody>
</table>

* SUBROUTINE TOPOLO

<p>| 9 | LNKNAM [4] | I5 (1-5) | integer &quot;name&quot; of link |
|   | II | I5 (6-10) | number of computational points on link (II &lt;= IMAX) |
|   | MU | I5 (11-15) | integer &quot;name&quot; of node at upstream end of link |</p>
<table>
<thead>
<tr>
<th>Field</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MD</td>
<td>I5 (16-20)</td>
<td>integer &quot;name&quot; of node at downstream end of link</td>
</tr>
</tbody>
</table>
| LTYPE   | I5 (21-25) | 0: normal fluvial link  
1: weir-type link  
2: Q(t), imposed discharge  
3: Y(t), imposed upstream water level  
5: P(t) for power plant, imposed power generation |
| MSEQ   | I5 (26-30) | * if LTYPE = 0  
sequence number of meteorological zone in list of meteorological time-dependent data (file = "meteo.dat")  
* if LTYPE = 2, 3, 4, or 5  
sequence number of time-dependent data in record 23; QTR(MSEQ(L)) -- Q(t) in cfs, Y(t) in ft, or P(t) in megawatts |
| NODNAM [5] | I5 (1-5) | Integer "name" of node |
| NINQ   | I5 (6-10) | Sequence number of water inflow in list of time-dependent data in record 23.  
NINQ = 0 indicates no external inflow.  
< 0: water level (boundary nodes only)  
> 0: discharge |
| NINQS [6] [23] | I5 (11-15) | NINQS > 0 denotes sequence number of sediment inflow in list of time-dependent data.  
NINQS = 0 indicates no external sediment inflow.  
NINQS < 0 indicates power-law computation of sediment inflow, see record 14. |
| MGROUP | I5 (16-20) | node group to which NODNAM belongs |
| MPOS [7] | I5 (21-25) | (see note 5) Relative position of node in its group |
| KKK   | I5 (26-30) | number of links attached to NODNAM.  
(KKK <= KMAX) |
| LL    | 10I5 (31-80) | Integer "name" of links attached to NODNAM.  
LL = +LNKNAM  
if NODNAM is same as MU for LNKNAM.  
LL = -LNKNAM if NODNAM is same as MD for LNKNAM.  
Total number of values for one node is KKK. |
<table>
<thead>
<tr>
<th>RECORD</th>
<th>ITEM</th>
<th>DIMENSION</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>10a</td>
<td>NINCO</td>
<td>16</td>
<td>sequence number of non-sediment constituent inflow data QTR(NINCO(M,J)) in record 23, by constituent</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>* required only if N2 &gt; 0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>* if IENTR = 21 sequence numbers must be provided for dissolved RN, suspended-sed. carried RN, and mixed-layer-sed carried RN.</td>
</tr>
</tbody>
</table>

**SUBROUTINE POINTS**

<table>
<thead>
<tr>
<th>RECORD</th>
<th>ITEM</th>
<th>DIMENSION</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>LNKNAM[8][15]</td>
<td>I5 (1-5)</td>
<td>Integer &quot;name&quot; of link</td>
</tr>
<tr>
<td></td>
<td>I</td>
<td>I5 (6-10)</td>
<td>Number of computational point</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>I &lt;= II, see record 9</td>
</tr>
<tr>
<td></td>
<td>NSEC</td>
<td>I5 (11-15)</td>
<td>Number of section-type associated with this point. NSEC &lt;= NSEC</td>
</tr>
<tr>
<td></td>
<td>NSED</td>
<td>I5 (16-20)</td>
<td>Number of sediment-type associated with this point. (see record 12)</td>
</tr>
<tr>
<td></td>
<td>RM [9]</td>
<td>F10.0 (21-30)</td>
<td>River station (miles) of this point</td>
</tr>
<tr>
<td></td>
<td>TALWEG</td>
<td>F10.0 (31-40)</td>
<td>Elevation (ft) of lowest point in cross section</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>* if LTYPE = 1 &amp; I = 1 weir crest elevation, ft</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>* if LTYPE = 1 &amp; I = 2 weir crest width, ft</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>* if LTYPE = 5 &amp; I = 1 constant condenser flow rate, cfs (CFR)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>* if LTYPE = 5 &amp; I = 2 nameplate power generation, Mw (RPG)</td>
</tr>
<tr>
<td></td>
<td>FFACT [10]</td>
<td>F5.0 (41-45)</td>
<td>Initial estimate of roughness (default = FFIMP)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>* if LTYPE = 5 &amp; I = 1 nameplate heat rejection rate, $10^6$ BTU/hr (HRR)</td>
</tr>
<tr>
<td></td>
<td>ALPHA [15]</td>
<td>F5.0 (46-50)</td>
<td>Kinetic energy coefficient $\alpha$ in Eq. (II.14) (default = ALIMP)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>* if LTYPE = 1 &amp; I = 1 discharge coefficient, flooded case</td>
</tr>
<tr>
<td><strong>BETA [15]</strong></td>
<td>F5.0 (51-55)</td>
<td>Energy slope weighting factor $\beta$ in Eq. (II.14) (default = BEIMP)</td>
<td></td>
</tr>
<tr>
<td>---------------</td>
<td>---------------</td>
<td>-------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>FX</strong></td>
<td>F5.0 (56-60)</td>
<td>Longitudinal dispersion coefficient, ft$^2$/sec (default = DIFL)</td>
<td></td>
</tr>
<tr>
<td><strong>WRF</strong></td>
<td>F5.0 (61-65)</td>
<td>Wind reduction factor (default = WRFG)</td>
<td></td>
</tr>
<tr>
<td><strong>ARF</strong></td>
<td>F5.0 (66-70)</td>
<td>Areal reduction factor (default = ARFG)</td>
<td></td>
</tr>
<tr>
<td><strong>BANK</strong></td>
<td>F5.0 (76-80)</td>
<td>Constant bank erosion rate (ft3/day/mile)</td>
<td></td>
</tr>
<tr>
<td><strong>11a</strong></td>
<td></td>
<td><strong>Y</strong>  F10.0 (1-10)</td>
<td>Initial estimate of water surface elevation (ft)</td>
</tr>
<tr>
<td><strong>Q</strong></td>
<td>F10.0 (11-20)</td>
<td>Initial estimate of water discharge (cfs), list of initial values of concentration by non-sediment constituent, N2 values</td>
<td></td>
</tr>
<tr>
<td><strong>CSL</strong></td>
<td>T21,6F10.0</td>
<td>(following Q)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>12</strong></td>
<td></td>
</tr>
<tr>
<td><strong>NSEDT [11]</strong></td>
<td>I5 (1-5)</td>
<td>Integer &quot;name&quot; of bed sediment type</td>
<td></td>
</tr>
<tr>
<td><strong>PTYP</strong></td>
<td>T6, 15F5.0</td>
<td>Cumulative distribution function relative to standard sediment sizes of bed materials DS (record 8) N1 +1 values, expressed as fraction, $0 \leq PTYP \leq 1$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(6-80)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>13</strong></td>
<td></td>
</tr>
<tr>
<td><strong>NODNAM [22]</strong></td>
<td>I5 (1-5)</td>
<td>Node name</td>
<td></td>
</tr>
<tr>
<td><strong>NODSTT</strong></td>
<td>I5 (6-10)</td>
<td>Nodal sediment type (dummy)</td>
<td></td>
</tr>
<tr>
<td><strong>PTYP</strong></td>
<td>T11,14F5.0</td>
<td>Cumulative size distribution for tributary inflow to nodes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(11-80)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SUBROUTINE RDACBC</strong></td>
<td></td>
<td>* required only if N1 &gt; 0</td>
<td></td>
</tr>
<tr>
<td><strong>14</strong></td>
<td></td>
<td><strong>AC, BC [20]</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2F14.0 (1-28)</td>
<td>Coefficients for tributary sediment inflow rating function</td>
<td></td>
</tr>
<tr>
<td><strong>SUBROUTINE SEXION</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>15</strong></td>
<td></td>
<td><strong>NUMSEC [12]</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>I5 (1-5)</td>
<td>Number of section type</td>
<td></td>
</tr>
<tr>
<td><strong>NLEVEL</strong></td>
<td>I5 (6-10)</td>
<td>Number of levels in A-K-R table</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td><strong>DH</strong></td>
<td>F10.0 (11-20)</td>
<td>Vertical interval (ft) in A-K-R table</td>
<td></td>
</tr>
<tr>
<td><strong>TITLE</strong></td>
<td>15A4 (21-80)</td>
<td>Character string naming the cross section</td>
<td></td>
</tr>
<tr>
<td><strong>ISEC</strong></td>
<td>I5 (1-5)</td>
<td>=0: sections given as pairs of &quot;level-width&quot; =1: sections given as pairs of &quot;distance-bed level&quot;</td>
<td></td>
</tr>
<tr>
<td><strong>NBSEC</strong></td>
<td>I5 (6-10)</td>
<td>Number of pairs (without gaps of course)</td>
<td></td>
</tr>
<tr>
<td><strong>Z, B or X, Y</strong></td>
<td>8F10.0 (1-80)</td>
<td>(level, width)pairs when ISEC=0 or(distance,level) when ISEC=1 defining the section, (ft). Up to four pairs per record, all records filled except, possibly, the last one.</td>
<td></td>
</tr>
<tr>
<td><strong>Z</strong></td>
<td>F10.0 (1-10)</td>
<td>Required value = -1.0 Marks the end of (level, width) data for this section.</td>
<td></td>
</tr>
<tr>
<td><strong>SUBROUTINE PILOT</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ITOUT</strong></td>
<td>16F5.5 (1-80)</td>
<td>* required only if NITOUT &gt; 0 List of times at which printed output is desired, in units specified by TCONST (record 7) number of dates = NITOUT</td>
<td></td>
</tr>
<tr>
<td><strong>ITIME, IDELT [18]</strong></td>
<td>8(2F5.5) (1-80)</td>
<td>* required only if NBDT &gt; 0 Pairs of (time - new time step) data, NBDT pairs, in units specified by TCONST (record 7)</td>
<td></td>
</tr>
<tr>
<td><strong>SUBROUTINE DAARMO</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>IARMOR</strong></td>
<td>I5 (1-5)</td>
<td>0: armoring size specified directly 1: automatic determination of armoring size</td>
<td></td>
</tr>
<tr>
<td><strong>MIND</strong></td>
<td>I5 (6-10)</td>
<td>If IARMOR = 0, number of smallest sediment size fraction in armor layer.</td>
<td></td>
</tr>
<tr>
<td><strong>QMAX</strong></td>
<td>F10.0 (11-20)</td>
<td>If IARMOR = 1 and IQMAX =0, constant discharge used to determine armor size.</td>
<td></td>
</tr>
<tr>
<td><strong>IQMAX</strong></td>
<td>I5 (21-25)</td>
<td>If IARMOR = 1, 0: armor size determined using QMAX 1: armor size determined using local Q</td>
<td></td>
</tr>
<tr>
<td><strong>IACF</strong></td>
<td>I5 (26-30)</td>
<td>0: all armoring factors set initially to zero 1: initial armoring factor read</td>
<td></td>
</tr>
</tbody>
</table>
| KARM | I5 (31-35) | Index for modifying armoring coefficient (CARM):
|      |           | 0: specified values
|      |           | 1: using Gessler's relation
|      |           | 2: using bed-load method
|      |           | 3: both Gessler's and bed-load methods
|      |           | 4: using dune-height method
|      |           | 5: both Gessler's and dune-height method
|      |           | see p. 63, IIHR #281
| C1   | F10.0 (36-45) | coefficient for bed-load method
| CARM | F10.0 (46-55) | armoring coefficient
| 22   | ARM [21]   | 16F5.0 (1-80) * required only if IACF = 1
|      |            | initial armor-covered area by size fraction

**SUBROUTINE INFLOW**

| 23   | ITDAT [14] | F10.0 (1-10) | date (time units) of time-dependent data (see TCONST, record 7)
|      | TFREAD     | F5.0 (11-15) | water temperature, °F. (for sediment only)
|      | YREAD      | F5.0 (16-20) | w/s level (ft) at the u/s end, used as w/s B.C.
|      |            |             | if super critical flow occurs (usually not used)
|      | QTRIB [23] | T21.6F10.0  | List of data, eg. w/s level (ft), water inflows (cfs) or sediment inflows (cfs) in a sequence consistent with the NINQ and NINQS sequence numbers assigned to nodes (see record 10)
### Input Data Guide (meteo.dat)

<table>
<thead>
<tr>
<th>record type</th>
<th>variable name</th>
<th>Format (columns)</th>
<th>Variable description and remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>* SUBROUTINE METMGT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>ITDAT</td>
<td>F10.0 (1-10)</td>
<td>date of time-dependent data (in units specified by TCONST)</td>
</tr>
<tr>
<td></td>
<td>TA</td>
<td>T11.3(4F10.0) (11-130)</td>
<td>air temperature, F</td>
</tr>
<tr>
<td></td>
<td>VENT</td>
<td></td>
<td>wind speed (2m above water surface), ft/s</td>
</tr>
<tr>
<td></td>
<td>CCOVER</td>
<td></td>
<td>cloud cover (fraction)</td>
</tr>
<tr>
<td></td>
<td>FI</td>
<td></td>
<td>relative humidity (fraction)</td>
</tr>
</tbody>
</table>

### Input Data Guide (layers.dat)

<table>
<thead>
<tr>
<th>record type</th>
<th>variable name</th>
<th>Format (columns)</th>
<th>Variable description and remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>* SUBROUTINE RDSTRATA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>LNKNam [25]</td>
<td>I5 (1-5)</td>
<td>integer &quot;name&quot; of link</td>
</tr>
<tr>
<td></td>
<td>NBEL</td>
<td>I5 (11-15)</td>
<td>number of layers (default = MDBED)</td>
</tr>
<tr>
<td></td>
<td>&lt; 0 : default NBSED, DTHBED used for [NBEL] layers (do not provide space for these)</td>
<td>overrides default MDBED</td>
<td></td>
</tr>
<tr>
<td></td>
<td>= 0 : no bed layer at this reach</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; 0 : NBEL pairs of (NBSED, THBED) should be given explicitly</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NBSED</td>
<td>T21.6(I5,F5.0) (21-80)</td>
<td>name of sed. type associated with a layer (default = NBSED)</td>
</tr>
<tr>
<td></td>
<td>THBED</td>
<td></td>
<td>thickness of this layer (default = DTHBED)</td>
</tr>
</tbody>
</table>
Notes for Input Data Guide

[1] Typical value of EPSHYD is 0.005 ft. Typical value of EPSQ is 1.0 cfs.

[2] Typical value of THETA is 0.55 for unsteady flow, or 1.0 for steady flow.

[3] Typical value of ADJRE is 1.0.

[4] One record 9 for each of LINKS links. Last record must have LNKNAM < 0, but the link name is [LNKNAM]. Order is irrelevant.

[5] One record 10 for each of NODES nodes. Last record must have NODNAM < 0, but the node name is [NODNAM].

[6] The bed layer model includes both user specification of initial subsurface bed strata; and progressive laydown of deposition strata. Layers are numbered sequentially from bottom to top; the first (bottom) layer is taken as infinitely thick (same as parent bed material if LBED=0). The last (top) layer is the one in contact with the mixed layer; its layer number must not exceed MAXBED (record 2), whether this number arises from the initial condition or from multiple deposition layers during the simulation. The maximum thickness of a deposition layer is specified as ZMAXD (record 7).

Layers are associated with computational reaches, not points. The default initial condition is that all reaches are initialized with MDBED (record 4) subsurface layers, each of thickness DTHBED (record 7) and sediment size distribution NBSED (record 4). This default condition is overridden for particular reaches by data in the file 'layers.dat'.

[7] Note that MGROUP and MPOS need simply follow increasing integer sequences, beginning with 1.

[8] One record 11 for each computational point on each link. Last record must have LNKNAM < 0. Order is irrelevant. See note 15 also.

[9] River mile is used only for labelling output and computing distances between adjacent points of a given reach. River miles must increase in an upstream direction, and refer to a common origin for any individual link.

[10] Note that if parameter IFFACT (record 4) is -1 or 0, then the given value of FFACT is used for the entire computation. If FFACT = 0, the default value FFIMP (record 6) is adopted. FFACT and FFIMP represent stickler coefficients or friction factors depending on the value of IFFACT < 0 or IFFACT ≥ 0, respectively.

[11] One record 12 for each bed-sediment type appearing in the point data (parameter NSED, record 11). Last record must have NSEDV < 0. Order is irrelevant.

[12] One record 15 followed by one or more records 16 and 17, for each of NSECS (record 2) section types.

[14] Records 22 are read as required during the simulation, time-dependent data for time ITIME are interpolated between adjacent dates ITDAT encountered on type 18 records. Thus at least two records 18 are required, and (ITDAT) first <= ITIME <= (ITDAT) last, where ITIME varies from the first to the last day of the simulation.
[15] For the points on a link which is a weir (LTYPE = 1, record 9), the record-9 data have the following interpretations:
   For point 1: NSEC, NSED, RM, FFACT not used
   \( TALWEG = \) weir crest elevation, ft.
   \( ALPH(A = \) discharge coefficient, flooded case.
   \( BETA = \) discharge coefficient, free-flowing case.
   For point 2: NSEC, NSED, RM, FFACT, ALPH(A, BETA not used
   \( TALWEG = \) weir crest width, ft.

[16] ITMAX is a protection device, the simulation is terminated when ITIME \( \geq \) ITEND or IT \( \geq \) ITMAX.

[17] By convention, negative times are taken to be periods initial-state stabilization, in which only hydrodynamic computations are performed. All time units must be consistent with TCONST.

[18] Record 20 is furnished only for NBDT>0. (see record 2)

[19] If NRIN \( > \) 0, the program replaces all model data with the result read on file NRIN at date ITREST. With one exception, all normal data records must be furnished, even though much of it is redundant. In particular:
   (a) Type 8 records (standard sediment size) must be furnished, but the program adopts the sized read on NRIN.
   (b) Type 9 records (link topology) must be furnished, and must be identical to those used in the run which created the NRIN file. (However the link type, LTYPE, can be changed without perturbing the topology of the model. If LTYPE is changed, the type 11 records must be changed accordingly.)
   (c) Type 10 records (node topology) must be furnished, and must be identical to those used in the run which created the NRIN file. (However a node's boundary inflow status, NINQ or NINQS, can be changed without perturbing the topology of the model. If NINQ or NINQS are changed, the type 22 records must be changed accordingly.)
   (d) Type 11 records (point data) need be furnished only for points at which some modification is effected. In this case, the data on the record replace the data read on NRIN. (The sediment type, MSED, must not be changed). If no point modification are desired, furnish one record with LNKNAM = -9999.
   (e) Type 12 records (sediment distributions) must be read, but are not used. The program adopts the distributions read on NRIN.
   (f) Type 15 records (section definitions) must be read, and can be modified in principle.

[20] One set of coefficients for each node having NINQS < 0 (see record 10) in the same order as node definitions. BC is the dimensionless exponent of the discharge (cfs) in the equation \( QS = AC \cdot Q^{BC} \); AC has units of tons/day.

[21] Read only if IACF = 1 and then only if LTYPE = 0. One or more data records for each link; initial armor factor by size fraction.
[22] Only for nodes which receive time-dependent tributary sediment inflow, NINQS > 0. The last NODNAM is set negative to signify the end of record 13; alternatively, a special NODNAM=9999 can be used to signify the end.

[23] Normally, for NINQS > 0, the imposed sediment inflow for upstream boundary, or tributary, nodes is furnished in the time-dependent data records (type 22), in the NINQS position of the QTRIB array. However if NINQS < 0, this signifies that the boundary (or tributary) sediment inflow is computed for all such nodes using a power law whose coefficients are given by data record 14. In this case, the subroutine INFLOW automatically computes the sediment inflow and loads it into the |NINQS| position of the QTRIB array for the node. Thus, any furnished values for QTRIB (NINQS) are always replaced by the power-law computed values. This also implies that the |NINQS| value assigned to sediment-inflow nodes must be the sequence number immediately following the NINQ value for the node.

[24] The value of TCONST sets the time units in all input/output operations. For example, if TCONST = 3600, all user times are taken to be in hours.

[25] Only for points which have non-default bed layers. Last record must have LNKNAM < 0, but the link name is | LNKNAM |. Order is irrelevant. A special LNKNAM=9999 can be used to signify the end.
Appendix C

Key to Error and Warning Messages in CHARIMA

Generic Messages:

WARNING NO. \( (\ ) IT = (\ ) ID1 = (\ ) ID2 = (\ ) PARAM = (\ )\)

ERROR NO. \( (\ ) IT = (\ ) ID1 = (\ ) ID2 = (\ ) PARAM = (\ )\)

\( IT = \) Time step number. ID1, ID2, PARAM are defined in the context of the particular message.
KEY TO ERROR MESSAGES

Error No. 1  Non-increasing elevation or width in (Z,B) pair section data. ID1 = number of section type; ID2 = sequence No. of data; PARAM = width.

Error No. 2  Singular matrix detected in GAUJOR (fatal). ID1 = node group number; ID2 not used; PARAM = determinant.

Error No. 3  Memory size used for storing section data exceeds the residual memory size (i.e., MEMO - ILAST). ID1 = section number; ID2 = elevation-width data sequence number; PARAM not used.

Error No. 4  Data apparently not furnished for point ID2 of link ID1. PARAM not used.

Error No. 5  Bed-sediment data apparently not furnished for point ID2 of link ID1 PARAM not used.

Error No. 6  Number of links read not equal to LINKS. ID1 = number of links read; ID2, PARAM not used.

Error No. 7  Number of nodes read not equal to NODES. ID1 = number of nodes read; ID2, PARAM not used.

Error No. 8  Data furnished for point ID2 of a non-existent link ID1; PARAM not used.

Error No. 9  Link definition ID1 (record 8) calls for a number of points ID2 greater than IMAX. PARAM not used.

Error No. 10 Definition of node ID1 (record 9) calls for number of connect-links ID2 greater than KMAX. PARAM not used.

Error No. 11 Definition of node ID1 (record 9) calls for ID2 = MPOS greater than MAXG. PARAM not used.

Error No. 12 Definition of node ID1 (record 9) calls for ID2 = MGROUP greater than NGROUP. PARAM not used.

Error No. 13 Definition of link ID1 (record 8) refers to an MU, MD, or both which are not themselves defined as nodes. ID2, PARAM not used.

Error No. 14 Link ID1 represents an illegal connection between node groups as defined by MU, MD. ID2, PARAM not used.

Error No. 15 Definition of node ID1 refers to a link name ID2 which is not defined. PARAM not used.

Error No. 16 Definition of node ID1 refers to a link name ID2 neither of whose MU or MD refer to this node. PARAM not used.

Error No. 17 Point ID2 of link ID1 refers to nonexistent section name. PARAM not used.
Error No. 18  Link ID1 was defined more than once. ID2, PARAM not used.

Error No. 19  Reach ID2 of link ID1 has a length PARAM which is zero or negative.

Error No. 20  Link ID1 has an MU or MD (ID2) which is inconsistent with the corresponding node definitions.

Error No. 21  Requested restart time ID1 is not found on file NRIN. Last time read on NRIN is ID2.

Error No. 22  Fatal Warning No. 6 (excessive depth).

Error No. 24  In input data record 13, a given NODNAM=ID1 is not found in the model. ID2, PARAM are not used.

Error No. 25  In input data record 8a (RDSED.FOR), constituent index J differs from JCLASS for non-radionuclide constituent IENTR(J).

Error No. 26  A tributary size distribution was given for a node which was defined as not having tributary inflow.

Error No. 27  The number of levels exceeded the maximum number of levels to be read. ID1 = NLEVMAX, ID2 = NLEV, PARAM not used. (fatal)

Error No. 28  A tributary-inflow sediment size distribution must be furnished for node ID1. ID2, PARAM are not used.

Error No. 29  In input data record 8a, for radionuclide constituent J, associated sediment-class index IDEP(J) greater than the total number of sediment classes N1. (manual input of sediment-associated RN classes)

Error No. 30  In input data record 8a, for radionuclide-constituent J, associated bed-layer index ICNS(J) greater than the total number of layers + 1. (manual input of sediment-associated RN classes.)

Error No. 31  Number of bed layers (PARAM) at point ID2, link ID1 is larger than MAXBED, because of the new deposit layers.

Error No. 32  Number of bed layers (PARAM) at point ID2, link ID1 given in layers.dat is larger than MAXBED

---

KEY TO WARNING MESSAGES

Warning No. 1  Bed-level change PARAM at node ID1 appears excessive, and is thus limited to 1 foot; ID2 not used.

Warning No. 2  Points associated with a node having only 2 links attached have different section numbers ID1 = node name; ID2, PARAM not used.

Warning No. 3  In HYSOR2, mixed-layer thickness PARAM for point ID2 of link ID1 appears excessively large, and is limited to 15% of the depth.

Warning No. 4  In HYSOR2, sum of size-class fractions PARAM for point ID2 of link ID1 is not unity.
Warning No. 5  Not used.

Warning No. 5  Depth at point ID2 of link ID1 is greater than NLEVEL * DH for the section allocated to the point. PARAM = depth. Areas, conveyances, hydraulic radii, widths are extrapolated upwards.

Warning No. 6  In subroutine RDSED, constituent J assigned as class JCL SS, with IENTR(J)

Warning No. 7  Definition of node ID1 refers to a link ID2 whose MU or MD appears inconsistent with the sign of this link as defined with the node. PARAM not used.

Warning No. 8  Armoring factor PARAM for point ID2 of link ID1 is greater than 0.98. Armoring factor reset to 0.98.

Warning No. 9  Dry bed conditions detected at point ID2 of boundary link ID1. PARAM = discharge. Bed elevation is left unchanged.

Warning No. 10  Bed-level change PARAM at point ID2 of link ID1 appears excessive, and is thus limited to 1 foot.

Warning No. 11  Point ID2 of link ID1 has a tendency for excessively large sediment load PARAM. The individual size fraction component is set to zero.

Warning No. 15  Depth of scouring PARAM at point ID2 of link ID1 is larger than 2 layers thick

Warning No. 16  Depth of deposition PARAM at point ID2 of link ID1 is larger than 2 layers thick
<table>
<thead>
<tr>
<th>Parameter</th>
<th>J</th>
<th>IENTR</th>
<th>IDEP</th>
<th>ICONS</th>
<th>SGRAVJ</th>
<th>POROSJ</th>
<th>PORODJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Format</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>F5.0</td>
<td>F5.0</td>
<td>F5.0</td>
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<tr>
<td>Columns</td>
<td>1-5</td>
<td>6-10</td>
<td>11-15</td>
<td>16-20</td>
<td>36-40</td>
<td>41-45</td>
<td>46-50</td>
</tr>
<tr>
<td>Non-Cohesive Sediment</td>
<td>1</td>
<td>N1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Specific gravity (SGRAV)</td>
<td>Loose porosity (POROS)</td>
</tr>
<tr>
<td>Cohesive Sediment</td>
<td>1</td>
<td>N1</td>
<td>1 Mehta</td>
<td>1 Mehta</td>
<td>1 Mehta</td>
<td>Specific gravity (SGRAV)</td>
<td>Loose porosity (POROS)</td>
</tr>
<tr>
<td>Heat</td>
<td>&gt;N1</td>
<td>11 Not used</td>
<td>not used</td>
<td>Long. diff. (ft2/sec)</td>
<td>Wind red. fact. (POROS)</td>
<td>Area red. fact. (POROS)</td>
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<td>Adsorbed Radionuclide</td>
<td>&gt;N1</td>
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<td>PENTR(3)</td>
<td>PENTR(4)</td>
<td>PENTR(5)</td>
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<td>not used</td>
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<td>partially consol. beds</td>
<td>surf eros rate (lb/ft²/sec)</td>
<td>sealed beds</td>
<td>mass erosion rate (lb/ft²/sec)</td>
<td>crit excess bed shear for mass erosion (lb/ft²)</td>
<td>crit bed shear for erosion (lb/ft²)</td>
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<td>evap. const b (sec/day/mmHg) [0.0001802]</td>
<td>water specific heat (Kcal/Kg/C) [1.0]</td>
<td>atmos. trans. coeff (°) [0.9]</td>
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<td>dissolved - susp. sed. distr. coefficient (ft³/lb)</td>
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<td>dissolved - bed attached distr. coeff. (ft³/lb)</td>
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<td>threshold conc for hindering (lb/ft³)</td>
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<td>reference altitude above sea level (ft)</td>
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<td>clock time at beginning of simulation (decimal hours)</td>
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Appendix C

Key to Error and Warning Messages in CHARIMA

Generic Messages:

WARNING NO.  ( ) IT = ( ) ID1 = ( ) ID2 = ( ) PARAM =
( )

ERROR NO.   ( ) IT = ( ) ID1 = ( ) ID2 = ( ) PARAM = ( )

IT = Time step number. ID1, ID2, PARAM are defined in the context of the particular message
### KEY TO ERROR MESSAGES

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<tr>
<th>Error No.</th>
<th>Description</th>
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<tr>
<td>1</td>
<td>Non-increasing elevation or width in (Z,B) pair section data. ID1 = number of section type; ID2 = sequence No. of data; PARAM = width.</td>
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<tr>
<td>2</td>
<td>Singular matrix detected in GAUJOR (fatal). ID1 = node group number; ID2 not used; PARAM = determinant.</td>
</tr>
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<td>3</td>
<td>Memory size used for storing section data exceeds the residual memory size (i.e., MEMO - ILAST). ID1 = section number; ID2 = elevation-width data sequence number; PARAM not used.</td>
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<tr>
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<td>Data apparently not furnished for point ID2 of link ID1. PARAM not used.</td>
</tr>
<tr>
<td>5</td>
<td>Bed-sediment data apparently not furnished for point ID2 of link ID1. PARAM not used.</td>
</tr>
<tr>
<td>6</td>
<td>Number of links read not equal to LINKS. ID1 = number of links read; ID2, PARAM not used.</td>
</tr>
<tr>
<td>7</td>
<td>Number of nodes read not equal to NODES. ID1 = number of nodes read; ID2, PARAM not used.</td>
</tr>
<tr>
<td>8</td>
<td>Data furnished for point ID2 of a non-existent link ID1. PARAM not used.</td>
</tr>
<tr>
<td>9</td>
<td>Link definition ID1 (record 8) calls for a number of points ID2 greater than IMAX. PARAM not used.</td>
</tr>
<tr>
<td>10</td>
<td>Definition of node ID1 (record 9) calls for number of connect-links ID2 greater than KMAX. PARAM not used.</td>
</tr>
<tr>
<td>11</td>
<td>Definition of node ID1 (record 9) calls for ID2 = MPOS greater than MAXG. PARAM not used.</td>
</tr>
<tr>
<td>12</td>
<td>Definition of node ID1 (record 9) calls for ID2=MGROUP greater than NGROUP. PARAM not used.</td>
</tr>
<tr>
<td>13</td>
<td>Definition of link ID1 (record 8) refers to an MU, MD, or both which are not themselves defined as nodes. ID2, PARAM not used.</td>
</tr>
<tr>
<td>14</td>
<td>Link ID1 represents an illegal connection between node groups as defined by MU, MD. ID2, PARAM not used.</td>
</tr>
<tr>
<td>15</td>
<td>Definition of node ID1 refers to a link name ID2 which is not defined. PARAM not used.</td>
</tr>
<tr>
<td>16</td>
<td>Definition of node ID1 refers to a link name ID2 neither of whose MU or MD refer to this node. PARAM not used.</td>
</tr>
<tr>
<td>17</td>
<td>Point ID2 of link ID1 refers to nonexistent section name. PARAM not used.</td>
</tr>
</tbody>
</table>
Error No. 18  Link ID1 was defined more than once. ID2, PARAM not used.
Error No. 19  Reach ID2 of link ID1 has a length PARAM which is zero or negative.
Error No. 20  Link ID1 has an MU or MD (ID2) which is inconsistent with the corresponding node definitions.
Error No. 21  Requested restart time ID1 is not found on file NRIN. Last time read on NRIN is ID2.
Error No. 22  Fatal Warning No. 6 (excessive depth).
Error No. 24  In input data record 13, a given NODNAM=ID1 is not found in the model. ID2, PARAM are not used.
Error No. 25  In input data record 8a (RDSED.FOR), constituent index J differs from JCLASS for non-radionuclide constituent IENTR(J).
Error No. 26  A tributary size distribution was given for a node which was defined as not having tributary inflow.
Error No. 27  The number of levels exceeded the maximum number of levels to be read. ID1 = NLEVMX, ID2 = NLEV, PARAM not used. (fatal)
Error No. 28  A tributary-inflow sediment size distribution must be furnished for node ID1. ID2, PARAM are not used.
Error No. 29  In input data record 8a, for radionuclide constituent J, associated sediment-class index IDEP(J) greater than the total number of sediment classes N1. (manual input of sediment-associated RN classes)
Error No. 30  In input data record 8a, for radionuclide-constituent J, associated bed-layer index ICONS(J) greater than the total number of layers + 1. (manual input of sediment-associated RN classes.)
Error No. 31  Number of bed layers (PARAM) at point ID2, link ID1 is larger than MAXBED, because of the new deposit layers.
Error No. 32  Number of bed layers (PARAM) at point ID2, link ID1 given in layers.dat is larger than MAXBED

KEY TO WARNING MESSAGES

Warning No. 1  Bed-level change PARAM at node ID1 appears excessive, and is thus limited to 1 foot; ID2 not used.
Warning No. 2  Points associated with a node having only 2 links attached have different section numbers ID1 = node name; ID2, PARAM not used.
Warning No. 3  In HYSOR2, mixed-layer thickness PARAM for point ID2 of link ID1 appears excessively large, and is limited to 15% of the depth.
Warning No. 4  In HYSOR2, sum of size-class fractions PARAM for point ID2 of link ID1 is not unity.
Warning No. 5  Not used.

Warning No. 5  Depth at point ID2 of link ID1 is greater than NLEVEL * DH for the section allocated to the point. PARAM = depth. Areas, conveyances, hydraulic radii, widths are extrapolated upwards.

Warning No. 6  In subroutine RDSED, constituent J assigned as class JCL SS, with IENTR(J)

Warning No. 7  Definition of node ID1 refers to a link ID2 whose MU or MD appears inconsistent with the sign of this link as defined with the node. PARAM not used.

Warning No. 8  Armoring factor PARAM for point ID2 of link ID1 is greater than 0.98. Armoring factor reset to 0.98.

Warning No. 9  Dry bed conditions detected at point ID2 of boundary link ID1. PARAM = discharge. Bed elevation is left unchanged.

Warning No. 10  Bed-level change PARAM at point ID2 of link ID1 appears excessive, and is thus limited to 1 foot.

Warning No. 11  Point ID2 of link ID1 has a tendency for excessively large sediment load PARAM. The individual size fraction component is set to zero.

Warning No. 15  Depth of scouring PARAM at point ID2 of link ID1 is larger than 2 layers thick

Warning No. 16  Depth of deposition PARAM at point ID2 of link ID1 is larger than 2 layers thick
Appendix D
CHARIMA Program

Structure of Results Output File
### Structure of Results Output File

<table>
<thead>
<tr>
<th>Record</th>
<th>Contents</th>
<th>Length (words)</th>
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<tbody>
<tr>
<td>1</td>
<td>TITLE</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>NODES,KMAX,LINKS,IMAX,N1,NSEC,NLEVMAX,NGROUP</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>NS(J),J=1,N1+1</td>
<td>N1+1</td>
</tr>
<tr>
<td>4</td>
<td>MU(LINKS),MD(LINKS),LL(NODES,KMOAX),KK(NODES),LTYPE(LINKS),YN(NODES),Y</td>
<td>LINKS*(5+IMAX)+</td>
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<tr>
<td></td>
<td>(IMAX,LINKS),NINQ(NODES),NINQS(NODES),MPOS(NODES),MGROUP(NODES),</td>
<td>+NODES*(7+KMAX)+</td>
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<td></td>
<td>NGSIZE(NGROUP),NODNAM(NODES),LNKNAM(LINKS),II(LINKS)</td>
<td>+GROUP</td>
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<td>5</td>
<td>IT,ITIME,ITHYD,DYNMAX,DQMAX,IDE LT</td>
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</tr>
<tr>
<td>6</td>
<td>L,I,DRYBED,Y,Q,VEL,RH,WIDTH,TALWEG,</td>
<td>22</td>
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<tr>
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<td>QSTOT,FFACT,ACF,D5OP,SF,VOLOUT,CDEP,D5OR,NSEC,RM,ALPHA,BETA,TALWGI</td>
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<tr>
<td>7</td>
<td>(PT(J),ARM(J),QS(J),J=1,N1)</td>
<td>3*N1</td>
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</table>

* One type 5 record for each time step
** One type 6 record and one type 7 record for each point of each link, for each time step (5-6-7-6-7-6-7...-5-6-7-6-7...etc.)
Appendix E

SAMPLE DATA SET
Note: Links not to scale.
This example data set includes the Job Control Language (JCL) for execution on an IBM mainframe with VS operating system.

```plaintext
//AEGRIN JOB (40), 'IIHR RFE', MSGLEVEL=(1,1), TIME=10, CLASS=0
/*PASSWORD
// EXEC FORTVCILG, PARM.FORT='NOMAP, LANGLVL(77), NOSOURCE, NOXREF',
// PARM.LKED='NOLIST, NOMAP, SIZE=(600K, 64K), LET', REGION.LKED=1600K,
// FVRGN=1600K, REGION.GO=3000K,
// PARM.GO='NOXFLOW'
//FORT.SYSIN DD *
  Any source-code modifications to objec-module library
  would be inserted here.
*/
/*LKED.SYSLMOD DD DSN=USER.AEG.FOR.CHARLIB(CHARIMA), DISP=SHR
//LKED.SYSPRINT DD SYSOUT=A
//LKED.SYSUT1 DD UNIT=VIO, SPACE=(TRK, (200,20))
//LKED.CHALIB DD DSN=USER.AEG.FOR.CHARLIB, DISP=SHR
//LKED.SYSIN DD *
  INCLUDE CHALIB(CHARIMA)
ENTRY MAIN
*/
/*GO.FI15F001 DD DSN=USER.AEG.RIN.AUG28, DISP=OLD
//GO.FI16F001 DD DSN=USER.AEG.RIN.MY1IC, DISP=(NEW,CATLG), UNIT=DISK,
/* SPACE=(TRK, (150,5), RLSE), DCB=(RECFM=VBS, BLKSIZE=9076)
//GO.SYSIN DD *
TEST RUN OF INITIAL DATA SET FOR CHO-SHIU RIVER IN TAIWAN
  12 3 16 13 3 5 3 47 50 30 0 0 0
  420 4320 15 262 30 1 1 1 0 0 0 1 0 1 1 0
  3 1 1 1 0 0 2 50 20 10
  0.1 1.0 10.0 0.01 0.01 1.0 1.0 1.0
  2.65 0.4 1.0 1.0 0.5 0.0465 0.0 1.0
  1.0 60.0 30.0 0.0006335 0.005 0.5
  0.32 0.36 0.43 0.65
  10 4 6 5 0
  11 4 101 6 0
  12 4 103 101 0
  13 4 105 103 0
  14 3 107 105 0
  15 3 7 107 0
  16 4 102 6 0
  17 4 104 102 0
  18 4 106 104 0
  19 3 108 106 0
  20 3 7 108 0
  505 2 102 101 1
  510 2 104 103 1
  515 2 106 105 1
  520 2 108 107 1
-21 13 8 7 0
  5 -1 0 1 1 1 -10
  6 0 0 1 2 3 -11 -16 10
  101 0 0 1 3 3 -12 -505 11
  102 0 0 2 1 3 -17 505 16
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| 2591.99 | 52.50 | 2838.06 | 54.14 | 2952.90 | 55.45 | 3034.93 | 54.14 |
| 3084.14 | 52.50 | 3198.98 | 50.86 | 4052.04 | 50.86 | 4363.73 | 49.87 |
| 4593.40 | 50.86 | 5249.60 | 50.86 | 5348.03 | 51.51 | 5758.15 | 50.53 |
| 6135.47 | 50.86 | 6479.97 | 49.21 | 6611.21 | 48.72 | 6676.83 | 49.21 |
| 6857.29 | 50.53 | 7316.63 | 50.86 | 8005.64 | 50.86 | 8202.50 | 49.21 |
| 8333.74 | 49.21 | 8497.79 | 50.86 | 8989.94 | 52.50 | 9383.66 | 52.50 |
| 9396.78 | 54.14 | 9409.91 | 55.78 | 9695.35 | 55.78 | 9695.35 | 54.14 |
| 9843.00 | 52.50 | 9908.62 | 52.50 | 9967.68 | 65.29 |   |   |

34  50  0.50  CROSS SECTION 33
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| 1197.56 | 54.14 | 1427.23 | 54.14 | 1640.50 | 53.48 | 2362.32 | 54.14 |
| 2952.90 | 54.14 | 3281.00 | 55.78 | 3740.34 | 57.42 | 3773.15 | 57.42 |
| 3789.55 | 55.78 | 4626.21 | 55.78 | 4642.61 | 54.14 | 4921.50 | 53.15 |
| 5151.17 | 54.14 | 5380.84 | 54.14 | 5413.65 | 53.81 | 5610.51 | 52.50 |
| 5676.13 | 52.17 | 5708.94 | 52.50 | 5872.99 | 52.50 | 5938.61 | 54.14 |
| 7004.93 | 54.14 | 7316.63 | 55.12 | 7775.97 | 55.78 | 8202.50 | 56.43 |
| 8596.22 | 55.78 | 9055.56 | 55.78 | 9121.18 | 54.14 | 9350.85 | 54.14 |
| 9383.66 | 59.06 | 9678.95 | 59.06 | 9728.16 | 68.93 |   |   |

35  50  0.50  CROSS SECTION 35
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| 656.20 | 60.70 | 951.49 | 62.34 | 1017.11 | 60.70 | 1049.92 | 59.06 |
| 1378.02 | 57.42 | 1542.07 | 57.09 | 1722.52 | 55.78 | 2132.65 | 55.78 |
| 2493.56 | 56.43 | 2624.80 | 55.78 | 2887.28 | 55.78 | 3084.14 | 57.42 |
| 3297.41 | 59.06 | 3428.65 | 60.70 | 4429.35 | 60.70 | 5183.98 | 59.06 |
| 5216.79 | 57.42 | 6004.23 | 57.42 | 6037.04 | 57.75 | 6365.14 | 57.42 |
| 6890.10 | 56.43 | 7136.17 | 55.78 | 7382.25 | 54.46 | 7611.92 | 55.78 |
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36  50  0.50  CROSS SECTION 37
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| 2411.53 | 63.98 | 2434.50 | 65.62 | 2861.03 | 65.62 | 3018.52 | 63.98 |
| 3166.17 | 62.34 | 3231.78 | 60.70 | 4068.44 | 60.70 | 4134.06 | 62.34 |
| 4265.30 | 62.34 | 4291.55 | 60.70 | 4429.35 | 59.71 | 4560.59 | 60.70 |
| 4724.64 | 61.35 | 4839.47 | 60.70 | 4921.50 | 60.37 | 5512.08 | 59.71 |
| 5872.99 | 59.71 | 6069.85 | 59.06 | 6283.11 | 57.42 | 6342.17 | 57.25 |
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-1

47 50

0.50 CROSS SECTION 51A-B (DOWNSTREAM)

| 1 45 |
| 115.54 | 91.87 | 1131.94 | 95.15 | 1164.75 | 96.79 | 1181.16 | 98.43 |
| 1378.02 | 99.09 | 1738.93 | 95.15 | 1765.18 | 93.51 | 1837.36 | 92.52 |
| 1886.57 | 92.52 | 1935.79 | 93.51 | 2624.80 | 93.51 | 2651.05 | 95.15 |
| 2887.28 | 95.15 | 3051.33 | 96.79 | 3412.24 | 97.77 | 3674.72 | 96.79 |
| 3871.58 | 95.15 | 4101.25 | 93.51 | 4114.37 | 93.18 | 4147.18 | 93.18 |
| 4193.12 | 93.51 | 4412.94 | 93.51 | 4462.16 | 93.18 | 4494.97 | 93.18 |
| 4527.78 | 93.51 | 4724.64 | 95.15 | 4987.12 | 95.81 | 5413.65 | 96.79 |
| 6168.28 | 98.10 | 6562.00 | 98.10 | 6791.67 | 96.79 | 7267.41 | 96.79 |
| 7382.25 | 95.15 | 7529.89 | 93.51 | 7546.30 | 91.87 | 7611.92 | 91.87 |
| 7628.32 | 93.51 | 7693.95 | 95.15 | 7726.75 | 96.79 | 7972.83 | 96.79 |
| 8015.48 | 108.21 |

-1

0 180 360 540 720 900 1080 1260 1440 1620 1800 1980 2160 2340 2520 2700

2880 3060 3240 3420 3600 3780 3960 4140 4320 4500 4600 4700 4800

| 1 1000. |
| 0 63. |
| 480 63. |
| 540 63. |
| 600 63. |
| 660 63. |
| 720 63. |
| 780 63. |
| 840 63. |
| 900 63. |
| 960 63. |
| 1020 63. |
| 1080 63. |
| 1140 63. |
| 1200 63. |
| 1260 63. |
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| 1440 63. |
| 1500 63. |
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| 1620 63. |
| 1680 63. |
| 1740 63. |
| 1800 63. |
| 1860 63. |
| 1920 63. |
| 1980 63. |
| 2040 63. |
| 2100 63. |
| 2160 63. |
| 2220 63. |
| 2280 63. |

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13.750 1109.04 0.3785
13.750 1215.00 0.4023
13.750 1433.99 0.4495
13.750 1734.20 0.5106
13.750 1628.24 0.4895
13.750 1889.61 0.5408
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13.750 2684.31 0.6841
13.750 3189.38 0.7679
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13.750 9642.32 1.6111
13.750 30269.10 3.4664
13.750 32352.97 3.6245
13.750 25324.33 3.0761
13.750 26066.04 3.1361
13.750 19991.03 2.6255
13.750 19002.07 2.5377
13.750 23946.85 2.9630
13.750 33412.57 3.7036
13.750 75231.26 6.3784
13.750 92891.18 7.3460
13.750 99248.75 7.6791
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13.750 244060.09 14.0296
13.750 395582.21 19.3877
13.750 399114.19 19.5035
13.750 395582.21 19.3877
13.750 381454.27 18.9212
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/*
 // EXEC WNOTIFY
 */
Appendix F

PLIAL5 PROGRAM
RESULTS PROCESSING FOR BRALLUVIAL, CHARIMA CODES
PLIAL5 PROGRAM
RESULTS PROCESSING FOR BRALLUVIAL, CHARIMA CODES
USER'S GUIDE

INTRODUCTION

The PLIAL5 code is an adaptation of CARIM5 to BRALLUVIAL and CHARIMA output results files (they are identical). All features of CARIM5, as outlined in the user's guide (SOGREAH Technical Note 1886, November 1978) remain valid subject to several modifications incorporated in this writing.

The program systems for unsteady flow simulation in urban storm drain networks and river systems - CARIMA, CAREDAS, CAREMUSK, MISTRAL, SIMOUN, BIDIM, MEKONS, etc. - produce output files, optionally, which contain all the results of the computation. Each program produces an output file having a unique structure, but they all contain the same basic information: information on identification of the program and model; general model structure; and then, for each time step, the state of the model, i.e. lists of water levels, discharges, velocities, surface areas, etc.

The CARIM5 program is a tool for detailed analysis of results stored on an output file. It was designed specifically for the CARIMA system, but is structured in such a way that output files from any of the above programs can in principle be treated. This chapter applies only to the use of CARIM5 with CARIMA; its use for other programs is described in their users' guides.

The user of PLIAL5 specifies his requests for printed or graphical output on records which constitute the input data for the program. These records follow the general rules adopted in CARIMA, see 2.6.1. In particular, each record must have a 4-character identifier in the first four columns, belonging to the family of pre-defined identifiers described herein.

The types of records in PLIAL5 can be divided into three general categories:

A. GENERAL PREPARATION AND SPECIFICATION OF INPUT AND OUTPUT FILES

- TITR - title records
- CLIE - client's coordinates
- PRNT - specification of print and punch output files
- FRES - specification of input results file(s)
- FMOD - specification of model input file
- OPTI - specification of working options
- MESS - message to the plotting room operator

B. CREATION OF A PLOT, DRAWING OF AXES, INSCRIPTION OF TEXTS, GEOMETRICAL ELEMENTS, CONTROL DATA

- CADR - initialization of a plot
- TEXT, TEXL, TEXF - inscription of a text
- VECT, VECF - drawing of a straight line
- RECT - drawing of a rectangle
- CART - drawing of a title block
DESS- localization of subplot axes
AXES, Y(T), Y(X), Q(T), Q(X), V(T), V(X)- drawing of axes with standard labels
LABL- user defined axis labels
CLIM- definition of plotting "window"
DONN- plotting of input control data
FOND- plotting of input data (thalweg)
SYM- assignment of symbol and legend text for control data

C. PRINTING AND PLOTTING OF COMPUTED RESULTS

SORT- output of time variation of some quantity for one model element
SORX- specification of a sequence of elements for longitudinal profile output by ENDX
ENDX- output of longitudinal profile along sequence defined by SORX
ETAT- output of entire model state at a given moment

Note that only the records of category C above require access to a results file.

All records are in principle optional, all parameters being initialized automatically to default values. However, the CADR and MESS records are indispensable for any graphics. The sequence of records is arbitrary except for the following constraints:
1) All category A records must precede the first record of category B or C.
2) If the CADR record is furnished, it must precede the category B and C records which request graphical work on the CADR graphic.
3) The LABEL and/or CLIM records must be immediately preceded by an AXES-type record.
4) Conditions imposed by the CADR, DESS, AXES, SORX records remain active until subsequent records of the same type are read.
5) a FIN record must end the data.

The COMM record has no effect on the execution, it is used simply for comments.

The general layout of all records is shown on the summary coding form on the next page. In the text descriptions of the various records and parameters, the values in parentheses are the default values, adopted automatically by the program if the record is not furnished or the parameter is left blank. Note that in general, a blank field is not equivalent to zero, and vice-versa.

Three Remarks
-- It is possible to plot results from several different calculations, even different models, in the same run and on the same axes. To do so one furnishes a FRES record for each results file to be used, and then specifies the appropriate file number on the SORT and ENDX output requests. If by error the model elements specified on SORT and SORX records do not exist in the model represented on the specified results file, the program signals an error.
The essential difference between SORT and ENDX outputs is the independent variable. For SORT, the independent variable is the time associated with each time step on the results file. For ENDX, the independent variable is the river station associated with each element name appearing on the SORX records which precede ENDX.

We recall that steady flow results in CARIMA are written onto the output file with fictitious times such as -98., -97., -96., etc. In a SORT-type output, these fictitious times will be treated as normal times.

Examples of Data Structure

P R I N T I N G O N L Y

- (TITR, CLIE, PRNT, OPTI) optionally
- One FRES record for each results file.
- One SORT record for each f(t) output desired.
- One grouping (SORX, SORX, ..., ENDX, ENDX, ...) for each f(x) output desired.
- One FIN record

Note: when CARIMA is executed in the same step with CARIMA/CALCUL, it is not necessary to furnish a FRES record for the currents results file.

One Plot in One Frame

- (TITR, CLIE, PRNT, OPTI) optionally
- One FRES record for each results file (see note, previous page)
- One MESS record for plotter operator (if applicable)
- One CADR record for specification of frame size
- One AXES record (or Y(T), Q(T), etc.) to define plot axes and scale.
- One SORT record for each f(t) output desired, or:
- One grouping (SORX, SORX, ..., ENDX) for each f(x) output desired
- One CART record for a title block, if desired
- One FIN record

Several Plots in Several Frames

- (TITR, CLIE, PRNT, OPTI) optionally
- One FRES record for each results file (see note, previous page)
- One MESS record for plotter operator (if applicable)
- One CADR record to set dimensions of first frame
  - A DRESS record to set the location of the first plot within the frame, and give it a title
  - A Q(T) record (or AXES, Y(X), etc.) to define the axes and scale of first plot
    - One SORT record (or SORX-ENDX grouping) for each curve to be drawn on the first plot
  - A DRESS record to locate the second plot within the frame, and give it a title
  - A Y(X) record (or Q(T), AXES, etc.) to the axes and scale of second plot
- One SORT record (or SORX-ENDX grouping) for each curve to be
drawn on the second plot
- A DESS record for the third plot
- A V(T) record (or Q(X), AXES, etc.) for the axes of the third
  plot
  - One SORT record (or SORX-ENDX) for each curve
- A CART record for the first frame's title block, if desired

- A CADR record to set dimensions of second frame
- DESS
  - O(X) etc
    - SORX etc.
- DESS
  - Q(T) etc.
    - SORT etc.
  - CART if desired

- One FIN record to end data

Remarks:

1) The TEXT, TEXL, TEXP, VECT, VECP, RECT records can be used to draw
texts or lines anywhere on the plot or in the frame, and at any
point in the sequence of records as long as they follow the CADR
record.

2) Observed data, bed profiles, etc. can be plotted by using DONN
and/or FOND records.

3) The axis records Y(T), Q(X), etc. write standard labels on the axes,
in French. Non-standard labels including English labels, can be
specified by furnishing a LABL record after each axis record.

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<td>2.0</td>
<td>DONN symbols</td>
</tr>
<tr>
<td>2</td>
<td>3.0</td>
<td>curve titles and symbols</td>
</tr>
<tr>
<td>3</td>
<td>3.0</td>
<td>Axes labels, title of frame</td>
</tr>
<tr>
<td>4</td>
<td>4.0</td>
<td>DESS title</td>
</tr>
<tr>
<td>5</td>
<td>3.0</td>
<td>TEXT, TEXL, TEXP texts</td>
</tr>
</tbody>
</table>

Note: These standard sizes can be modified on the CADR card for each frame.
**ERROR CODES**

1. One or more syntax errors on the record printed
2. Record not recognized or record sequence illegal
3. Insufficient memory - increase region for job
4. The element printed does not exist in the model represented on the specified FRES file
5. Requested function does not exist for the element specified (2-D cell does not have Q; 1-D reach does not have Y, etc.)
6. ENDX is not preceded by a SORX sequence
7. Requested function TRAV non-operational
8. Number of FRES records exceeds 5
9. File reference not recognized
10. Non-operational program type
11. File number not recognized (an FRES record must be furnished for each results file mentioned)

**TITR** record - Title page and title block texts

The number of title records is unlimited. However, only the first **four** are printed on the output listing and inscribed in the title block (if the CART record is furnished). Each record contains 64 characters of text, columns 5-68 inclusive.

**CLEIE** record - Clients' Reference

The number of CLIE records is unlimited. However, only the first **two** are printed on the title page and inscribed in the title block (if CART record is used). Each record contains two lines of text; columns 5-36, and 37-68 inclusive.

**PRNT** record - Modification of Output File Numbers

This record is used only if it is necessary to modify the standard output file reference numbers, which are the default values shown below.

**IMPL** I4 (6)
Printer for normal results

**IMP2** I4 (IMPL)
Printer for error and warning messages

**IPUN** I4 (7)
record punch, 80 columns
MESS record - Message to plotter operator

Text of 64 characters containing instructions to plotter operator, where required.

OPT1 record - Working Options

IPGM I4 (0)
Not used

LANG A4 (FRAN)
Not used, all output is in French.

MAXY I4 (0)
Option for printing maximum value of water or piezometric levels attained during the calculation, for all points. These maximum values are printed with the time at which they occurred. Not operational for PLIAL5.

TFINB F8.0 (+999999.)
Last time to be read on the results file(s), in units consistent with JEDI. Use of TFINB makes it possible to read a file created during a job which ended abnormally, thus having an incomplete set of records. If TFINB is larger than the last time on the file, all of the file is read.

JEDI I4 (0)
Option for time units. JEDI is used to declare the units in which the user expresses any and all times connected with a given plot run:
0 = seconds 1 = minutes 2 = hours
3 = days 4 = years

The results file always contains times in decimal days, whatever time units were used in the computation.

MEMO I8 (all available memory in JOB region)
Core memory for data storage, in words.

FRES record - Declaration of Results File

Each results file to be used in a run must be declared on a FRES record (see note below for and exception). Up to 5 FRES results files, all created by the same program, can be used in one run.

NRES I4 (0)
Reference number for the results file, i.e. the FORTRAN reference number attributed to the file in the Job Control Language.
Reference text of file NRES. This text should correspond to the comparable 20 character text written onto the file when it was created (e.g. the REFRES parameter of CARIMA/CALCUL, REF2 record. If the two texts do not agree, character by character, the programs signals ERROR 9, but continues normal execution.

PLIALS: The verification text REFRES is taken to be the first 20 characters of the title of the BRALLUVIAL or CHARIMA job.

Note: Whenever CARIMA is executed in the same job step as CARIMA/CALCUL (see section 3.10), the program automatically generates a FRES record for the current results file.

**FMOD** record - Declaration of Model File

The FMOD record is not used, all model information being contained in the results file.

**COM** record - Comment

Comment records have no effect on the execution of the program. They can be used to label data, separate blocks of data, prompt formats, etc.

**CADR** record - Initialization of a Frame

The CADR record is indispensable if graphical output is desired. If a CADR record is not furnished, the program ignores all subsequent graphical output requests. By using the NORM parameter below, the user can generate frame sizes in standard metric proportions. Alternatively, the user can specify any frame size using the DIMX, DIMY parameters.

**NORM** A4 (non-standard frame, DIMX by DIMY)

Standard frame option
A1-- = A1 frame (84 cm by 59.4 cm)
A1C-- = A1 frame with empty title block
A1V-- = A1 frame split into two panels, 84 by 29.7 cm
A1VC = A1V frames, each with empty title block
A3-- = A3 frame (42 cm by 29.7 cm)
A4-- = A4 frame (21 cm by 29.7 cm)

These key words cause the program to generate the indicated dimensions with an exterior border (see ICAD = 1 option below) as well as standard interior borders around the working zones.

**DIMX** F8.0 (21.0) }

Frame width, cm. }

} ---- these dimensions apply only if a NORM keyword is not furnished

**DIMY** F8.0 (29.7) }

Frame height, cm }
CARA, CARE, CARC, record, CARE  5F8.0  (10)
Multiplying factors to modify standard character heights, see page
5/8. The factors are applied to the current character sizes,
already modified, possibly, by a previous CADR record.

ICAD  I4  (1)
Option for drawing an exterior border around the frame. ICAD = -1
suppresses it.

IPLI  I4  (1)
Option for drawing fold marks on the exterior border of standard
frame sizes (see NORM). The marks are drawn at the following
distances (cm) from the left boundary:

0 = no fold marks
1 = 21-40-59-71.5-84  (fold-out A1)
2 = 21-42-63-84  (folded A1)
3 = 42-63-84  (folded A1)
4 = 21-31.5-42  (A3)
5 = 12.5-23-42  (A3)

Remarks: The CAREDAS-SIMOUN title block (see CART record) can be used
with any frame, standard or not. For the standard frames, the title
block coordinates X0, Y0 should be:

A1, A1V: X0 = 63 cm,  Y0 = 1 cm
A3 : X0 = 21.5 cm,  Y0 = 0.5 cm

The (X0, Y0) coordinates on the DESS, TEXT, VECT, RECT, CART records
specify positions measured from the lower left hand corner of the frame,
drawn or not.

TEXT, TEXL, TEXP records - Inscription of a text

The TEXT, TEXL and TEXP records are used to write a line of text
on the plot, i.e. anywhere in the frame, and at any point in the record sequence.

X0, XO  2F8.0  (0.0; 0.0)
2F4.0 for TEXL
Coordinates of the lower left hand corner of the first
character:
> for TEXT and TEXL, in cm relative to the lower left hand
corner of the frame;
> for TEXP, in the physical units of the current axes.

ANGLE  F8.0  (F4.0 for TEXL)  (0.0)
Angle of the text from the x-axis, in degrees, positive
clockwise.

ICAR  I4  (5)
Number of the desired character type (see p. 5/8)

TEXT  9A4 (12A4 for TEXL)  (blank)
Line of text to be written.
Note: Obviously TEXP cannot be used until the axes have been defined.

**CART** record - Drawing of a Title Block

The CART record is used to draw a CAREDAS-SIMOUN type title block, anywhere in the frame and at any time. As seen below, the block is rather large (13 cm by 6.5 cm is the smallest practical size), thus it normally is used in large frames only (A3 and larger).

**X0, Y0** 2F8.0 (0.0, 0.0) Coordinates of the lower left hand corner of the title block, in cm relative to the lower left hand corner of the frame.

**IOPT** I4 (0) Option for title block type. 0 = CAREDAS-SIMOUN, nominally 20 cm wide, 10 cm high. The texts on the first four TITR records and first two CLIE records are written in the block following the example on the next page.

**FACT** F8.0 (1.0) Size reduction factor for the title block dimensions. Normally 0.65<=FACT<=1.0

**DESS** record - Localisation of subplot axes

The DESS record is optional, normally used only when multiple plots are created in one frame.

**X0, Y0** 2F5.0 (5.0, 5.0) Coordinates of the origin of the axes (physical units XOR, YOR, see below) relative to lower left hand corner of frame, in cm.

**TITRE** 12A4 (blank) Title of subplot, inscribed below abscissa, character no. 4.

**VECT, VECP** records - Drawing of a straight line

The VECT and VECP records can be used to draw a straight line segment anywhere in the frame, at any time.

**X0, Y0** 2F8.0 (0.0 ; 0.0) Coordinates of the beginning of the line segment: - for VECT, in cm relative to the lower left hand corner of the
frame.
- for VECP, in the physical units of the current axes.

**XI, X1**  2F8.0  (0.0 ; 0.0)
Coordinates of the end of the line segment, in cm for VECT, in
physical units
for VECT, in physical units for VECP.

**LINE**  I4  (1)
Thickness of the line, 1<=LINE<=8

**AXES. Y(T), Y(X), O(T), O(X), V(X), V(T)** records - Definition of
subplot axes

These records define the axes for a subplot and set the scale
for subsequent
work in physical units. The records are all equivalent; the
different
identifiers simply provoke automatic labelling of the ordinate
and abscissa,
in French - Y(T) = "NIVEAU" and "TEMPS", etc. For all other
labels, or when
the AXES identifier is used, the LABL record (see below)
replaces standard
labels with the user's desired labels (e.g. in English). It is
important to note
that the axis record identifiers specify only the labels placed
on the axes - the
kind of function to be plotted (y(t), O(X), etc. ) must be
specified on the SORT
and ENDX records, TRAV parameter, see below.

**XMIN, XMAX**  2F8.0  (0.0 ; 0.0)
Values of the independent variable (usually time or distance) at
the left and
right ends of the abscissa, in physical units (hours,
kilometers, etc.)

**YMIN, YMAX**  2F8.0  (0.0 ; 0.0)
Values of the dependent variable (level, discharge, velocity,
volume,
surface area, ... ) at the lower and upper ends of the ordinate,
in physical units
( meters; m³/s, m/s, m³, m², ... )

**XOR, YOR**  2F8.0  (XMIN; YMIN)
Values of the dependent and independent variables at the
coordinate origin
(XO, YO of DESS record) of the subplot axes. XOR not equal to
XMIN and/or YOR
not equal to YMIN imply crossed-axes. XOR, YOR are in physical
units
consistent with the units of XMIN, YMIN.

**ECHX, ECHY**  2F4.0  (1.0 ; 1,0)
Abscissa and ordinate scales, in physical units per centrimetre
(m/cm, m³/s/cm, etc.)

ECAX, ECAY  2F4.0  (2.0 ; 2.0)
Paper distance between markers on the abscissa and ordinate, in cm.

Remark: The program automatically suppresses any attempt to plot data
or results to the left of the base of the abscissa. This restriction
can be changed or modified by using the CLIM record, see below.

LABL record - Specification of user-defined axis labels

The LABL record is optional, but must follow an axis record or
CLIM record if used. LABL is typically used to replace the standard (French)
labels of Y(T),
e tc.

LABLX  4A4  (blank)
Abscissa label, 16 characters, character no. 3

LABLY  4A4  (blank)
Ordinate label, 16 characters, character no. 3

CLIM record - Definition of plotting window and modification of
standard legend
location

Normally the program allows data and results to be plotted
anywhere to the
right of the base of the abscissa, and automatically places a
legend on the
upper right hand corner of the subplot. The optional CLIM
record can be used
to modify either or both of these standard procedures. If used,
CLIM must
follow an axis or LABL record.

CXMIN, CXMAX  2F8.0  (XMIN; frame limit)
Left- and right-hand limits of the data and results plotting
window, in
physical units of the current abscissa.

CYMIN, CYMAX  2F8.0  (frame limits)
Upper and lower limits of the data and results plotting window, in
physical
units of the current ordinate.

XLEG, YLEG  2F8.0  (4cm to the left of the paper coordinates of
XMAX, YMAX )
Paper coordinates, in cm relative to lower left hand corner of
frame, of the
beginning of automatic legend for SYMB, SORT, ENDX plots.

**FOND** record - Plot of a Longitudinal Profile

*PLIAL5:* not used

**SYMB** record - Definition of Symbol and Legend Title for Data

The optional SYMB record is used to specify the legend and symbol for data on subsequent DONN records.

**NSYM**

<table>
<thead>
<tr>
<th>I4</th>
<th>(+5)</th>
</tr>
</thead>
</table>

**TITRE**

<table>
<thead>
<tr>
<th>6A4</th>
<th>(blank)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 character text to be inscribed in legend for the data.</td>
<td></td>
</tr>
</tbody>
</table>

**DONN** records - Plotting of User-Furnished Data

Data furnished on DONN records (unlimited in number) are plotted sequentially on the current axes as numbered lines.

**absc**

<table>
<thead>
<tr>
<th>F8.0</th>
<th>(0.0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abscissa of the data point, in current physical units.</td>
<td></td>
</tr>
</tbody>
</table>

**ord**

<table>
<thead>
<tr>
<th>F8.0</th>
<th>(0.0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ordinate of the data point, in current physical units.</td>
<td></td>
</tr>
</tbody>
</table>

**SORT** record - Output of a time-dependent function

Each SORT record contains all the information needed to obtain the f(t) function for an element. Each SORT record with ISOR = 3 causes a curve to be drawn on the current axes, if applicable.

**NSYM**

<table>
<thead>
<tr>
<th>I4</th>
<th>(+5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symbol code for subsequent control data furnished on DONN records, if used.</td>
<td></td>
</tr>
</tbody>
</table>

*(If a SYMB record appears before the DONN records, its symbol code replaces the NSYM of the most recent SORT record.)*

**NPAM**

<table>
<thead>
<tr>
<th>A4</th>
<th>(blank)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name of the link (integer) on which the desired point is located.</td>
<td></td>
</tr>
</tbody>
</table>
NPAV  A4  (blank)
Number of the point (integer) on the requested link.

TITRE  6A4  (blank)
Text of 24 characters to be used in the legend for the f(t)
curve. Character No. 2 is used.

TRAV  A4
Type of f(t) function requested. The following options are active:

WSEL = water surface elevation, ft
QH2O = water discharge, cfs
VELO = water velocity, ft/sec
HYDR = hydraulic radius, ft
WIDT = water-surface width, ft
THAL = thalweg elevation, ft
QSTO = total sediment load, cfs
FFAC = friction factor
ARMO = global armoring factor
D50P = d50 at the point, mm
ENSL = energy slope
VOLO = bed-level change in last time step for the reach, ft
CDEP = cumulative degradation, ft
PT01, PT02, ..., PT15 = fractional representation of each size
class in mixed

AR01, AR02, ..., AR15 = size-class component of armoring factor
QS01, QS02, ..., QS15 = size-class component of sediment load, cfs

Special SORT Functions: The time abscissa can be replaced by
any other variable by putting the appropriate TRAV keyword in columns
13-16 (between NPAV and NPAV). The resulting data pairs for the
specified point will be printed and plotted sequentially in time.

ISOR  I4  (3)
Output option for the chosen f(t) function.
0 or 1 : printer
2 : printer plus punch on F(T) records usable in
CARIMA/CALCUL
(Sect 3.3)
3 : printer plus plotter (if a CADR record has been
furnished and axes have been defined).

NOMP  I4  (1)
Option for inscription of the name of the element in the legend
along with
TITRE. NOMP not equal to 1 suppresses the inscription.

NFIC  I4  (file number on first FRES record)
Reference number of desired results file.

NSEQ  I4  (0)
Curve numbering option. If NSEQ > 0, it is the number which
will be inscribed
in the curve. If NSEQ = 0, the number inscribed will be the
sequence number
of the current SORT record. Since the most recent DESS record,
character no. 2
is used for inscribed numbers. If NSEQ < 0, the f(t) function
will be plotted
with symbols at all data points; the absolute value of NSEQ is
the symbol type,
see NSYM parameter, DONN record.

Remark: Since cumulative volumes (TRAV = -VOL and VOLT) can greatly
vary in order of magnitude from one model to another, the program
automatically expresses them in units of 1, 10³, 10⁶, 10⁹ etc. as
necessary. The axes must be dimensioned accordingly, so a preliminary
run with ISCR = 1 should be made to determine the units chosen by the
program.

**SORX record - Specification of a Sequence of Elements**

The output of a longitudinal profile of some quantity requires
the specification of the names of points which establish the
longitudinal stationing. There is a longitudinal coordinate associated with
each point - it is the river station (PK) parameter assigned during model
construction, PTLI record. The role of SORX records is to define the sequence of
points and to associate longitudinal coordinates and bed elevations with the
sequence, automatically or manually.

**NPAM**
A4 (blank)
Name of the link (integer) for which a function of distance is requested.

**PK**
F8.0 (0.0)
not used

**ENDX record - Output of a Longitudinal Profile**

The ENDX record requests the output of a longitudinal profile
along the sequence of points previously defined on SORX records. Each
ENDX record previously defined on SORX records. Each ENDX record generates
one curve on the current axes, if applicable.

**NSYM**
I4 (+5)
Symbol code for subsequent control data plots, DONN records, if
used. A subsequent SYMB record will replace NSYM by its
own value, if furnished.
MCLE  A4  (blank)
Keyword for the nature of the operation to be performed on the
f(x) function.
- blank = output of f(x) for a particular time of the
calculation, see "temps"
- PERM = output of f(x) associated with a particular steady
flow, see "perno"
- MINI = output of the envelope of minimum values of the f(x)
function from "temps" to the end of the calculation.
- MAXI = output of the envelope of maximum values of f(x) from
"temps" onwards.
- MEAN = output of mean values of f(x) from "temps" onwards.

PERNO/TEMPS  F8.0  (0.0 for MCLE = blank or PERM)
(beginning of calculation for
MCLE = MINI, MAXI, MEAN)
- number of steady flow if MCLE = PERM
- particular time during calculation, if MCLE = blank (decimal
hours)
- time of beginning of mean or envelope computation of MCLE =
MINI, MAXI, MEAN.

PLIAL5 : PERN0 is not used

TITRE  6A4  (blank)
Text of 24 characters to be placed in the legend for this curve.
Character no. 2 is used.

TRAV  A4  (blank)
Type of f(t) function requested. The following options are
active:

WSEL = water surface elevation, ft
QH2O = water discharge, cfs
VELO = water velocity, ft/sec
HYDR = hydraulic radius, ft
WIDT = water-surface width, ft
THAL = thalweg elevation, ft
QSTO = total sediment load, cfs
FFAC = friction factor
ARMO = global armoring factor
D50P = d50 at the point, mm
ENSL = energy slope
VOLO = bed-level change in last time step for the reach, ft
CDEP = cumulative degradation, ft
PT01, PT02, ..., PT15 = fractional representation of each size
class in mixed layer
AR01, AR02, ..., AR15 = size-class component of armoring factor
QS01, QS02, ..., QS15 = size-class component of sediment load,
ISOR I4 (0)
Option for type of output
0 or 1 : printer only
2 : printer plus punch (non-operational)
3 : printer plus plotter (if CADR, DESS, AXES current)

NOMP I4 (0)
Option for inscription of point names on the abscissa. NOMP not equal to 1 suppresses the inscription. One should be careful to specify NOMP = 1 only on one of the ENDX records following a SORX sequence, to avoid redundant inscriptions.
PLIAL5 : The linkname only is inscribed below the abscissa of each point on the link.

NFIC I4 (file defined by first FRES record)
Reference number of desired results file.

NSEQ I4 (0)
Option for curve numbering. If NSEQ > 0, it is the number inscribed in the curve for the present ENDX record. If NSEQ = 0, the curve is numbered sequentially from the first ENDX on the current axes, automatically.
(character 2 is used for curve inscriptions) If NSEQ = -1, the curve is plotted as a continous line with no inscriptions.

IFON I4 (0)
not used

Special ENDX Functions: The distance abscissa can be replaced by any other variable by putting the appropriate TRAV keyword in columns 9-12 (i.e. in place of variable MCLE.) The resulting data pairs at the specified time will be printed and plotted sequentially in space.

Note: If an incorrect link/point specification, or an incorrect TRAV operator, is furnished, PLIAL5 may or may not flag the error clearly. In case of doubt, recheck your data carefully.

Note: To assure the last plot of a series is recovered, place a blank CADR record at the end of the output requests, immediately preceding the FIN record.

RETRANS PROGRAM. IALLUVIAL results files can be translated into CHARIMA results files for direct processing using PLIAL5. The program RETRANS takes the IALLUVIAL results file as input (FORTRAN reference number 15) and generates a CHARIMA output file number 16. For this generated file, TRAV keywords VOLO, CDEP, AR.., and QS.. are not operational.
** Table - General Format of Data Cards/Lines for Subsystem **

<table>
<thead>
<tr>
<th>Trace</th>
<th>Title</th>
<th>CIE</th>
<th>PRINT IMPRINT</th>
<th>RESER</th>
<th>REFRES</th>
<th>MODER</th>
<th>OPT I</th>
<th>LANGMAXY</th>
<th>TFINB</th>
<th>JEDI</th>
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** CADR NORM **

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<thead>
<tr>
<th>CADR</th>
<th>DIMX</th>
<th>DIMY</th>
<th>CARA</th>
<th>CARB</th>
<th>CARC</th>
<th>CARD</th>
<th>CARE</th>
<th>ICARD</th>
<th>PLC</th>
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</thead>
<tbody>
<tr>
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</table>

** CADR | X0 | Y0 | IOPT | FACT | ANGLE | ICAR | TEXT | TEXT | TEXT |
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</table>

<table>
<thead>
<tr>
<th>VECT</th>
<th>Y0</th>
<th>XI</th>
<th>Y1</th>
<th>LINE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
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</tbody>
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<table>
<thead>
<tr>
<th>VECP</th>
<th>Y0</th>
<th>XI</th>
<th>Y1</th>
<th>LINE</th>
</tr>
</thead>
<tbody>
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<table>
<thead>
<tr>
<th>RECT</th>
<th>Y0</th>
<th>DIMX</th>
<th>DIMY</th>
<th>LINE</th>
</tr>
</thead>
<tbody>
<tr>
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<table>
<thead>
<tr>
<th>DESS</th>
<th>Y0</th>
<th>TITRE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Indispensable for job start/end
** Indispensable for graphics
*** Axes for Y(t), Y(x), Q(t), Q(x), V(t), V(x)
// AEGHSU JOB (,10), 'IIHR MAR', MSGLEVEL=(1,1), TIME=05, CLASS=1
// PASSWORD
// JOBLIB DD DSN=USER.AEG.FOR.CHARLIB, DISP=SHR
// */ EXEC SCRATCH, DSN='USER.AEG.SED.AUG19'
// */ EXEC SCRATCH, DSN='USER.AEG.SED.AUG20'
// EXEC PGM=FLIAL5, REGION=1000K
// GO.FT05F001 DD DNNAME=SYSIN
// GO.FT06F001 DD SYSOUT=*.
// GO.FT04F001 DD SYSOUT=*, DCF=(RECFM=FBA, LRECL=133, BLKSIZE=931)
// */ USE FULL RESULTS FILE NAME USER.AEG.SED.#### FOR RESULTS FILES
// */GO.FT25F001 DD DSN=USER.AEG.SED.MAR26, DISP=SHR
// GO.FT26F001 DD DSN=USER.AEG.HSU.LEO35, DISP=SHR
// */GO.FT28F001 DD DSN=USER.AEG.SED.MAR26, DISP=SHR
// GO.FT22F001 DD DSN=&&PLFILE, DISP=(NEW, PASS), UNIT=VIO,
// SPACE=(4000, (100, 100))
// GO.SYSIN DD *

TRACE
PRNT 6 6
OPTI 1.0
FRES 26

CAADR27.9 21.6 1.5 1.5 1.5 1.5 1.5

DESS3.5 3.50 BED CUMULATIVE DEGRADATION IN TIME
Y(T) 0.0000 500.00 -0.40 0.24 25.0 0.04
LABLTIME (MIN) DEGRADATION(FT)
CLIM 20.

COMM_1

<table>
<thead>
<tr>
<th>COMM 1</th>
<th>PT. LEGEND ENTRY</th>
<th>VAR.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SORT</td>
<td>1 01 D/S</td>
<td>CDEP 3 1 26</td>
</tr>
<tr>
<td>SORT</td>
<td>1 3</td>
<td>CDEP 3 1 26</td>
</tr>
<tr>
<td>SORT</td>
<td>1 5</td>
<td>CDEP 3 1 26</td>
</tr>
<tr>
<td>SORT</td>
<td>1 7</td>
<td>CDEP 3 1 26</td>
</tr>
<tr>
<td>SORT</td>
<td>1 8 U/S</td>
<td>CDEP 3 1 26</td>
</tr>
</tbody>
</table>

CAADR27.9 21.6

DESS3.5 3.50 LONGITUDINAL ELEVATION PROFILES
Y(X) 0.0 132 32.5 33.8 6.00 0.08
LABLDISTANCE (FT) ELEVATION (FT)
CLIM 10.0

COMM_2

<table>
<thead>
<tr>
<th>COMM 2</th>
<th>PT. LEGEND ENTRY</th>
<th>VAR.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENDX</td>
<td>0.00 INITIAL BED</td>
<td>THAL 3 26</td>
</tr>
<tr>
<td>ENDX</td>
<td>100.00 BED AT 100 min</td>
<td>THAL 3 26</td>
</tr>
<tr>
<td>ENDX</td>
<td>200.00 BED AT 200 min</td>
<td>THAL 3 26</td>
</tr>
<tr>
<td>ENDX</td>
<td>300.00 BED AT 300 min</td>
<td>THAL 3 26</td>
</tr>
<tr>
<td>ENDX</td>
<td>400.00 BED AT 400 min</td>
<td>THAL 3 26</td>
</tr>
<tr>
<td>ENDX</td>
<td>500.00 FINAL( 500)BED</td>
<td>THAL 3 26</td>
</tr>
<tr>
<td>ENDX</td>
<td>0. INITIAL WS</td>
<td>WSEL 3 26</td>
</tr>
<tr>
<td>ENDX</td>
<td>10. 10 MIN WS</td>
<td>WSEL 3 26</td>
</tr>
<tr>
<td>ENDX</td>
<td>500.00 FINAL( 500)WS</td>
<td>WSEL 3 26</td>
</tr>
</tbody>
</table>

CAADR27.9 21.6 1.0 1.0 1.0 1.0 1.0

DESS3.5 3.50 BED-LEVEL CHANGES IN TIME
Y(T) 0.0000 500.00 32.5 33.2 25.0 0.050
LABLTIME (MIN) BED ELE.(FT)

COMM_3

<table>
<thead>
<tr>
<th>COMM 3</th>
<th>PT. LEGEND ENTRY</th>
<th>VAR.</th>
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</thead>
<tbody>
<tr>
<td>SORT</td>
<td>1 01 D/S</td>
<td>THAL 3 1 26</td>
</tr>
<tr>
<td>SORT</td>
<td>1 03</td>
<td>THAL 3 1 26</td>
</tr>
<tr>
<td>Command</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>-----------</td>
<td>------------------------------------------------------------------------------</td>
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<tr>
<td>CADR27.9</td>
<td>21.6</td>
<td></td>
</tr>
<tr>
<td>DESS3.5</td>
<td>3.50 WATER-LEVEL CHANGES IN TIME</td>
<td></td>
</tr>
<tr>
<td>Y(T)0.0000</td>
<td>500.00 32.6 33.4 25.0 .050</td>
<td></td>
</tr>
<tr>
<td>LABLTIME</td>
<td>(MIN) W/S ELE. (FT)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Command</th>
<th>PT. LEGEND ENTRY</th>
</tr>
</thead>
<tbody>
<tr>
<td>SORT</td>
<td>1 01 D/S WSEL 3 1 26</td>
</tr>
<tr>
<td>SORT</td>
<td>1 03 WSEL 3 1 26</td>
</tr>
<tr>
<td>SORT</td>
<td>1 5 WSEL 3 1 26</td>
</tr>
<tr>
<td>SORT</td>
<td>1 7 WSEL 3 1 26</td>
</tr>
<tr>
<td>SORT</td>
<td>1 9 U/S WSEL 3 1 26</td>
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<tr>
<td>CADR27.9</td>
<td>21.6</td>
</tr>
<tr>
<td>DESS3.5</td>
<td>3.50 TOTAL SEDIMENT LOAD AT DIFFERENT LOCATION</td>
</tr>
<tr>
<td>Q(T)0.0000</td>
<td>500.00 0.0 5.000 25.00 .30</td>
</tr>
<tr>
<td>LABLTIME</td>
<td>(MIN) Qs*1000 (CFS)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Command</th>
<th>PT. LEGEND ENTRY</th>
</tr>
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<tr>
<td>SORT</td>
<td>1 01 D/S Qs QSTO 3 1 26</td>
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<tr>
<td>SORT</td>
<td>1 5M/S Qs QSTO 3 1 26</td>
</tr>
<tr>
<td>SORT</td>
<td>1 8U/S Qs QSTO 3 1 26</td>
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<tr>
<td>SORT</td>
<td>1 9U/S Qs QSTO 3 1 26</td>
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<tr>
<td>CADR27.9</td>
<td>21.6</td>
</tr>
<tr>
<td>DESS3.5</td>
<td>3.50 LONGITUDINAL Qs VARIATION</td>
</tr>
<tr>
<td>Y(X)0.0</td>
<td>132 0.0 6.000 6.00 .40</td>
</tr>
<tr>
<td>LABLTIME</td>
<td>(FT) Qs*1000 (CFS)</td>
</tr>
<tr>
<td>CLIM</td>
<td>10.0</td>
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</table>

<table>
<thead>
<tr>
<th>Command</th>
<th>PT. LEGEND ENTRY</th>
</tr>
</thead>
<tbody>
<tr>
<td>SORT</td>
<td>1 00 INITIAL Qs QSTO 3 26</td>
</tr>
<tr>
<td>ENDX</td>
<td>100.00 Qs AT 100 min QSTO 3 26</td>
</tr>
<tr>
<td>ENDX</td>
<td>200.00 Qs AT 200 min QSTO 3 26</td>
</tr>
<tr>
<td>ENDX</td>
<td>300.00 Qs AT 300 min QSTO 3 26</td>
</tr>
<tr>
<td>ENDX</td>
<td>400.00 Qs AT 400 min QSTO 3 26</td>
</tr>
<tr>
<td>ENDX</td>
<td>500.00 FINAL (500)Qs QSTO 3 26</td>
</tr>
<tr>
<td>CADR27.9</td>
<td>21.6</td>
</tr>
<tr>
<td>DESS3.5</td>
<td>3.50 LONGITUDINAL D50 VARIATION</td>
</tr>
<tr>
<td>Y(X)0.0</td>
<td>132 0.0 5.6 6.00 .40</td>
</tr>
<tr>
<td>LABLTIME</td>
<td>(FT) D50 (mm)</td>
</tr>
<tr>
<td>CLIM</td>
<td>10.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Command</th>
<th>PT. LEGEND ENTRY</th>
</tr>
</thead>
<tbody>
<tr>
<td>SORT</td>
<td>1 00 INITIAL D50P 3 26</td>
</tr>
<tr>
<td>ENDX</td>
<td>100.0 100 MIN D50P 3 26</td>
</tr>
<tr>
<td>ENDX</td>
<td>200.0 200 MIN D50P 3 26</td>
</tr>
<tr>
<td>ENDX</td>
<td>300.0 300 MIN D50P 3 26</td>
</tr>
<tr>
<td>ENDX</td>
<td>400.0 400 MIN D50P 3 26</td>
</tr>
<tr>
<td>ENDX</td>
<td>500.0 500 MIN D50P 3 26</td>
</tr>
<tr>
<td>CADR27.9</td>
<td>21.6 1.0 1.0 1.0 1.0 1.0</td>
</tr>
<tr>
<td>DESS3.5</td>
<td>3.50 GLOBAL ARMORING FACTOR CHANGE IN TIME</td>
</tr>
<tr>
<td>Y(T)0.0000</td>
<td>500.00 0.00 1.20 25.0 .08</td>
</tr>
<tr>
<td>LABLTIME</td>
<td>(MIN) ACF(I,T) OR ARM</td>
</tr>
<tr>
<td>CLIM</td>
<td>20.</td>
</tr>
</tbody>
</table>
COMM | PT. LEGEND ENTRY | VAR.
S.ORT | 1 | 02 D/S | ARMO 3 1 26
S.ORT | 1 | 3 | ARMO 3 1 26
S.ORT | 1 | 5 | ARMO 3 1 26
S.ORT | 1 | 7 | ARMO 3 1 26
S.ORT | 1 | 9 U/S | ARMO 3 1 26

EXEC DISPPLC,PPDSN='&&PLFILE',
COND.GO=EVEN,PLATFORM=3201
/* CHANGE PLOTTER= TO CORRESPOND TO TERMINAL BEING USED.
EXEC DISPPWY,PPDSN='&&PLFILE',PLOTTER=TK4012
*/
EXEC DISPPWY,PPDSN='&&PLFILE',PLOTTER=HP7470
EXEC WNOTIFY
Appendix G

CHARIMA SOURCE CODE

(IBM mainframe version, 5/90)
FIRST CARD OF MAIN

DEFINITION OF VARIABLES

L=INDEX OF LINKS
I=INDEX OF COMPUTATIONAL POINTS
MU=UPSTREAM NODE OF A LINK
MD=DOWNSTREAM NODE OF A LINK
M=INDEX OF NODES
K=INDEX OF LINKS ATTACHED TO A NODE
LL=NUMBER OF A LINK ATTACHED TO A NODE
P=COEFFICIENT IN LINEARIZED FLOW EQUATION
Q=COEFFICIENT IN LINEARIZED FLOW EQUATION
R=COEFFICIENT IN LINEARIZED FLOW EQUATION
S=COEFFICIENT IN LINEARIZED FLOW EQUATION
E=RECURSION COEFFICIENT
F=RECURSION COEFFICIENT
H=RECURSION COEFFICIENT
Y=WATER LEVEL, INTERIOR POINT
DYN=WATER LEVEL CHANGE AT A NODE
BO=BASE WIDTH OF A SECTION
RMR=SIDE SLOPE OF SECTION, RIGHT
RML=SIDE SLOPE OF SECTION, LEFT
D=DEPTH
TALWEG=BED ELEVATION OF SECTION
PER=PERIMETER, WETTED
AREA=AREA OF SECTION
VEL=VELOCITY
RH=HYDRAULIC RADIUS
F=FRICTION FACTOR
GRAV=GRAVITATIONAL ACCELERATION
RK=CONVEYANCE, K
RKP=K'
WIDTH=TOP WIDTH
Q=DISCHARGE
LINKS=NUMBER OF LINKS
NODES=NUMBER OF NODES
ILAST=INDEX TO CHECK END OF SECTION INPUT
LLAST=INDEX TO CHECK END OF SECTION INPUT
DEPTH=DEPTH
KK=NUMBER OF LINKS ATTACHED TO A NODE
II=NUMBER OF COMPUTATIONAL POINTS ON A LINK
RM=COMPUTATIONAL POINT STATIONS, ET
AMAT=COEFFICIENT MATRIX, NODE CONTINUITY EQUATION
BVEC=FREE TERM VECTOR, NODE CONTINUITY EQUATIONS
YN=WATER LEVEL AT NODES

COMMON/TARRAY/T(10000),TITLE(20)
COMMON/DIMS/NODES,KMAX,LINKS,IMAX,MEMO,NODESI,NTRIB,N1,IMAX1
1
1,1,NGROUP,MAXG,IMLAST,NSECS,NLEVMX,E1RR,EVAR,
2
MAXBED,NITOUT,NBDT,IEND,NODES2
COMMON/TLMCF/TLM1,TLM2,TLM3,TLM4,TLM5,TLM6,TLM7,TLM8,
1
TLM9

WHEN CHANGING DIMENSION T(XXXX) ALSO CHANGE MEMO
DIMENSION T(5000), TITLE(20)
MEMO=10000

C IERR=0
IWAR=0

C I1=MU(LINKS)
I2=MD(LINKS)
I3=LL(NODES, KMAX)
I4=E(LINKS, IMAX)
I5=F(LINKS, IMAX)
I6=H(LINKS, IMAX)
I7=Y(LINKS, IMAX)
I8=Q(LINKS, IMAX)
I9=DYN(NODES)
I10=NSEC(IMAX, LINKS)
I11=ISECAD(NSECS)
I12=SEGEOM(NSECS*(3+3*NLEVMAX))
I13=TALNEG(LINKS, IMAX)
I14=AREA(LINKS, IMAX)
I15=VEL(LINKS, IMAX)
I16=RH(LINKS, IMAX)
I17=FFACT(LINKS, IMAX)
I18=WIDTH(LINKS, IMAX)
I19=LINKNAM(LINKS)
I20=II(LINKS)
I21=KK(NODES)
I22=RM(LINKS, IMAX)
I23=EMAT(MAXG, MAXG, NGROUP)
I24=FVECT(MAXG, NGROUP)
I25=YN(NODES)
I26=ETYPE(LINKS)
I27=ALPHA(IMAX, LINKS)
I28=BETA(IMAX, LINKS)
I29=NINQ(NODES2)
I30=NINQS(NODES2)
I31=QTRIB(NODES2)
I32=QTR(NODES2)
I33=DS(N1P1)
I34=PT(IMAX, N1P1, LINKS)
I35=D50R(IMAXM1, LINKS)
I36=DSG(N1)
I37=D50P(IMAX, LINKS)
I38=SF(IMAX, LINKS)
I39=QS(IMAX, N1, LINKS)
I40=QSTOT(IMAX, LINKS)
I41=QSP(IMAX, N1, LINKS)
I42=TDELD(IMAX, N1, LINKS)
I43=REACH(IMAXM1, LINKS)
I44=CDEP(IMAX, LINKS)
I45=CDEPP(IMAX, LINKS)
I46=DARM(IMAX, LINKS)
I47=TALWGP(IMAX, LINKS)

K48=VOLCUT(IMAX, LINKS)

I49=ACF(IMAX, LINKS)
I50=QSTR(NODES)
I51=D(IMAX, LINKS)
I52=NGSIZE(NGROUP)
I53 = RMAT (MAXG, MAXG)
I54 = SMAT (MAXG, MAXG)
I55 = TMAT (MAXG, MAXG)
I56 = VVECT (MAXG)
I57 = MPOS (NODES)
I58 = MGROUP (NODES)
I59 = YWORK (MAXG)
I60 = IROW (MAXG)
I61 = JCOL (MAXG)
I62 = JORD (MAXG)
I63 = NODNAM (NODES)
I64 = DRYBED (LINKS)
I65 = VOLIN (IMAX, N1, LINKS)
I66 = PTT (IMAX, NIP1, LINKS)
I67 = B2 (IMAX, N1, LINKS)
I68 = LLIM (IMAX, LINKS)
I69 = DELT (IMAX, N1, LINKS)
I70 = TI (IMAX, N1, LINKS)
I71 = TH (IMAX, LINKS)
I72 = PTP (IMAX, NIP1, LINKS)
I73 = EL1 (IMAX, LINKS)
I74 = EL2 (IMAX, LINKS)
I75 = PTU (IMAX, NIP1, LINKS)
I76 = BML (IMAX, LINKS)
I77 = TB (IMAX, N1, LINKS)
I78 = NBE1 (IMAXM1, LINKS)
I79 = THBED (IMAXM1, LINKS)
I80 = PBED (IMAXM1, N1, BAXBED, LINKS)
I81 = TALWGI (IMAX, LINKS)
I82 = PTA (IMAXM1, N1, LINKS)
I83 = ARM (IMAX, N1, LINKS)
I84 = PAC (IMAX, N1, LINKS)
I85 = ARMP (IMAX, N1, LINKS)
I86 = ACF1 (IMAX, LINKS)
I87 = TH1 (IMAX, LINKS)
I88 = CDF (NIP1)
I89 = ITOUT (NITOUT)
I90 = IDTCHG (2*NBDT)
I91 = W (N1)
I92 = PTP (IMAX, NIP1, LINKS)
I93 = CDF1 (NIP1)
I94 = RK (IMAX, LINKS)
I95 = RPK (IMAX, LINKS)
I96 = RKP (IMAX, LINKS)
I97 = RPKP (IMAX, LINKS)
I98 = AREAP (IMAX, LINKS)
I99 = YP (IMAX, LINKS)
I100 = QP (IMAX, LINKS)
I101 = EF (IMAX, LINKS)
I102 = FF (IMAX, LINKS)
I103 = HP (IMAX, LINKS)
I104 = RL (IMAXM1, LINKS)
I105 = RMM (IMAXM1, LINKS)
I106 = RN (IMAXM1, LINKS)
I107 = USLINK (LINKS)
I108 = PTRIB (N1, NODES)
I109 = WASHLO (N1)
C
I110=QSJNOD(N1)
I111=NODSED(NODES)
I112=AC(NODES2)
I113=BC(NODES)
I114=DEGLO(N1)
I115=QSCAP(IMAX,N1,LINKS)
I116=QSCUTF(N1)
I117=BANK(IMAX,LINKS)
I118=TALWGM(IMAX,LINKS)

I119=IMLAST=TWORK(MEMO-IMLAST)

READ(5,1001) TITLE
1001 FORMAT(20A4)
WRITE(6,2003) TITLE
2003 FORMAT(1H1,/,T30,20A4,/,T30,80(1H-),/)
READ(5,1000) NODES,KMAX,LINKS,IMAX,N1,MAXG,NGROUP,NSECS,NLEVEL
1,NITOUT,NBDT,ISHEAR,IYALIN
MAXBED=1
1000 FORMAT(16I5)

WRITE(6,2000) NODES,KMAX,LINKS,IMAX,N1,MAXG,NGROUP,NSECS,NLEVEL
1,NAXBD,NITOUT,NBDT,ISHEAR,IYALIN
2000 FORMAT(T30,'PROGRAM CHARAIMA',/T30,21(1H-),/)
1,"/T20,'IOWA INSTITUTE OF HYDRAULIC RESEARCH',"
2,"/T05,'DYNAMIC ALLOCATION PARAMETERS:',/"
3,T3,' NODES= ',I5,T20,' KMAX= ',I5,T40,' LINKS= ',I5,/,"
4,T3,' IMAX= ',I5,T20,' N1= ',I5,T40,' MAXG= ',I5,/,"
5,T3,' NGROUP= ',I5,T20,' NSECS= ',I5,T40,' NLEVEL= ',I5,/,"
6,T3,' MAXBED= ',I5,T20,' NITOUT= ',I5,T40,' NBDT= ',I5,/,"
7,T3,' ISHEAR= ',I5,T20,' IYALIN= ',I5,/

C
NBED=2*NBDT
NODES1=NODES+1
NODES2=NODES*2
ILMAX=LINKS*IMAX
MAXG2=MAXG*MAXG
N1F1=N1+1
IMAXM1=IMAX-1
ILMAX1=IMAXM1*LINKS
TLTM1=-2.2786
TLTM2=2.9719
TLTM3=1.0600
TLTM4=0.2989
TLTM5=0.9045
TLTM6=0.1665
TLTM7=0.0831
TLTM8=0.2166
TLTM9=-0.0411
I1=1
I2=I1+LINKS
I3=I2+LINKS
I4=I3+NODES*KMAX
I5=I4+ILMAX
I6=I5+ILMAX
I7=I6+ILMAX
I8=I7+ILMAX
I9=I8+ILMAX
I10=I9+NODES
I11=I10+ILMAX
I12=I11+NSECS
I13=I12+NSECS*(3+3*NLEVMAX)
I14=I13+ILMAX
I15=I14+ILMAX
I16=I15+ILMAX
I17=I16+ILMAX
I18=I17+ILMAX
I19=I18+ILMAX
I20=I19+LINKS
I21=I20+LINKS
I22=I21+NODES
I23=I22+ILMAX
I24=I23+MAXG2*NGROUP*2
I25=I24+MAXG*NGROUP*2
I26=I25+NODES
I27=I26+LINKS
I28=I27+ILMAX
I29=I28+ILMAX
I30=I29+NODES2
I31=I30+NODES2
I32=I31+NODES2
I33=I32+NODES2
I34=I33+N1P1
I35=I34+ILMAX*N1P1
I36=I35+ILMAX1
I37=I36+N1
I38=I37+ILMAX
I39=I38+ILMAX
I40=I39+ILMAX*N1
I41=I40+ILMAX
I42=I41+ILMAX*N1
I43=I42+ILMAX*N1
I44=I43+ILMAX1
I45=I44+ILMAX
I46=I45+ILMAX
I47=I46+ILMAX
I48=I47+ILMAX
I49=I48+ILMAX
I50=I49+ILMAX
I51=I50+NODES
I52=I51+ILMAX
I53=I52+NGROUP
I54=I53+MAXG2*2
I55=I54+MAXG2*2
I56=I55+MAXG2*2
I57=I56+MAXG*2
I58=I57+NODES
I59=I58+NODES
I60=I59+MAXG*2
I61=I60+MAXG
I62=I61+MAXG
I63=I62+MAXG
I64=I63+NODES
I65=I64+LINKS
I66=I65+ILMAX*N1
I67=I66+ILMAX*N1P1
I68=I67+ILMAX*N1
I69=I68+ILMAX
I70=I69+ILMAX*N1
I71=I70+ILMAX*N1
I72=I71+ILMAX
I73=I72+ILMAX*N1P1
I74=I73+ILMAX
I75=I74+ILMAX
I76=I75+ILMAX*N1P1
I77=I76+ILMAX
I78=I77+ILMAX*N1
I79=I78+ILMAX1
I80=I79+ILMAX1
I81=I80+ILMAX1*N1*MAXBED
I82=I81+ILMAX
I83=I82+ILMAX1*N1
I84=I83+ILMAX*N1
I85=I84+ILMAX*N1
I86=I85+ILMAX*N1
I87=I86+ILMAX
I88=I87+ILMAX
I89=I88+N1P1
I90=I89+NITOUT
I91=I90+2*NBDT
I92=I91+N1
I93=I92+ILMAX*N1P1
I94=I93+N1P1
I95=I94+ILMAX
I96=I95+ILMAX
I97=I96+ILMAX
I98=I97+ILMAX
I99=I98+ILMAX
I100=I99+ILMAX
I101=I100+ILMAX
I102=I101+ILMAX
I103=I102+ILMAX
I104=I103+ILMAX
I105=I104+ILMAX1
I106=I105+ILMAX1
I107=I106+ILMAX1
I108=I107+LINKS
I109=I108+N1*NODES
I110=I109+N1
I111=I110+N1
I112=I111+NODES
I113=I112+NODES2
I114=I113+NODES2
I115=I114+N1
I116=I115+ILMAX*N1
I117=I116+N1
I118=I117+ILMAX
IMLAST=I118+ILMAX
IEND=MEMO-IMLAST
WRITE(6,2001) IMLAST,MEMO
2001 FORMAT(/,’T3,’MEMORY=’,I10,T40,’ MEMORY ALLOCATED=’,I10)
IF(IMLAST.GT.MEMO) CALL ERRWAR(3,3,0,0,0,0.)
C
CALL PILOT(T(I1),T(I2),T(I3),T(I4),T(I5),T(I6),T(I7),T(I8),
C

WRITE(6,2002)

2002 FORMAT(''//,T30,'END OF SIMULATION',//,T30,17(1H-))
STOP 9999
END
SUBROUTINE PILOT

SUBROUTINE PILOT (MU, MD, LL, E, F, H, Y, Q, DYN, NSEC, ISECAD, SEgeom,
1 TALWEG, AREA, VEL, RH, FFACT, WIDTH, II, KK, RM, EMAT, FVICT,
2 YN, IYPE, ALPHABET, NINQ, NINQS, QTRIB, QTR, DS,
3 PT, D50R, DSG, D50P, SF, QS, QSTOT, QSP, TDELD, REACH,
4 CDEP, CDEPP, DARM, TALWGP, VOLOUT, ACF, QSTR, D, NGSIZE, RMAT, SMAT,
5 TMAT, VVECT, MPOS, MGROUP, YWORK, IROW, JCOL, JORD, NODNAM, TWORK,
6 LNK Nam, DRYBED, VOLIN, PTT, BZ, LLIM, DELT, TI, TH, PTP, EL1, EL2, PTU,
7 BML, TB)

CHARACTER*4 DRI, BLANK, DRY
CHARACTER*8 TSTEP

REAL*8 RMAT (MAXG, MAXG), SMAT (MAXG, MAXG), TMAT (MAXG, MAXG),
1 VVECT (MAXG), EMAT (MAXG, MAXG), NGROUP, FVICT (MAXG, NGROUP),
2 YWORK (MAXG)

DIMENSION MU (LINKS), MD (LINKS), LL (NODES, KMAX), E (IMAX, LINKS),
1 F (IMAX, LINKS), H (IMAX, LINKS), Y (IMAX, LINKS), Q (IMAX, LINKS),
2 DYN (NODES), NSEC (IMAX, LINKS), ISECAD (NSEC),
3 SEgeom (1), TALWEG (IMAX, LINKS), AREA (IMAX, LINKS),
4 VEL (IMAX, LINKS), RH (IMAX, LINKS), FFACT (IMAX, LINKS),
5 WIDTH (IMAX, LINKS), II (LINKS), KK (NODES), IYPE (LINKS),
6 RM (IMAX, LINKS), NODSDE (NODES),
7 YN (NODES), ALPHABET (IMAX, LINKS), NINQ (NODES),
8 NINQS (NODES), QTRIB (NODES), QTR (NODES), DS (N1P1),
9 PT (IMAX, N1P1, LINKS), D50R (IMAX, N1P1, LINKS), DSG (N1)

DIMENSION D50P (IMAX, LINKS), SF (IMAX, LINKS), QS (IMAX, N1, LINKS),
1 QSTOT (IMAX, LINKS), VISC (72), TF (72), QSP (IMAX, N1, LINKS),
2 TDELD (IMAX, N1, LINKS), REACH (IMAX, LINKS), CDEP (IMAX, LINKS),
3 DARM (IMAX, LINKS), TALWGP (IMAX, LINKS),
4 VOLOUT (IMAX, LINKS), ACF (IMAX, LINKS), QSTR (NODES),
5 D (IMAX, LINKS), NGSIZE (NGROUP), QSNOD (N1), WASHO (N1),
6 MPOS (NODES), MGROUP (NODES), QTRIB (N1, NODES),
7 IROW (MAXG), JCOL (MAXG), JORD (MAXG), NODNAM (NODES),
8 TWORK (IEND), LNK Nam (LINKS), DRYBED (LINKS), IDTCHG (NBDT),

DIMENSION VOLIN (IMAX, N1, LINKS), PTT (IMAX, N1P1, LINKS),
1 BZ (IMAX, N1, LINKS), LLIM (IMAX, LINKS), DELT (IMAX, N1, LINKS),
2 TI (IMAX, N1, LINKS), TH (IMAX, LINKS), PTP (IMAX, N1P1, LINKS),
3 EL1 (IMAX, LINKS), EL2 (IMAX, LINKS), PTP (IMAX, N1P1, LINKS),
4 BML (IMAX, LINKS), TB (IMAX, N1, LINKS), NBEL (IMAX, LINKS),
5 DIMENSION THBED (IMAX, LINKS), PBED (IMAX, N1, MAXBED, LINKS),
1 TALWGI (IMAX, LINKS), PTA (IMAX, N1, LINKS), TITLE (20), W (N1),
2 ARN (IMAX, N1, LINKS), PAC (IMAX, N1, LINKS), ARM (IMAX, N1,
3 LINKS), ACF1 (IMAX, LINKS), CDF (N1P1), TH1 (IMAX, LINKS), ITOUT (NITOUT),
4 PTT (IMAX, N1P1, LINKS), CDF1 (N1P1)

DIMENSION RK (IMAX, LINKS), RPK (IMAX, LINKS), RPK (IMAX, LINKS),
1 AREAP (IMAX, LINKS), YP (IMAX, LINKS), QP (IMAX, LINKS),
2 EP (IMAX, LINKS), TP (IMAX, LINKS), HP (IMAX, LINKS), RL (IMAX, LINKS),
3 RMM (IMAX, LINKS), RN (IMAX, LINKS), TALWGI (IMAX, LINKS),
4 USLINK (LINKS), AC (NODES), BC (NODES), DEGLO (N1)
LOGICAL DRYBED, FIRCAl, PRINT, USLINK, WASHLO, DEGLO

DATA VISC /1.92, 1.89, 1.85, 1.82, 1.79, 1.76, 1.72, 1.69, 1.66, 1.64, 
61.61, 1.58, 1.55, 1.50, 1.48, 1.45, 1.43, 1.41, 1.39, 1.37, 1.34, 
& 1.32, 1.30, 1.28, 1.26, 1.25, 1.23, 1.21, 1.19, 1.17, 1.16, 1.14, 1.13, 
& 1.11, 1.10, 1.08, 1.07, 1.05, 1.04, 1.03, 1.01, 0.999, 0.986, 0.974, 0.961, 
& 0.949, 0.938, 0.926, 0.915, 0.904, 0.893, 0.883, 0.873, 0.862, 0.852, 0.843, 0.833, 
& 0.824, 0.814, 0.805, 0.796, 0.788, 0.779, 0.771, 0.762, 0.754, 0.746, 0.738, 0.731, 0.723, 0.716 /

DATA DRI/' DRY'/',BLANK/' ' /

RETURN

***********************************************

ENTRY PILOT1 (NBEL, THBED, PBED, TALWGI, PTA, ARM, PAC, ARMP, ACF1, 1 TH1, CDF, ITOUT, IDTHCG, TITLE, W, PTPT, CDF1, RK, RPK, RPKP, AREAP, 2 YP, QP, EP, FP, HP, RL, RMM, RN, USLINK, PTRIB, WASHLO, QSJNOD, NODSED, 3 AC, BC, DEGLO, QSCAP, QSOUTF, BANK, TALWGM)

***********************************************

FUNITS=62.4*2.65/2000.
GRAV=32.174
FIRCAl=. TRUE.
VOLMAX=1.0

C-------------------------------------------------------------------------------
C READ NUMERICAL OPTIONS (INPUT RECORD 3,4)
READ(5,1001) ITBEG,ITEND,IDELT,ITMAX,ITREST,IPLINK,IPNODE,
1   IPOINT,IPSECT,NRIN,NROUT,IUNST,IITRIB,ISTRK,IDSBC,
2   IUSBC
IF(ITMAX.LE.0) ITMAX=10
1004 FORMAT(8I10)
WRITE(6,2007)
ITBEG,ITEND,IDELT,ITMAX,ITREST,IPLINK,IPNODE,IPOINT,
1   IPSECT,NRIN,NROUT,IUNST,IITRIB,ISTRK,IDSBC,IUSBC
2007 FORMAT(///,T3,'ITBEG=',I5,T20,'ITEND=',I5,T40,'IDELT=',I5,///,
1   T3,'ITMAX=',I5,T20,'ITREST=',I5,T40,'IPLINK=',I5,///,
2   T3,'IPOINT=',I5,T20,'IPSECT=',I5,///,
3   T3,'NRIN=',I5,T20,'NROUT=',I5,T40,'IUNST=',I5,///,
4   T3,'IITRIB=',I5,T20,'ISTRK=',I5,T40,'IDSBC=',I5,///,
5   T3,'IUSBC=',I5,///)
READ(5,1005) MITMAT,MITHYD,IFFACT,ISEDI,IEXNER,ISORT,IARM,ITERMX
1   ,ITGLMX,IDTMX,IDTTMX

C---------------------------------------------------------------------
C
C
C---------------------------------------------------------------------
C
READ(5,1002) EPSHYD,EPSQ,DRYQ,EPS,EPSYB,FDELTB,WKB0,WKB1
READ(5,1003) SGRAV,POROS,THETA,ADJRE,PHI,FFIMP,ALIMP,BEIMP,THETAS
1   ,TCONST,STRK,SO,CRT,QSDF

C DEFAULT VALUES FOR STEADY FLOW STABILIZATION
C TIME STEP MANAGEMENT

IF(IDTMX.EQ.0) IDTMX=20
IF(IDTMX.EQ.0) IDTTMX=10
IF(FDELTB.EQ.0) FDELTB=IDELT*TCONST/60.0

C TIME STEP PRINTED OUT AS A CHECK FOR USER

IF(TCONST.EQ.86400.) TSTEP='DAYS'
IF(TCONST.EQ.3600.) TSTEP='HOURS'
IF(TCONST.EQ.60.) TSTEP='MINUTES'
IF(TCONST.EQ.1.) TSTEP='SECONDS'
WRITE(6,2005) TSTEP
C
C IF(EPSHYD.EQ.0.0) EPSHYD=0.01
IF(EPSQ.EQ.0.0) EPSQ=100.0
IF(DRYQ.EQ.0.0) DRYQ=100.0
IF(SGRAV.EQ.0.0) SGRAV=2.65
IF(POROS.EQ.0.0) POROS=0.4
IF(THETA.EQ.0.0) THETA=0.5
IF(THETAS.EQ.0.0) THETAS=0.5
IF(ADJRE.EQ.0.0) ADJRE=1.0
WRITE(6,2005) TSTEP
C
WRITE(6,2005) MITMAT,MITHYD,IFFACT,ISEDI,IEXNER,ISORT,IARM,ITERMX
1   ,ITGLMX,IDTMX,IDTTMX
2005 FORMAT(///,T3,'MITMAT=',I5,T20,'MITHYD=',I5,T40,'IFFACT=',I5,///,
1   T3,'ISEDI=',I5,T20,'IEXNER=',I5,T40,'ISORT=',I5,///,
2   T3,'IARM=',I5,T20,'ITERMX=',I5,T40,'ITGLMX=',I5,///,
3   T3,'IDTMX=',I5,T20,'IDTTMX=',I5)
WRITE(6,2006) EPSHYD,EPSQ,DRYQ,EPS,EPSYB,FDELTB,WKB0,WKB1
2006 FORMAT(///,T3,'EPSHYD=',F10.5,T40,'EPSQ=',F10.5,T80,'DRYQ=',///,
1   T3,'EPS=',F10.5,T40,'EPSYB=',F10.5,T80,'FDELTB=',///,
2   T3,'WKB0=',F10.5,T40,'WKB1=',F10.2)
SGRAV, POROS, THETA, ADJRE, PHI, FFIMP, ALIMP, BEIMP, THETAS
1, TCONST, STRK, CRIT, QSDIF

WRITE(6, 2003)

WRITE(6, 3001)

3001 FORMAT(/,'T3, '*** THIS VERSION IS ADAPTED FOR FLUME EXPERIMENT
2 : '/,'T4, '*** ENLARGE QsT0T : QsOUT= QsTOT*1000 IN OUTPUT FILE
3 FOR PLS PLOT -PILOT', '/,'T4, '*** RIVER MILE = FT (RMFT) -PILOT'

2020 FORMAT(/,'T3, 'INTEGER TIME UNITS ARE TAKEN AS ', A8)

C

TRANSFER GENERAL DATA TO NROUT FILE

IF(NROUT.LE.0) GO TO 5
WRITE(NROUT) TITLE
WRITE(NROUT) NODES, KMAX, LINKS, IMAX, N1, NSECS, NLEVMX, NGROUP

READ SEDIMENT SIZES FROM NRIN

DUMMY READ TO SKIP RECORDS 1 & 2

5 IF(NRIN.GT.0) READ(NRIN)
IF(NRIN.GT.0) READ(NRIN)

INPUT RECORD 8 (READ DS(N1+1))

READ(5, 1000) (DS(J), J=1, N1P1)
IF(NRIN.GT.0) READ(NRIN) (DS(J), J=1, N1P1)
IF(NROUT.GT.0) WRITE(NROUT) (DS(J), J=1, N1P1)

READ STANDARD SEDIMENT SIZE

WRITE(6, 2004) (DS(J), J=1, N1P1)

CONVERT mm TO ft

DS(1)=DS(1)/304.8
DO 10 J=2, N1P1
    DS(J)=DS(J)/304.8

    geometric mean size

DSG(J-1)=SQRT(DS(J-1)*DS(J))
10 CONTINUE

READ LINK AND NODE TOPOLOGICAL DATA

IF(NRIN.GT.0) READ(NRIN)
CALL TOPOLO(MU, MD, LL, II, KK, LTYPE, YN, Y, NINQ, NINQS, MPOS, MGROUP, 1 NGSIZE, NODNAM, LNKNAM)
IF(NROUT.GT.0) WRITE(NROUT) MU, MD, LL, KK, LTYPE, YN, Y, NINQ, NINQS,
LOAD POINT DATA FROM RESTART FILE NRIN

READ (NRIN, END=998) IT, DAYS, ITERDT, DYNMAX, DQMAX, DTDAYS
IF (NRIN.GT.0.AND.ITBEG.EQ.ITREST) WRITE (NROUT) IT, DAYS, ITERDT,
DYNMAX, DQMAX, DTDAYS
DO 13 L=1, LINKS
ILAIST=II(I)
DO 13 I=1, ILAIST

READ (NRIN, END=998)

---

TO CONVERT RM & QSTOT BACK TO THE ORIGINAL SCALE
---

RM(I,L)=RMFT/5280.
QSTOT(I,L)=QSTOUT/1000.

READ (NRIN, END=998) (PT(I,J,L), ARM(I,J,L), QS(I,J,L), J=1,N1)
IF (NROUT.GT.0.AND.ITBEG.EQ.ITREST) WRITE (NROUT) L, I,
DUBD(I,L), Y(I,L), Q(I,L), VEL(I,L), RH(I,L), WIDTH(I,L),
TALWEG(I,L), QSTOUT, FFCT(I,L), ACF(I,L), D50P(I,L),
SF(I,L), VOLOUT(I,L), CDEF(I,L), D50R(I,L), NSEC(I,L),
RMFT, ALPH(I,L), BETA(I,L), TALWGI(I,L), BANK(I,L)
IF (NROUT.GT.0.AND.ITBEG.EQ.ITREST) WRITE (NROUT) (PT(I,J,L),
ARM(I,J,L), QS(I,J,L), J=1,N1)

---

CDEF(I,L)=CDEF(I,L)
TALWG(I,L)=TALWEG(I,L)
DO 12 J=1,N1
PTP(I,J,L)=PT(I,J,L)
PTT(I,J,L)=PT(I,J,L)
ARMP(I,J,L)=ARM(I,J,L)
QSP(I,J,L)=QS(I,J,L)

---

READ DATA FOR COMPUTATIONAL POINTS
---

CALL POINTS (NSEC, TALWEG, FFCT, Y, II, RM, Q, ALPHA, BETA, E, LNKAM,
TALWG, NRIN, NODAM, KK, LL, LTYPE, PTRIB, NODSED, NINQS,
BANK)
DO 15 L=1, LINKS
USLXK(L)=.FALSE.
ILAST=II(L)-1
DO 15 I=1,ILAST
    REACH(I,L)=(RM(I+1,L)-RM(I,L))*5280.
15 CONTINUE

IDENTIFY U/S BOUNDARY LINKS

DO 16 M=1,NODES
    KKK=KK(M)
    L=IABS(LL(M,KKK))
    IF(KKK.EQ.1.AND.LL(M,KKK).GT.0) USLINK(L)=.TRUE.
16 CONTINUE

READ BED MATERIAL DISTRIBUTIONS,
LOAD IN POINT ARRAYS

----------------------------------------
INPUT RECORD 12
----------------------------------------

CALL SEDINP(PT,DS,D50R,QS)

READ SEDIMENT SIZE DISTRIBUTION
FOR TRIBUTARY SEDIMENT INFLOW

----------------------------------------
INPUT RECORD 13
----------------------------------------

CALL SEDTRB

READ COEFF. AC AND BC WHICH ARE USED TO
COMPUTE TRIBUTARY SEDIMENT INFLOW

ITRIB <= 0 MEANS NO TRIBUTARY SEDIMENT

IF(ITRIB.LE.0) GO TO 19
WRITE(6,2015)
2 015 FORMAT(/,10X,'COEFFICIENTS AC,BC',/1018('X'))
DO 990 I=1,NTRIB
    DO 970 M=1,NODES
        IF(NINQ(M).EQ.1) GO TO 980
970    CONTINUE
    GO TO 990
990   CONTINUE

----------------------------------------
INPUT RECORD 14
----------------------------------------

980   READ(5,1006,END=24) AC(I),BC(I)
R

990   CONTINUE
    GO TO 19
2 4   CALL ERRWAR(2,26,0,NTRIB,I,0.0)
1 006  FORMAT(2F14.0)
2 014  FORMAT(15X,2F14.8)
C
    IF(NRIN.GT.0) GO TO 25
C
TRANSLATE D50 FROM REACH TO SECTION
DO 21 L=1, LINKS
   ILAST=II(L)
   D50P(1,L)=D50R(1,L)
   D50P(ILAST,L)=D50R(ILAST-1,L)
   DO 22 J=1,N1
      PT(1,J,L)=PT(1,J,L)
      PTPT(1,J,L)=PT(1,J,L)
      PTPT(ILAST,J,L)=PT(ILAST-1,J,L)
   22 CONTINUE
   ILAST1=ILAST-1
   IF(ILAST1.LT.2) GO TO 21
   DO 20 I=2, ILAST1
      DO 23 J=1,N1
         PT(1,J,L)=PT(I,J,L)
         PTPT(I,J,L)=(PT(I,J,L)+PT(I-1,J,L))/2.
      23 CONTINUE
   20 CONTINUE
21 CONTINUE

READ AND PROCESS SECTION DATA

CALL SEXION(TALWEG, AREA, RH, FFACT, WIDTH, Y, NSEC, ISSECAD, SEGEOM, 1 SEGEOM, TWORK, DRYBED, LNKNAM, II, RK, RPK, RKF, RPKF, AREAF)

VERIFY THAT DATA WERE FURNISHED FOR ALL
COMPUTATIONAL POINTS

TWMX=-9999.
TWMN=+9999.
FFMX=-9999.
FFMN=-9999.
RCHMX=-999999.
RCHMN=+999999.
D50MX=-9999.
D50MN=+9999.
ACFMX=-9999.
ACFMN=-9999.
CRELMX=-9999.
CRELMN=+9999.
CREWMX=-99999.
CREWMN=+99999.

DO 18 L=1, LINKS
   IF(NRIN.LE.0) DRYBED(L)=.FALSE.
   ILAST=II(L)
   DO 18 I=1, ILAST
      AREAP(I,L)=AREA(I,L)
      YP(I,L)=Y(I,L)
      QP(I,L)=Q(I,L)
      RPKF(I,L)=RK(I,L)
      RPKP(I,L)=RPK(I,L)
      IF(NSEC(I,L).LE.0) CALL ERRWAR(2,17,0,LNKNAM(L),I,0.)
      IF(FFACT(I,L).EQ.0.0) CALL ERRWAR(2,4,0,LNKNAM(L),I,0.0)
      IF(I.LT.ILAST.AND.D50R(I,L).EQ.0.0)
1      CALL ERRWAR(2,5,0,LNKNAM(L),I,0.0)
      IF(I.LT.ILAST.AND.REACH(I,L).LE.0.0)
1     CALL ERRWAR(2,19,0,LNKNAM(L),I,REACH(I,L))
IF (LTYPE(L) .EQ. 1) GO TO 17
TWMX=AMAX1 (TWMX, TALWEG(I,L))
TWMN=AMIN1 (TWMN, TALWEG(I,L))
FFMX=AMAX1 (FFMX, FFAC(I,L))
FFMN=AMIN1 (FFMN, FFAC(I,L))
D50MX=AMAX1 (D50MX, D50P(I,L))
D50MN=AMIN1 (D50MN, D50P(I,L))
ACFMX=AMAX1 (ACFMX, ACF(I,L))
ACFMN=AMIN1 (ACFMN, ACF(I,L))
IF (I.EQ. ILAST) GO TO 18
RCHMX=AMAX1 (RCHMX, REACH (I,L))
RCHMN=AMIN1 (RCHMN, REACH (I,L))
GO TO 18

1 7 IF (I.EQ. 1) CRELMX=AMAX1 (CRELMX, TALWEG(I,L))
IF (I.EQ. 1) CRELMN=AMIN1 (CRELMN, TALWEG(I,L))
IF (I.EQ. 2) CREWMX=AMAX1 (CREWMX, TALWEG(I,L))
IF (I.EQ. 2) CREWMN=AMIN1 (CREWMN, TALWEG(I,L))
18 CONTINUE

READ LIST OF PRINTED OUTPUT DATES

WRITE (6, 2013) TWMN, TWMX, FFMN, FFMX, D50MN, D50MX, ACFMN, ACFMX,
1 RCHMN, RCHMX, CRELMX, CRELMN, CREWMX, CREWMN
2 FORMAT ('///, T30, 'PHYSICAL DATA CHECKS: ', T60, 'MINIMUM', T70,
1 'MAXIMUM', '/ ', T30, 21 (1H-), T60, 7 (1H-), T70, 7 (1H-), //,
2 T50, 'TALWEG: ', T60, G10.3, T70, G10.3, /, T50, 'FRICITION: ',
3 T60, G10.3, T70, G10.3, /, T50, 'D50: ', T60, G10.3, T70, G10.3,
4 /, T50, 'ARM. FACT. : ', T60, G10.3, T70, G10.3, /, T50, 'REACH: ',
5 T60, G10.3, T70, G10.3, /, T50, 'CR. ELEV.: ', T60, G10.3, T70,
6 G10.3, /, T50, 'CR. WIDTH: ', T60, G10.3, T70, G10.3, ///)

INPUT RECORD 19

READ (5, 1005) (ITOUT (ITPRNT), ITPRNT=1, NITOUT)
WRITE (6, 2009) (ITOUT (ITPRNT), ITPRNT=1, NITOUT)
2009 FORMAT ('///, T5, 'PRINTED OUTPUT DATES: ', (T30, 10I10))

READ LIST OF TIME STEP CHANGES

IF (NBDT. LE. 0) GO TO 42

INPUT RECORD 20

READ (5, 1001) (IDTCHG(I), I=1, NBDT)
WRITE (6, 2010) (IDTCHG(I), I=1, NBDT)
2 FORMAT ('///, T5, 'TIME STEP CHANGES: ', (T30, 10I10))

GENERATE STANDARD TEMP & VISC TABLE

TF(I)=32.0
VISC(I)=VISC(I)*1.0E-5
DO 40 I=2, 72
   TF(I)=TF(I-1)+1.0
   VISC(I)=VISC(I)*1.0E-5
40 CONTINUE
INITIAL SUBROUTINE CALLS TO TRANSFER ARRAY ADDRESSES

CALL DOLINK (MU, MD, LL, E, F, H, EP, FP, HP, Y, XP, Q, QP, DY, AREA,  
1 AREAP, VEL, RH, WIDTH, II, REACH, LTYPE, ALPHA, YN,  
2 BETA, SF, TALWEG, DRYBED, LNKNAM, RM, RK, RKP, RPK, RPKP,  
3 RL, RMM, RN)

CALL SLINKS (Y, Q, TALWEG, ALPHA, BETA, LTYPE)

CALL DONODE (MU, MD, E, F, H, DY, KK, Q, II, YN, NINQ, NINSQ, QTRIB,  
1 QTR, TQMF, NGSIZE, SMAT, RMAT, TMAT, VVECT, EMAT, FVECT,  
2 MGROUP, MPQ, EP, FP, HP, AC, BC, ITRIB, LL, SF)

CALL FRIC (VEL, Q, WIDTH, FFACT, RH, D50P, II, LTYPE, DRYBED)

CALL TLTM (LTYPE, II, QSTOT, RH, SF, DSG, D50P, PTPT, QS, Q, LL, KK, WIDTH,  
1 VEL, DRYBED, ACF, LNKNAM, QSCAP)

CALL ACKER (LTYPE, II, QSTOT, RH, SF, DSG, D50P, PTPT, QS, Q, LL, KK,  
1 WIDTH, VEL, DRYBED, ACF, LNKNAM, QSCAP)

CALL EXNER (QS, QSP, TDEL, REACH, CDEP, CDEPP, DARM, TALWEG, TALWGP,  
1 VOLOUT, LTYPE, II, KK, LL, WIDTH, DRYBED, Q, LNKNAM, DSG,  
2 W, RH, SF, MU, NODSEP, VEL, QTR, NINQ, PTRIB, PTT, BANK)

CALL USTLM (D50R, D50P, AREA, VEL, Q, FFACT, RH, X, D, QSTR, ACF,  
1 WIDTH, REACH, TALWEG, TALWGP, SF, VOLOUT,  
2 QSTOT, II, LL, LNKNAM, DRYBED)

CALL GAUJ (YWOR, IROW, JCOL, JORD)

CALL LODMAT (MPQ, E, F, H, II, MU, MD, KK, Q, NINQ, QTRIB, QTR, TEMPF, LL,  
1 MGROUP, EP, FP, HP, YN, RK, RPK, DY, SF)

INPUT RECORD 21 & 22

CALL DAARMO (ACF, ACF1, PT, DSG, CDEP, PTT, VOLOUT, WIDTH, SF,  
& D50R, THBED, ETA, NEEL, TALWGP, PBED, Q, RH, DARM, EL1, ARM, PAC,  
& TDEL, ARM, II, LTYPE, NRIN)

CALL DAHYHOS (VOLIN, TALWEG, D50R, PT, PTT, QS, SF, ACF,  
1 RH, BZ, TDEL, VOLOUT, LLLM, DELT, TI, TH, TH1, PT, EL1, EL2,  
2 PTT, BM, TB, NEEL, THBED, PBED, CDEP, DSG, LNKNAM)

CALL NODSEP (KK, LL, DRYBED, Q, LTYPE, REACH, WIDTH, QSTOT, D50R,  
1 D50P, PT, CDF, DS, PTTPT, TALWEG, TALWGP, CDEP, NODSEP, II, Q,  
2 PTRIB, NINQ, NODSEP, QTR, TDEL, NINQ, ACF, FFACT, RH, SF, DSG, W, QSJNOD,  
3 WASHLO, LNKNAM, VOLOUT, DEGLO, VEL, QSCAP, QOUTF)

CALL ENHAN (LTYPE, II, LL, KK, LNKNAM, RH, WIDTH, SF, VEL, Q, DSG,  
1 D50P, PTPT, QS, QSTOT, ACF, DRYBED, QSCAP)

CALL USENHA (D50P, AREA, VEL, ACF, FFACT, RH, X, D, QSTR, ACF,  
1 WIDTH, REACH, TALWEG, TALWGP, SF, VOLOUT,  
2 QSTOT, II, LL, LNKNAM, DRYBED)

CALL COEFF (AREA, AREAP, XP, Y, QP, Q, REACH, WIDTH, ALPHA, BETA,  
1 RK, RKP, RPK, RPKF, DRYBED)
CALL DASHIE
CALL CRITER(RH, SF, DSG, W, VEL)
CALL FLOCA(MU, MD, LL, E, F, H, EP, FP, HP, Y, YP, Q, QP, DYN, AREA,
1 AREAP, VEL, RH, WIDTH, II, REACH, LTYPE, ALPHA, YN,
2 BETA, SF, TALWEG, DRYBED, LNKNAM, RM, RK, RKP, RPK, RPKP,
3 RL, RMM, RR, KK, NINQ, NINQS, QTIB, QTR, TEMPF,
4 NGSIZE, SMAT, RMAT, TMAT, VVECT, EMAT, FVECT, MGROUP, MPOS,
5 D50P)

CALL TMCHG
CALL DSCB(LL, E, F, H, RK, RPK, NINQ, Q, QTR, YN, DYN, SF)
CALL POWFCT(LTYPE, II, LL, KK, LNKNAM, RH, WIDTH, SF, VEL, Q, DSG,
1 D50P, PTPT, QS, QSTOT, ACF, DRYBED, QSCAP)
CALL USPOW(D50R, D50P, AREA, VEL, Q, FFACT, RH, Y, D, QSTR, ACF,
1 WIDTH, REACH, TALWEG, TALWGP, SF, VOLOUT,
2 QSTOT, II, LL, LNKNAM, DRYBED)
CALL USACK(D50R, D50P, AREA, VEL, Q, FFACT, RH, Y, D, QSTR, ACF,
1 WIDTH, REACH, TALWEG, TALWGP, SF, VOLOUT,
2 QSTOT, II, LL, LNKNAM, DRYBED)

WRITE(6,2008) IERR, IWAR
2008 FORMAT(///, T10,'PREPARATORY OPERATIONS COMPLETED WITH', I5,
1 'ERRORS AND', I5, 'WARNINGS', ///, T10, 70(1H.))
IF(IERR.GT.0) STOP

INBDT=1
ITBEG=ITBEG
ITEND=ITEND
ITIME=ITBEG-IDELT
IT=0

UPDATE TIME STEP

IF(NRIN.LE.0) GO TO 45
INBDT=INBDT-2
46 INBDT=INBDT+2
IF(ITIME.GT.IDTCHG(INBDT).AND.INBDT.LE.NBDT) GO TO 46
45 IF(ITIME.LT.IDTCHG(INBDT).OR.INBDT.GT.NBDT) GO TO 47
IDELT=IDTCHG(INBDT+1)
INBDT=INBDT+2
47 ITIME=ITIME+IDELT
7 IT=IT+1
IF(ITIME.GT.ITEND.OR.IT.GT.ITMAX) GO TO 500

PERMIT PRINTING OF THE INITIAL CONDITION

IF(IT.EQ.1) GO TO 420
ITERDT=0
BEGINNING OF THE GLOBAL ITERATION LOOP

ITERDT=ITERDT+1
DO 49 L=1,LINKS
   ILAST=II(L)
   IF(LTYPE(L).NE.0) GO TO 49
   DO 49 I=1,ILAST
      TALWGM(I,L)=TALWEG(I,L)
49 CONTINUE
DELDZM=0.0

WATER FLOW COMPUTATION

CALL FLOCAL(DETER,FIRCAL)

IF(DETER.EQ.0.0) PRINT=.TRUE.
IF(DETER.EQ.0.0) GO TO 425

EXTRACT VISCOSITY FROM THE TABULATION

DO 50 I=1,72
   IF(TEMPF.LE.TF(I)) GO TO 60
50 CONTINUE
I=72

VIS=VISC(I)

IF(ITIME.LT.0) GO TO 420

SEDIMENT DISCHARGE COMPUTATION

IF(ISEDI.EQ.0) GO TO 420
IF(ISEDI.EQ.1) CALL TLTMQS
IF(ISEDI.EQ.2) CALL ENHAN1
IF(ISEDI.EQ.3) CALL POWFQS
IF(ISEDI.EQ.4) CALL ACKQS

C*******GO TO 66

TRANSPORT

CAPACITIES
NOTE: ARRAYS VOLIN AND DELT ARE USED FOR
THE E,F COEFFICIENTS OF THE
DOUBLE SWEEP.

PDUMP: IBM PACKAGE FOR DEBUG (NOT USED NOW)

C****IF(IT.GE.5.AND.IT.LE.10) CALL PDUMP(QS(1,1,1),QS(19,1,1),5)
   DO 65 L=1,LINKS
C
   IF KARIM (NORMAL) UPSTREAM CONDITION IS USED
   (1) LOAD QS-imposed (BY SIZE FRACTION)
   AT U/S POINT INSTEAD OF LOCAL TRANSPORT
CAPACITY AT THE SAME POINT. ALSO
(2) LOAD Qs-imposed AT U/S POINT AS QSTOT
JUST FOR PRINTOUT & GRAPHIC USE

IF(IUSBC.EQ.0.AND.NINQS(MU(L)).NE.0) THEN
  DO 64 J=1,N1
  64 QS(I(I(L),J,L)=QTR(NINQS(MU(L)))*PTRIB(J,MU(L))
  QSTOT(I(I(L),L)=QTR(NINQS(MU(L)))
END IF

ILAST=II(I(L))-1
DO 61 I=1,ILAST
  DXBAR=0.5*(REACH(I-1,L)+REACH(I,L))
  PDIF=-QSIF*IDEKT*TCONST/DXBAR/REACH(I-1,L)
  RDIF=PDIF*REACH(I-1,L)/REACH(I,L)
  SMOOTHING Qs
  QDIFF=1.-PDIF/RDIF
  DO 61 J=1,N1
    SDIF=-QS(I,J,L)
    IF(I.EQ.2) VOLIN(I,J,L)=0.0
    IF(I.EQ.2) DELT(I,J,L)=QS(1,J,L)
    DENOM=PDIF*VOLIN(I-1,J,L)+QDIFF
    VOLIN(I,J,L)=-RDIF/DENOM
    DELT(I,J,L)=(-SDIF-PDIFF*DELT(I-1,J,L))/DENOM
  CONTINUE
  I=ILAST
  62 QSTOT(I,L)=0.0
  DO 63 J=1,N1
    QS(I,J,L)=VOLIN(I,J,L)*QS(I+1,J,L)+DELT(I,J,L)
    QSTOT(I,L)=QSTOT(I,L)+QS(I,J,L)
  CONTINUE
  I=I-1
  IF(I.GT.1) GO TO 62
  65 CONTINUE
  66 CONTINUE

C***IF(IT.GE.5.AND.IT.LE.10) CALL PDUMP(QS(1,1,1),QS(19,1,1),5)

APPLY EXNER EQ. TO COMPUTE BED EVOLUTION
IN EACH REACH

IF((IT.EQ.2.AND.NRN1.LE.0).OR.IEXNER.EQ.0) GO TO 420
CALL EXNER1(FIRCAL,USLNX)
CALL NODSD2

PROCEED SORTING PROCEDURE IF ISORT.NE.0

IF(ISORT.EQ.0) GO TO 72
DO 70 L=1,LINKS
  IF(DRYBED(L).OR.LTYPE(L).NE.0) GO TO 70
  ILAST=II(L)-1
  DO 69 I=1,ILAST
    IF(ABS(Q(I,L)).LT.DRYQ.OR.ABS(Q(I+1,L)).LT.DRYQ) GO TO 69
  CONTINUE
  70 CONTINUE
IF(ISORT.EQ.1) THEN
   CALL HYSORT(I,L,FIRCAL)
ELSE
   CALL HYSOR2(I,LNKNAM(L),ACF(I,L),RH(I,L),VOLOUT(I,L),
            SP(I,L),D50R(I,L),TDELD(I,1,L),PT(1,1,L),
            PTT(1,1,L),WIDTH(1,L),WIDTHP(1,L),TALWEG(1,L),
            WE DO NOT HAVE WIDTHP IN SECPRO NOW
            USE WIDTHP=WIDTH IN HYSOR2 FOR THE TIME
C***
C
BEIN
C
PTT(1,1,L),WIDTH(1,L),TALWEG(1,L),
TALWGP(1,L),PTP(1,1,L),REACH(I,L),
QS(1,1,L),QSP(1,1,L),EL1(I,L),TMP(I),DSG(1))

END IF
C
69 CONTINUE
70 CONTINUE
C
CONTINUITY
C
U/S BOUNDARY CONDITION (IUSBC=0 : NORMAL
   (IUSBC.NE.0: CUNGE'S

CONDTI.)
72 IF(IUSBC.EQ.0) GO TO 333
72 DO 75 M=1,NODES
    KKK=KK(M)
    QSTR(M)=0.0
    L=IABS(LL(M,KKK))
    IF(.NOT.USLNK(L).OR.DRYBED(L).OR.ABS(Q(II(L),L)).LT.DRYQ
1    .OR.ABS(Q(II(L)-1,L)).LT.DRYQ) GO TO 75
    IF(LL(M,KKK).LT.0) GO TO 75
    QSTR(M)=QTR(NINQS(M))
C
C
CC***** WRITE(*,38)QSTR(M),QTR(NINQS(M))
   FORMAT(1X,'QSTR(M)='.2F12.6)
   IF(ISEDI.EQ.1) CALL USTLT1(M,FIRCAL)
   IF(ISEDI.EQ.2) CALL USENH1(M,FIRCAL)
   IF(ISEDI.EQ.3) CALL USFOW1(M,FIRCAL)
   IF(ISEDI.EQ.4) CALL USACK1(M,FIRCAL)
75 CONTINUE
C
C
CHECK
C
CC
CC
333 CALL EXNER2
C
C
IF(ISORT.EQ.0.OR.IARM.EQ.0) GO TO 145
C
C
DO 80 L=1,LINKS
   IF(DRYBED(L).OR.
1   LTYPE(L).NE.0) GO TO 80
   ILAST=II(L)-1
C
C
PROCEED ARMORING PROCEDURE
C

DO 79 I=1,ILAST
   IF(ABS(Q(I,L)).LT.DRYQ.OR.ABS(Q(I+1,L)).LT.DRYQ)
      CALL ARMOR(I,L,FIRCAL)
   GO TO 79
7 9 CONTINUE
8 0 CONTINUE

RECALCULATION OF SEDIMENT D50. AFTER SEDIMENTATION IN EACH TIME STEP BY USING THE VALUE FROM HYSORT

1 45 IF(ISORT.EQ.0) GO TO 210
   DO 300 L=1,LINKS
      IF(DRYBED(L).OR.
         LTYPE(L).NE.0) GO TO 300
      ILAST=II(L)-1
      DO 286 I=1,ILAST
         IF(ABS(Q(I,L)).LT.DRYQ.OR.ABS(Q(I+1,L)).LT.DRYQ) GO TO 286
         CDF(I)=0.0
         DO 280 J=2,N1P1
            CDF(J)=CDF(J-1)+PT(I,J-1,L)
            IF(CDF(J).GE.0.5) GO TO 285
         CONTINUE
2 80 CONTINUE
2 85 D50R(I,L)=DS(J-1)+(0.5-CDF(J-1))/(CDF(J)-CDF(J-1))
   @ (DS(J)-DS(J-1))
   IF(CDF(J).EQ.0.5) D50R(I,L)=DS(J)
2 86 CONTINUE

TRANSLATE D50R AND ACF FROM REACHES TO SECTION

ACF(II(L),L)=ACF(ILAST,L)
ACFI=ACF(I,L)
D50F(I,L)=D50R(I,L)
D50P(II(L),L)=D50R(ILAST,L)
   DO 292 J=1,N1
      PTPT(I,J,L)=PT(I,J,L)
      PTPT(II(L),J,L)=PT(ILAST,J,L)
   CONTINUE
2 92 CONTINUE
   IF(ILAST.LT.2) GO TO 300
   DO 290 I=2,II(L)
      IF(I.EQ.II(L)) GO TO 297
      D50P(I,L)=(D50R(I,L)+D50R(I-1,L))/2.0
   CONTINUE
2 90 CONTINUE

*** CHECK(11/30/1989)
*** PRINT *, 'I-1,I,D50RI-1,D50RI,D50PI ',I-1,I,D50R(I-1,L)*304.8,
*** $ D50R(I,L)*304.8,D50P(I,L)*304.8

   DO 291 J=1,N1
      PTPT(I,J,L)=(PT(I,J,L)+PT(I-1,J,L))/2.
   CONTINUE
ACFI1=ACFI
   ACFI=0.5*(ACF(I-1,L)+ACF(I,L))
   ACF(I-1,L)=ACFI1
2 90 CONTINUE
3 00 CONTINUE

NODAL SEDIMENT CONTINUITY
VERSION OF FEB. 1986
CALL NODSD1
CALL NODSD3
DO 215 L=1,LINKS
ILAST=II(L)
IF(LTYPE(L).NE.0) GO TO 215
DO 215 I=1,ILAST
DELDZ=ABS(TALWEG(I,L)-TALWGM(I,L))
IF(DELDZ.GT.DEILDZM) DEILDZM=DELDZ
215 CONTINUE
IF(ITERD.T.LT.MITMAT.AND.DEILDZM.GT.CRIT) GO TO 48

END OF THE GLOBAL ITERATION LOOP

FIRCAL=.FALSE.
PRINT=.TRUE.
DO 423 IPRNT=1,NITOUT
IF(IABS(ITIME-ITOUT(IPRNT)).LT.IDELT) GO TO 425
423 CONTINUE
PRINT=.FALSE.

PRINTED OUTPUT CYCLE

LINE=53
VOLUME=0.0

CHANGE ITIME AND IDELT TO DECIMAL DAYS
FOR COMPATIBILITY WITH PLIAL5

DAYS = ITIME*TCONST/86400.0
DTDAYS = IDELT*TCONST/86400.0

IF(NROUT.GT.0) WRITE(NROUT) IT,DAYS,ITERDT,DYNMAX,DQMAX,DTDAYS

OUTPUT RECORD 5

IF(.NOT.PRINT) WRITE(6,2012) IT,ITIME,IDELT,ITERDT,DQNMAX,
DYNMAX,DEILDZM,Q(I,1)

1 DO 450 L=1,LINKS
1 IF(PRINT) WRITE(6,2001)
1 LINE=LINE+1
1 IF(MOD(LINE,55).EQ.0.AND.PRINT) WRITE(6,2000) IT,ITIME,
1 IDELT,ITERDT,DQNMAX,DYNMAX,DEILDZM

DYNMAX,DEILDZM

1 IF(DRYBED(L)) DRY=DRI
ILAST=II(L)
DO 450 I=1,ILAST
1 D50PP=D50PP(I,L)*304.8
1 DEG=TALWGI(I,L)-TALWEG(I,L)
1 IF(Q(I,L).NE.0.0) FR2=WIDTH(I,L)*(VEL(I,L)**3)/
1 (GRAV*Q(I,L))
1 LINE=LINE+1
1 IF(MOD(LINE,55).EQ.0.AND.PRINT) WRITE(6,2000) IT,ITIME,
1 IDELT,ITERDT,DYNMAX,DQMAX,DEILDZM
1 IF(IT.EQ.1.OR.ITIME.LE.0) GO TO 430
IF (I.LT.ILAST) VOLUME = VOLUME + REACH (I, L) * 0.25 * (WIDTH(I, L) +
                  WIDTH(I+1, L) - TALWEG(I, L) - TALWEG(I+1, L))
                  I+1, L) - TALWEG(I+1, L))
430 IF (PRINT) WRITE (6, 2002) LNKNAM(L), I, DRY, RM(I, L), Y(I, L),
1 Q(I, L), VEL(I, L), RH(I, L), WIDTH(I, L), TALWEG(I, L),
2 QSTOT(I, L), FFACT(I, L), DEG, ACF(I, L), D50PP,
3 SF(I, L), VOLOUT(I, L), FR2

***** RIVER MILES CONVERTED TO FEET FOR THE NTU FLUME SIMULATIONS
FOR USE WITH PLIAL5.

RMFT = RM(I, L) * 5280.0

***** QSTOT ENLARGED TO 1000 * QSTOT FOR THE NTU INDOOR FLUME
IMULATIONS
FOR USE WITH PLIAL5.

QSTOT = QSTOT(I, L) * 1000.
IF (NRGUT.GT.0) WRITE (NRGUT) L, I, DRYBED (L), Y(I, L), Q(I, L),
1 VEL(I, L), RH(I, L), WIDTH(I, L), TALWEG(I, L), QSTOT,
2 FFACT(I, L), ACF(I, L), D50PP, SF(I, L), VOLOUT(I, L),
3 CDEP (I, L), D50R(I, L), NSEC(I, L), RMFT, ALPHA(I, L),
4 BETA(I, L), TALWGI(I, L), BANK(I, L)
IF (NRGUT.GT.0) WRITE (NRGUT) PT(I, J, L), ARM(I, J, L),
1 QS(I, J, L), J=1, NL
CDEPP(I, L) = CDEP(I, L)
TALWGP(I, L) = TALWEG(I, L)
DO 440 J=1, NL
   PTF(I, J, L) = PT(I, J, L)
   ARMP(I, J, L) = ARM(I, J, L)
   QSP(I, J, L) = QS(I, J, L)
440 CONTINUE

4 40 CONTINUE
4 50 IF (IT.EQ.1) GO TO 45

FOR TESTING SUPERCritical CASE (DEC.8, '88)

4 99 IF (DETER.EQ.0.0) STOP 1984
C: CC499 IF (DETER.EQ.0.0) CONTINUE
   GO TO 45
5 00 CONTINUE
   GO TO 999
4 3 FORMAT(/, 'C, 70 ('*', ', '15X, '*, ', '68X, '*, ', '15X, '*, ', '68X, '*, ',
*, '15X, '*, ', '9X, 'MAXIM. VALUE OF TIME INTERVAL WHICH WILL NOT ',
*, 'VIOLATE', '8X, '*, ', '15X, '*, ', '23X, 'SEDIMENT CONTINUITY IS',
*, '23X, '*, ', '15X, '*, ', '23X, 'SEDIMENT CONTINUITY IS',
*, 'I10, '13X, '*, ',
*, '15X, '*, ', '68X, '*, ', '15X, '*, ',
*, '3X, 'DEGR. VOL. (Sed. Cont.) =', 'E12.5, '2X, 'CFT', ', ('', 'E12.5, '2X,
*, 'TONS/YR ) , ', 'T85, '*, ', '15X, '*, ',
*, '3X, 'DEGR. VOL. (Profile) =', 'E12.5, '2X, 'CFT', ', ('', 'E12.5, '2X,
*, 'TONS/YR ) , ', 'T85, '*, ', '15X, '*: ', '3X,
3 'CURRENT SCOUR RATE =', 'E12.5, 'TONS/YR', 'T85, '*/,
* 15X,70(1H*),//)
1000 FORMAT(8F10.0)
1001 FORMAT(16I5)
1002 FORMAT(8F10.0)
1003 FORMAT((8F10.0))
1005 FORMAT(16I5)
2003 FORMAT(///,T3,'SGRav=',F10.4,T40,'FROs=',F10.4,T80,'THETA=',',
1     F10.2, ///,T3,'ADJRe=',F10.2,T40,'PHI=',',F10.2,T80,'FFIMP=',
2     F10.3, ///,T3,'ALIMP=', F10.2,T40,'BEIMP=',
3     F10.2,T80,'THETAS=',',
4     F10.2, ///,T3,'TCONG=',F10.2,T40,'STRK=',',F10.2,T80,'CRIT=',',
4     G10.2, ///,T3,'QSDIF=',G10.3)
2004 FORMAT(///,T20,'BED MATERIAL SIZES (DS)',//,T20,24(1H-),
1     (T45,10F8.3))
2000 FORMAT(1H1,T3,'IT=',I4,' ITIME=',I5,
1     ' IDELT=',I10,' ITERDT=',I5,
1     ' DELQM=',G10.3,' DELYM=',G10.3,' DELZM=',G10.3,
1     '//,T4,'LINK',T9,'PT',T17,'STATION',
2     T27,'STAGE',T36,'DISCHG',T46,'VEL',T52,'RH',
3     T58,'WIDTH',T65,'THALWEG',T74,'SED LOAD',T84,'FFACT',T90,
4     ' DEG',T96,'ARM',T102,'D50',T112,'SF',T120,'VOLOUT',
5     T129,'FR2',//,T2,130(1H-))
2001 FORMAT(1X)
1     T42,F7.2,T49,F6.2,T55,F8.2,T63,F9.3,T72,G10.3,
2     T82,F6.3,T89,F7.5,T96,F6.3,T102,F7.3,T109,G10.3,
3     T119,G9.2,T129,F3.1)
2012 FORMAT(///,T5,'IT=',I5,' ITIME=',I10,
1     ' IDELT=',I5,' ITERDT=',I5,' DQNM=',G10.3,
2     ' DYNMAX=',G10.3,' D2M=',G10.3,' OUTFLOW=',F10.2)
998 CALL ERRWAR(2,21,0,ITREST,IFIX(DAYS*86400./TCONST),DAYS)
999 RETURN
C%%%%%%%%%%%%%%%% 2ND LAST LINE OF PILOT %%%%%%%%%%%%%%%%%%%
END
SUBROUTINE DSBC (LL, E, F, H, RK, RPK, NINQ, Q, QTR, YN, DYN, SF)

DIMENSION LL(NODES, KMAX), E(IMAX, LINKS), F(IMAX, LINKS),
1 RK(IMAX, LINKS), RPK(IMAX, LINKS), NINQ(NODES2), H(IMAX, LINKS),
2 Q(IMAX, LINKS), QTR(NODES2), YN(NODES), DYN(NODES), SF(IMAX, LINKS)

COMMON/DIMS/NODES, KMAX, LINKS, IMAX, MEMO, NODESI, NTRIB, N1, IMAXM1
1 , N1P1, NGROUP, MAXG, IMLAST, NSECS, NLEVMAX, IERR, IWAR,
2 MAXBED, NITOUT, NBDT, IEND, NODES2
COMMON/SCALR/GRAV, POROS, SGRAV, VIS, THETA, IT, IDELT, ITIME, PHI, EPS
1 , FDELTE, FFIMP, ALIMP, BEIMP, THETAS, TCONST, STRK, S0
RETURN

ENTRY DSBC1 (M)

ALLOW ONLY ONE LINK ATTACHED TO THE D/S NODE

L=IABS (LL(M, 1))
I=1
SF(I, L) = S0
AL = SQRT (SF(I, L) * RPK(I, L))
BETA = -1.0
GAMA = Q(I, L) - SQRT (SF(I, L) * RK(I, L))
DYN(M) = (GAMA / BETA - F(I, L)) / (E(I, L) + AL / BETA)
QTR(IABS(NINQ(M)) = YN(M) + DYN(M)
H(1, L) = 0.0
RETURN
END
SUBROUTINE SLINKS

DIMENSION X(IMAX,LINKS),Q(IMAX,LINKS),
1 TALWEG(IMAX,LINKS),ALPHA(IMAX,LINKS),
2 LTYPE(LINKS),BETA(IMAX,LINKS)

COMMON/DIMS/NODES,KMAX,LINKS,IMAX,MEMO,NODESI,NTRIB,N1,IMAXM1
1 ,N1P1
COMMON/SCALR/GRAV,POROS,SGRAV,VIS,THETA,IT,IDELT,ITIME PHI, EPS

RTEPS=0.5
ROOT2G=SQRT(2.0*GRAV)
WCONST=ROOT2G*SQRT(1./3.)*2./3.

GO TO 999

ENTRY SLINK1(L,A,B,C,D,G,AP,BP,CP,DP,GP,*

I=LTYPE(L)
GO TO (100,999), I

CONSIDER AS RECTANGULAR WEIR
DETERMINE UPSTREAM,DOWNSTREAM WATER LEVEL

100
AP=0.0
BP=1.0
CP=0.0
DP=1.0
GP=Q(1,L)-Q(2,L)
YW=TALWEG(1,L)
WIDTH=TALWEG(2,L)
YUS=Y(2,L)
QUS=Q(2,L)
YDS=Y(1,L)
QDS=Q(1,L)
DEPDF=YUS-YDS
IF(DEPDF.GE.0.) GO TO 200
YDS=YUS
QDS=QUS
QUS=Q(1,L)
YUS=Y(1,L)

DETERMINE IF FLOW IS POSSIBLE

200
IF(YUS.LE.YW) WIDTH=0.1*WIDTH
IF(YUS.LE.YW) YW=YUS-RTEPS*RTEPS
IF(ABS(YUS-YDS).GT.EPS) GO TO 250
DFUS=ALPHA(1,L)*WIDTH*ROOT2G*(YDS-YW)*SQRT(EPS)/EPS
DFDS=ALPHA(1,L)*WIDTH*ROOT2G*SQRT(EPS)*(YW-YDS)/EPS
F=ALPHA(1,L)*WIDTH*ROOT2G*(YDS-YW)*SQRT(EPS)*(YUS-YDS)/EPS
GO TO 350

CHECK FOR FLOODED/FREE FLOWING

IF(YDS-YW.LT.2./3.*(YUS-YW)) GO TO 300

THE FOLLOWING IS FOR FLOODED CASE

DFDS=ALPHA(1,L)*WIDTH*ROOT2G*((YW-YDS)*0.5/(YUS-YDS)**0.5)
1*(YUS-YDS)**0.5
DFUS=ALPHA(1,L)*WIDTH*ROOT2G*(YDS-YW)*0.5/(YUS-YDS)**0.5
F=ALPHA(1,L)*WIDTH*ROOT2G*(YUS-YDS)**0.5*(YDS-YW)
GO TO 350

THE FOLLOWING IS FOR FREE FLOWING CASE

DFDS=0.0
DFUS=BETA(1,L)*WIDTH*ROOT2G*SQRT(1./3.)*(YUS-YW)**0.5
F=BETA(1,L)*WIDTH*WCONST*(YUS-YW)**1.5
IF(DEPDF.LT.0.) GO TO 400

FLOW FROM TOPOLOGICAL UPSTREAM TO DOWNSTREAM

A=DFUS
C=-DFDS
G=QUS-F
GO TO 450

FLOW FROM TOPOLOGICAL DOWNSTREAM TO UPSTREAM

A=-DFDS
C=DFUS
G=QDS+F
450 B=-1.0
D=0.0
WRITE(6,SLKCHK)
999 RETURN 1
END
C#FIRST CARD OF GAUJOR ####################################
C
SUBROUTINE GAUJOR(YWORK, IROW, JCOL, JORD)
C
REAL*8 YWORK(N), A(N,N), PIVOT
C
DIMENSION IROW(N), JCOL(N), JORD(N)

EPS=0.00001
GO TO 999
C
C
ENTRY INVERT(A,N,DETER)
C
C
INVERT SQUARE MATRIX A(N,N) IN PLACE BY GAUSS-
JORDAN ELIMINATION
C
BEGIN ELIMINATION PROCEDURE

5
DETER=1.
DO 18 K=1,N
   KM1=K-1
   DETER=DETER*A(KM1,KM1)

18

SEARCH FOR THE PIVOT ELEMENT
C
C
PIVOT=0.
DO 11 I=1,N
   DO 11 J=1,N
      SCAN IROW AND JCOL ARRAYS FOR
      INVALID PIVOT SUBSCRIPTS
      IF(K.EQ.1) GO TO 9
      DO 8 ISCAN=1,KM1
         DO 8 JSCAN=1,KM1
            IF(I.EQ.IROW(ISCAN)) GO TO 11
            IF(J.EQ.JCOL(JSCAN)) GO TO 11
            CONTINUE
         8
      IF(DABS(A(I,J)).LE.DABS(PIVOT)) GO TO 11
      PIVOT=A(I,J)
      IROW(K)=I
      JCOL(K)=J
   11 CONTINUE
C
C
INSURE THAT SELECTED PIVOT IS
LARGER THAN EPS
C
IF(DABS(PIVOT).GT.EPS) GO TO 13
WRITE(6,2000) N,A
2000 FORMAT(1X,15,,(10G10.3))
DETER=0.
GO TO 999
C
C
UPDATE THE DETERMINANT VALUE
C
13
IROWK=IROW(K)
JCOLK=JCOL(K)
DETER = DETER * PIVOT

NORMALIZE PIVOT ROW ELEMENTS

DO 14 J = 1, N
  A(IROWK, J) = A(IROWK, J) / PIVOT
  CONTINUE

CARRY OUT ELIMINATION AND DEVELOP INVERSE

A(IROWK, JCOLK) = 1. / PIVOT
DO 18 I = 1, N
  AIJCK = A(I, JCOLK)
  IF (I.EQ. IROWK) GO TO 18
  A(I, JCOLK) = -AIJCK / PIVOT
  DO 17 J = 1, N
    IF (J.NE. JCOLK) A(I, J) = A(I, J) - AIJCK * A(IROWK, J)
  CONTINUE
DU0
CONTINUE

ORDER SOLUTION VALUES (IF ANY) AND CREATE BJORD ARRAY

DO 20 I = 1, N
  IROWI = IROW(I)
  JCOLI = JCOL(I)
  JORD(IROWI) = JCOLI
  CONTINUE

ADJUST SIGN OF DETERMINANT

INTCH = 0
NM1 = N - 1
DO 22 I = 1, NM1
  IP1 = I + 1
  DO 22 J = IP1, N
    IF (JORD(J) .GE. JORD(I)) GO TO 22
    JTEMP = JORD(J)
    JORD(J) = JORD(I)
    JORD(I) = JTEMP
    INTCH = INTCH + 1
  CONTINUE
22
IF (INTCH / 2 * 2 .NE. INTCH) DETER = -DETER

UNSCRAMBLE THE INVERSE FIRST BY ROW

DO 28 J = 1, N
  DO 27 I = 1, N
    IROWI = IROW(I)
    JCOLI = JCOL(I)
    YWORK(JCOLI) = A(IROWI, J)
  CONTINUE
27
DO 28 I = 1, N
  A(I, J) = YWORK(I)
28
CONTINUE

THEN BY COLUMNS
C
   DO 30 I=1,N
   DO 29 J=1,N
      IROWJ=IRGW(J)
      JCOLJ=JCOL(J)
      YWORK(IROWJ)=A(I,JCOLJ)
   29 CONTINUE
   DO 30 J=1,N
      A(I,J)=YWORK(J)
   30 CONTINUE
C
C
999 RETURN
C
C
END
SUBROUTINE MATMLT(A, U, T, M, N, P)

INTEGER P
REAL*8 A(M,N), B(M,N), C(M,N), T(M,P), U(N,P), X(N), Y(N), Z(M), S
DIMENSION V(N,M)
CALL RAZ(T,M*P*2)
DO 2 I=1,M
     DO 2 J=1,P
          DO 2 K=1,N
          T(I,J)=A(I,K)*U(K,J)+T(I,J)
 2 CONTINUE
C(M, N)=A(M,N)+B(M,N)

ENTRY MATADD(A, B, C, M, N)

DO 3 I=1,M
     DO 3 J=1,N
        C(I,J)=A(I,J)+B(I,J)
 3 CONTINUE
C(M, N)=A(M,N)-B(M,N)

ENTRY MATSUB(A, B, C, M, N)

DO 4 I=1,M
     DO 4 J=1,N
        C(I,J)=A(I,J)-B(I,J)
 4 CONTINUE
Z(M)=A(M,N)*X(N)

ENTRY MATVEC(A, X, Z, M, N)

CALL RAZ(Z,M*2)
DO 6 I=1,M
     DO 6 J=1,N
        Z(I)=A(I,J)*X(J)+Z(I)
 6 CONTINUE
RETURN
\[ Y(N) = S \times X(N) \]

**ENTRY SCAVEC(S, X, Y, N)**

**ENTRY SCAMAT(S, A, B, M, N)**

\[ B(M, N) = S \times A(M, N) \]

\[ S = X(N) \times Y(N) \]

**ENTRY VECVEC(X, Y, S, N)**

\[ S = 0.0 \]

\[ X(N) = Z(M) \times A(M, N) \]

\[ B(M, N) = A(M, N) \]

**ENTRY MATEQ(A, B, M, N)**
SUBROUTINE ERWRD(IEW, NO, IT, L, I, PARAM)
COMMON/DIMS/NODES, KMAX, LINKS, IMAX, MEMO, NODESI, NTRIB, N1, IMAXM1,
1,
N1P1, NGROUP, MAXG, IMLAST, NSEC, NLEVMX, IERR, IWAR

IF(IEW.GE.2) GO TO 100
WRITE(6,2000) NO, IT, L, I, PARAM
2000 FORMAT(1X,20(IH-), ' WARNING NO. ', I2, ' IT=', I3, ' ID1=', I5,
1, ' ID2=', I5, ' PARAM=', G20.10)
IWAR=IWAR+1
GO TO 999
100 WRITE(6,2001) NO, IT, L, I, PARAM
2001 FORMAT(' ERROR NO. ', I2, ' IT=', I3, ' ID1=', I5,
1, ' ID2=', I5, ' PARAM=', G20.10)
IERR=IERR+1
IF(IEW.GT.2) STOP 0002
999 RETURN
END
SUBROUTINE RAZ(TABLE, LENGTH)
DIMENSION TABLE(LENGTH)
DO 100 I=1, LENGTH
100 TABLE(I)=0.
RETURN
END
C.  ######################## FIRST CARD OF SHIELD ########################

SUBROUTINE DASHIE

DIMENSION SHP1(50), SHP2(500)
COMMON/SHD/REYN, SHIPAR

INITIAL LOADING OF SHIELD TABLES

DO 10 I=1,50
   REYN=I*0.1
   IF(REYN.GE.1.AND.REYN.LE.2.0) SHPP=0.118*(REYN**(-.973))
   IF(REYN.GT.2.0.AND.REYN.LE.4.0) SHPP=0.090*(REYN**(-.585))
   IF(REYN.GT.4.0.AND.REYN.LE.10.0) SHPP=0.0434*(REYN**(-.119))
   SHP1(I)=SHPP
10 CONTINUE

DO 20 I=5,500
   REYN=I
   IF(REYN.GT.4.0.AND.REYN.LE.10.0) SHPP=0.0434*(REYN**(-.119))
   IF(REYN.GT.10.0.AND.REYN.LE.30.0) SHPP=0.0275*(REYN**(.0792))
   IF(REYN.GT.30.0.AND.REYN.LE.500.) SHPP=0.0194*(REYN**(.181))
   SHP2(I)=SHPP
20 CONTINUE
RETURN

ENTRY SHIELD

IF (REYN<5.) 40,50,50
40 INDX1=10*AMAX1(0.1,REYN)
   SHIPAR=SHP1(INDX1)
   GO TO 60
50 INDX2=AMIN1(REYN,500.)
   SHIPAR=SHP2(INDX2)
60 RETURN
END
SUBROUTINE TMCHG

THIS PROGRAM MANAGES THE ITERATION TIME INTERVAL
USED FOR THE STABILIZATION PROCEDURES

SUBROUTINE TMCHG

COMMON/SCALAR/GRAV,POROS,SGRAV,VIS,THETA,IT,IDELT,ITIME PHI,EPS
1 ,FDELTB
COMMON/TMPHAS/IDT,ITDT,ITGLOB,UNST,DELTB,ITGLMX,IDTMX
COMMON/ITCON/ITTOT,ITHYD,EPHYD,EPSQ,MITMAT,MITHYD,DYNMAX
1 ,DQMAX,DRYQ,ILINK,IPNODE,IPINT,IPSECT
COMMON/STABLE/EPSYB,EPSY,DYMAX,ITERMX

GO TO 999

ENTRY TMCHG1

-------------------------

IF (IDT.GT.IDTMX) GO TO 100
GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20), IDT
100 GO TO (1,2,3,4,5,6,7,8,9,10), IDT
GO TO 999
20 DELTB=50*FDELTB
EPSY=1.0*EPSYB
GO TO 999
19 DELTB=50*FDELTB
EPSY=1.0*EPSYB
GO TO 999
18 DELTB=50*FDELTB
EPSY=1.0*EPSYB
GO TO 999
17 DELTB=50*FDELTB
EPSY=1.0*EPSYB
GO TO 999
16 DELTB=50*FDELTB
EPSY=1.0*EPSYB
GO TO 999
15 DELTB=50*FDELTB
EPSY=1.0*EPSYB
GO TO 999
14 DELTB=50*FDELTB
EPSY=1.0*EPSYB
GO TO 999
13 DELTB=50*FDELTB
EPSY=1.0*EPSYB
GO TO 999
12 DELTB=50*FDELTB
EPSY=1.0*EPSYB
GO TO 999
11 DELTB=50*FDELTB
EPSY=1.0*EPSYB
GO TO 999
DELTB=50*FDELTB
EPSY=1.0*EPSYB
GO TO 999

9
DELTB=40*FDELTB
EPSY=2.0*EPSYB
GO TO 999

8
DELTB=30*FDELTB
EPSY=3.0*EPSYB
GO TO 999

7
DELTB=20*FDELTB
EPSY=4.0*EPSYB
GO TO 999

6
DELTB=10*FDELTB
EPSY=5.0*EPSYB
GO TO 999

5
DELTB=5*FDELTB
EPSY=7.0*EPSYB
GO TO 999

4
DELTB=2*FDELTB
EPSY=15.0*EPSYB
GO TO 999

3
DELTB=1*FDELTB
EPSY=50.0*EPSYB
GO TO 999

2
DELTB=FDELTB/2
EPSY=50.0*EPSYB
GO TO 999

1
DELTB=FDELTB/5
EPSY=50.0*EPSYB
GO TO 999

9
RETURN
END
SUBROUTINE TOPOLO

SUBROUTINE TOPOLO(MU, MD, LL, II, KK, LTYPE, YN, Y, NING, NINGQ, MPOS,
  1 MGROUP, NGSIZE, NODNAM, LNKNAM)

DIMENSION MU(LINKS), MD(LINKS), LL(NODES, KMAX), II(LINKS), KK(NODES)
  1, LTYPE(LINKS), Y(NODES), Y(IMAX, LINKS), NINGQ(NODES),
  2 NINGQ(NODES2), MPOS(NODES), MGROUP(NODES), NGSIZE(NGROUP),
  3 NODNAM(NODES), LNKNAM(LINKS)

COMMON/DIMS/NODES, KMAX, LINKS, IMAX, MEMO, NODESI, NTTRB, N1, IMAX1
  1, NIPL, NGROUP, MAXG, IMLAST, NSEC, NLEV, MAXI, IERR, IMAR
  2, MAXBED, NITOUT, NBDT, IEND, NODES2
COMMON/ITCON/IITOT, ITHYD, EPSHYD, EPSQ, MITMAT, MITHYD, DYNMAX
  1, DQMAX, DRYQ, IPLINK, IPNODE, IPOINT, IPSECT

L=1
M=1
NTTRB=0
MLAST=0
LLAST=0

IF (IPLINK.NE.0) WRITE(6,2000)
2000 FORMAT(1H1,T30,'LINK TOPOLOGY',//,T30,13(1H-),//,T20,'LINK',T30,
  1 'II',T40,'MU',T50,'MD',T60,'LTYPE',//,T20,50(1H-))
10 READ(5,1000) LNKNAM(L), II(L), MU(L), MD(L), LTYPE(L)
1000 FORMAT(16I5)
1 WRITE(6,2001) L, LNKNAM(L), II(L), MU(L), MD(L), LTYPE(L)
2001 FORMAT(T2,6I10)
IF (II(L).GT.IMAX) CALL ERRWAR(2,9,0,LNKNAM(L),II(L),0.0)
DO 15 LLIST=1,L
  15 CONTINUE

IF (LNKNAM(L).LT.0) GO TO 30
L=L+1
GO TO 10

30 IF (IPNODE.NE.0) WRITE(6,2002)
LNKNAM(L)=-LNKNAM(L)
IF (L.NE.LINKS) CALL ERRWAR(2,6,0,L,0.0)
2002 FORMAT(1H1,T30,'NODE TOPOLOGY',//,T30,13(1H-),//,T8,'NODE',
  1 'T3',T13,'T8',T19,'T24','MGROUP',T31,'MPOS',T36,'KK',
  2 'T40', 'LL(1)', 'T45', 'LL(2)', 'T55', '....',//,T08,52(1H-))
CALL RAZ (NGSIZE, MGROUP)
40 READ(5,1001) NODNAM(M), NINGN(M), NINGQ(M), MGROUP(M), MPOS(M), KKK,
  1 (LL(M,K),K=1,KKK)
1001 FORMAT(4I5, (T21, 10I5))
NGSIZE(MGROUP(M))=NGSIZE(MGROUP(M))+1
NTTRB=MAX0(NTTRB, IABS(NINGQ(M)), NINGQ(M))
KK(M)=KKK
IF (MGROUP(M).NE.MGROUP(M-1).AND.M.NE.1.AND.IPNODE.NE.0)
1 WRITE(6,2004)
2004 FORMAT(/)
   IF(IPNODE.NE.0)
1 WRITE(6,2003) M,NODNAM(M),NINQ(M),NINQS(M),MGROUP(M),MPOS(M),
   1 KK(M), (LL(M,K),K=1,KKK)
2003 FORMAT(T02,71S, (T42,10I5))
   IF(KK(M).GT.KMAX) CALL ERRWAR(2,10,0,NODNAM(M),KK(M),0.0)
   IF(MPOS(M).GT.MAXG) CALL ERRWAR(2,11,0,NODNAM(M),MPOS(M),0.0)
   IF(MGROUP(M).GT.NGROUP) CALL ERRWAR(2,12,0,NODNAM(M),
   1 MGROUP(M),0.0)
   IF(NODNAM(M).LT.0) GO TO 50
   M=M+1
50 GO TO 40
   NODNAM(M)=-NODNAM(M)
   IF(M.NE.NODES) CALL ERRWAR(2,7,0,M,0.0)
   VERIFY THAT ALL MU, MD CORRESPOND TO
   DEFINED NODES AND REPRESENT LEGAL NODE
   GROUP COMBINATIONS.

C C
C DO 60 L=1,LINKS
C MUNODE=0
C MDNODE=0
C DO 58 M=1,NODES
C   IF(MU(L).EQ.NODNAM(M)) MUNODE=M
C   IF(MD(L).EQ.NODNAM(M)) MDNODE=M
C 58 CONTINUE
C   IF(MUNODE*MDNODE.EQ.0) CALL ERRWAR(2,13,0,LNKNAM(L),0.0)
C   IF(MUNODE*MDNODE.NE.0.AND.IABS(MGROUP(MUNODE))
1   1 -MGROUP(MUNODE)).GT.1) CALL ERRWAR(2,14,0,LNKNAM(L),
2   2 0.0)
C   IF(MUNODE.LE.0) GO TO 100
C   KKK=KK(MUNODE)
C   DO 90 K=1,KKK
C     IF(LNKNAM(L).EQ.IABS(LL(MUNODE,K))) GO TO 100
C 90 CONTINUE
C   CALL ERRWAR(2,20,0,LNKNAM(L),MUNODE,0.0)
C   IF(MDNODE.LE.0) GO TO 60
C   KKK=KK(MDNODE)
C   DO 110 K=1,KKK
C     IF(LNKNAM(L).EQ.IABS(LL(MDNODE,K))) GO TO 60
C 110 CONTINUE
C   CALL ERRWAR(2,20,0,LNKNAM(L),MDNODE,0.0)
C 60 CONTINUE
C C
C DO 70 M=1,NODES
C   KKK=KK(M)
C   DO 68 K=1,KKK
C     DO 66 L=1,LINKS
C       IF(IABS(LL(M,K)).EQ.LNKNAM(L)) GO TO 67
C 66 CONTINUE
C   CALL ERRWAR(2,15,0,NODNAM(M),LL(M,K),0.0)
C   GO TO 68
C 67 IF(NODNAM(M).NE.MU(L).AND.NODNAM(M).
1   1 NE.MD(L)) CALL ERRWAR(2,16,0,NODNAM(M),LL(M,K),0.0)
IF((LL(M,K).LT.0.AND.NODNAME(M).NE.MD(L)).OR.
   (LL(M,K).GT.0.AND.NODNAME(M).NE.MU(L)))
1  CALL ERRWAR(1,7,0,NODNAME(M),LL(M,K),0.0)
68  CONTINUE
70  CONTINUE

REPLACE REFERENCES TO NODE NAMES BY REFERENCES TO NODE SEQUENCE

DO 150 L=1,LINKS
   DO 140 M=1,NODES
      IF(MU(L).EQ.NODNAME(M)) MUNODE=M
      IF(MD(L).EQ.NODNAME(M)) MDNODE=M
140  CONTINUE
   MUNODE=MUNODE
   MD(L)=MDNODE
150 CONTINUE

REPLACE REFERENCES TO LINK NAMES BY REFERENCES TO LINK SEQUENCE

DO 200 M=1,NODES
   KKK=KK(M)
   DO 200 K=1,KKK
      DO 190 L=1,LINKS
         IF(IABS(LL(M,K)).EQ.LKNAM(L)) LLLINK=L
190  CONTINUE
      LL(M,K)=ISIGN(LLINK,LL(M,K))
200 CONTINUE

999 RETURN
END
SUBROUTINE DOLINK

SUBROUTINE DOLINK(MU, MD, LL, E, F, H, EP, FP, HP, Y, YP, Q, QP, DYN, AREA,
1 AREADP, VEL, RH, WIDTH, II, REACH, LTYPE, ALPHA, YN,
2 BETA, SF, TALWEG, DRYBED, LNKNAM, RM, RK, RKP, RPK,
3 RPKP, RL, RMM, RN)

DIMENSION MU(LINKS), MD(LINKS), LL(NODES, KMAX), E(IMAX, LINKS),
1 F(IMAX, LINKS), H(IMAX, LINKS), EP(IMAX, LINKS), FP(IMAX, LINKS),
2 HP(IMAX, LINKS), Y(IMAX, LINKS), YP(IMAX, LINKS), Q(IMAX, LINKS),
3 QP(IMAX, LINKS), DYN(NODES), AREA(IMAX, LINKS), AREADP(IMAX, LINKS),
4 VEL(IMAX, LINKS), RH(IMAX, LINKS), WIDTH(IMAX, LINKS), II(LINKS),
5 REACH(IMAX1, LINKS), LTYPE(LINKS), ALPHA(IMAX, LINKS), BETA(IMAX,
6 LINKS), TALWEG(IMAX, LINKS), DRYBED(LINKS), LNKNAM(LINKS), RM(IMAX,
7 LINKS), SF(IMAX, LINKS), RK(IMAX, LINKS), RKP(IMAX, LINKS),
8 RPK(IMAX, LINKS), RPKP(IMAX, LINKS), YN(NODES)
DIMENSION RL(IMAX1, LINKS), RMM(IMAX1, LINKS), RN(IMAX1, LINKS)

LOGICAL DRYBED, DRY

COMMON/DIMS/NODES, KMAX, LINKS, IMAX, MEMO, NODESI, NTRIB, N1, IMAXM1
1 , NIPI, NGROUP, MAXG, IMLAST, VSECS, NLEVMAX, IERR, IWAR,
2 MAXBED, NITOUT, NBDT
COMMON/SCAR/LGRAV, POROS, SGRAV, VIS, Theta, IT, IDELT, ITIME, PHI, EPS
COMMON/ITCON/ITTOT, ITHYD, EPSHYD, EPSQ, MITMAT, MITHYD, DYNMAX
1 , DQMAX, DRYQ, IPLINK, IPNODE, IPOINT, IPSECT, FIRCAH
COMMON/STABL/EPSYB, EPSY, DYNMAX, ITERMX
LOGICAL FIRCAH

NAMELIST/QYCKH/I, L, DYL, DYL, DQ1, DQ1

**INITIALIZE YN**

DO 10 L=1, LINKS
  YN(MU(L)) = Y(I1(L), L)
  YN(MD(L)) = Y(1, L)
1 CONTINUE
GO TO 999

-----------------------------

ENTRY LINKS1

-----------------------------

DO 100 L=1, LINKS
  ILAST=II(L) - 1
  DRY=DRYBED(L)
  DO 90 IJ=1, ILAST
    I=ILAST-IJ+1

  COMPUTE A, B, C, ---- ETC. FOR WEIR FLOW

  IF(LTYPE(L).NE.0)
COMPUTE A, B, C, ------ ETC. FOR FLUVIAL REACH

CALL COEFF1(L, I, A, B, C, DD, G, AP, BP, CP, DP, GP)
WRITE(6, CFCHK)

COMPUTE RECURSION RELATION COEFF E, F, ---- ETC.

IF(IJ.GT.1) GO TO 50
DENOM=-B*DP+BP*DD
E(I,L)=(CP*B-C*BP)/DENOM
F(I,L)=(GP*B-G*BP)/DENOM
H(I,L)=(A*BP-AP*B)/DENOM
DENOM=-DD*BP+DP*B
EP(I,L)=(C*DP-CP*B)/DENOM
FP(I,L)=(G*DP-GP*DD)/DENOM
HP(I,L)=(AP*DD-A*DP)/DENOM
IF(LTYPE(L).NE.0) GO TO 100
GO TO 90
DENOM=A*BP-AP*B
RL(I,L)=(C*BP-CP*B)/DENOM
RMM(I,L)=(DD*BP+DP*B)/DENOM
RN(I,L)=(G*BP-GP*B)/DENOM
DENOM=(A+B*E(I+1,L)) RMM(I,L)-DD
E(I,L)=(C-RL(I,L) (A+B*E(I+1,L)))/DENOM
F(I,L)=G-(A+B*E(I+1,L)) RN(I,L)-B*F(I+1,L))/DENOM
H(I,L)=B*H(I+1,L)/DENOM
EP(I,L)=EP(I+1,L) (RL(I,L)+RMM(I,L)*E(I,L))
FP(I,L)=FP(I+1,L)+EP(I+1,L) (RMM(I,L)*F(I,L)+RN(I,L))
HP(I,L)=HP(I+1,L)+H(I,L) *EP(I+1,L) RMM(I,L)
100 CONTINUE
FIRCAH=.FALSE.
GO TO 999

---------------
ENTRY LINKS2
---------------

DQMAX=0.0
DO 200 L=1, LINKS
ILAST=II(L)

COMPUTE THE CHANGE OF WATER DISCHARGE
AND WATER SURFACE LEVEL AT BOTH ENDS OF
EACH LINK

DY1=DYN(MD(L))
DYI=DYN(MU(L))
DQ1=E(1,L)DY1+F(1,L)+H(1,L)*DYI
DQ1=EP(1,L)DY1+FP(1,L)+HP(1,L)*DYI
WRITE(6, QYCHK)
WRITE(6, 2004) E(ILAST,L), F(ILAST,L), H(ILAST,L), EP(ILAST,L),
FP(ILAST,L), HP(ILAST,L)
FORMAT(/, 1X, 6G10.3)
Q(ILAST,L)=Q(ILAST,L)+DQ1
Y(ILAST,L)=Y(ILAST,L)+DY1
Q(1,L)=Q(1,L)+DQ1
Y(1,L)=Y(1,L)+DY1
DQMAX=AMAX1(ABS(DQ1),ABS(DQI),DQMAX)
DRYBED(L)=.FALSE.
IF(ILAST.LE.2) GO TO 160
ILAST1=ILAST-1

BACKWARD SWEEP

DO 155 I=1,ILAST1
   IF(I.EQ.1) GO TO 155
   DY=RL(I-1,L)*DY1+RMM(I-1,L)*DQ1+RN(I-1,L)
   DQ=E(I,L)*DY+F(I,L)+H(I,L)*DY1
   DMAX=AMAX1(DMAX,ABS(DY))
   DQMAX=AMAX1(DQMAX,ABS(DQ))
   Y(I,L)=Y(I,L)+DY
   Q(I,L)=Q(I,L)+DQ
   DY1=DY
   DQ1=DQ
1  55 CONTINUE
1  60 IF(LTYPE(L).NE.0) GO TO 200
   DO 170 I=1,ILAST
      CALL SECPR0(L,I)
      VEL(I,L)=Q(I,L)/AREA(I,L)
   CONTINUE
1  70 CONTINUE
2  00 CONTINUE
9 99 RETURN
END
C#--------------------------- FIRST CARD OF LODMAT #---------------------------

C

C

SUBROUTINE LODMAT (MPOS, E, F, H, II, MU, MD, KK, Q, NINQ, QTRIB, QTR,
1 TEMPF, LL, MGROUP, EP, FP, HP, YN, RK, RPK, DYN, SF)

C

REAL*8 RMAT (NGC, NGL), SMAT (NGC, NGC), TMAT (NGC, NGR), VVECT (NGC)

C DIMENSION MPOS (NODES), E (IMAX, LINKS), F (IMAX, LINKS), H (IMAX, LINKS),
2 II (LINKS), MU (LINKS), MD (LINKS), KK (NODES), Q (IMAX, LINKS),
3 NINQ (NODES2), QTRIB (NODES2), QTR (NODES2), LL (NODES, KMAX), YN (NODES),
4 MGROUP (NODES), EP (IMAX, LINKS), FP (IMAX, LINKS), HP (IMAX, LINKS)
5 RK (IMAX, LINKS), RPK (IMAX, LINKS), DYN (NODES), SF (IMAX, LINKS)

CCOMMON/DIMS/NODES, KMAX, LINKS, IMAX, MEMO, NODESI, NTRIB, N1, IMAXM1
1 , N1P1, NGROUP, MAXG, IMLAST, NSECS, NLEVMX, IERR, IWAR
2 , MAXBED, NITOUT, NBDT, IEND, NODES2

COMMON/SCALAR/GRAC, POROS, SGRAV, VIS, THETA, IT, IDELT, ITIME, PHI, EPS
COMMON/ITCON/ITOT, ITHYD, EPSHY, EPSQ, MIMAT, MITHYD, DYNMAX
1 , DMAX, DRYQ, IFLINK, IFNODE, IPOINT, IPSECT, FIRCAH, ISTRK
1 , IDSB2
NAMELIST/LMAT/ISEQ, M, MBECC, MENDD, MR, KKK, K, L, RLSIGN, I, MCON,
1 MCONR, ICOLE, ICOILH

GO TO 999

C

C

+NTRY LODMA1 (RMAT, SMAT, TMAT, VVECT, NGL, NGC, NGR, MBECC, MENDD, NG)

C

C

MBECC=MBECC
MENDD=MEND

C

LOOP ON NODES OF CENTRAL GROUP

C

DO 100 M=MBECC, MEND

C

NOTE RELATIVE POSITION OF NODE M IN THE GROUP

C

MR=MPOS (M)
KKK=KK (M)
IF (NINQ (M) .GE. 0) GO TO 300
SMAT (MR, MR)=1.0D00
IF (IDSB2.EQ.1) CALL DSB2C (M)
VVECT (MR)=QTR (IABS (NINQ (M))) -YN (M)
QTR=QTR (IABS (NINQ (M)))
GO TO 100

PLR

LOAD BOUNDARY INFLOW

C

DO 90 K=1, KKK
300 L=IABS (LL (M, K))
RLSIGN=ISIGN (1, LL (M, K))
I=1

IDENTIFY NODE GROUP TO WHICH OPPOSITE END
OF LINK BELONGS

MCON=MU(L)
IF(MCON.EQ.M) MCON=MD(L)
MCONR=MPOS(MCON)
IF(NGROUP.EQ.1) GO TO 30
IF(NG-MGROUP(MCON)) 40,30,20

LINK WITH LEFT GROUP

IF(RLSIGN.LT.0.) GO TO 25

CASE WHEN CONNECTING NODE IS AT BEGINNING OF LINK

RMAT(MR,MCONR)=RMAT(MR,MCONR)-EP(I,L)
SMAT(MR,MR)=SMAT(MR,MR)-HP(I,L)
WRITE(6,2002) MR,MCONR,RMAT(MR,MCONR),RMAT(MCONR,MR)
2002
FORMAT(/,1X,'MR=',M5,'MCONR=',M5,'RMAT=',F2.10,3) GO TO 50

CASE WHEN CONNECTING NODE IS AT END OF LINK

RMAT(MR,MCONR)=RMAT(MR,MCONR)+H(I,L)
SMAT(MR,MR)=SMAT(MR,MR)+E(I,L)
GO TO 50

LINK WITH SAME CENTRAL GROUP

30
ICOLH=MR
ICOLE=MCONR
IF(RLSIGN.GT.0.) GO TO 32
ICOLE=MR
ICOLH=MCONR
SMAT(MR,ICOLE)=SMAT(MR,ICOLE)-RLSIGN*E(I,L)
SMAT(MR,ICOLH)=SMAT(MR,ICOLH)-RLSIGN*H(I,L)
GO TO 50

32
SMAT(MR,ICOLE)=SMAT(MR,ICOLE)-RLSIGN*EP(I,L)
SMAT(MR,ICOLH)=SMAT(MR,ICOLH)-RLSIGN*HP(I,L)
GO TO 50

LINK WITH RIGHT GROUP

40
IF(RLSIGN.LT.0.) GO TO 45

CASE WHEN CONNECTING NODE IS AT BEGINNING OF LINK

TMAT(MR,MCONR)=TMAT(MR,MCONR)-EP(I,L)
SMAT(MR,MR)=SMAT(MR,MR)-HP(I,L)
GO TO 50

CASE WHEN CONNECTING NODE IS AT END OF LINK

45
TMAT(MR,MCONR)=TMAT(MR,MCONR)+H(I,L)
SMAT(MR,MR)=SMAT(MR,MR)+E(I,L)
LOAD FREE VECTOR

50 IF (RLSIGN.GT.0.) VVECT(MR) = VVECT(MR) + (FP(I,L) + Q(I(L),L))
   IF (RLSIGN.LT.0.) VVECT(MR) = VVECT(MR) + RLSIGN * (F(I,L) + Q(I,L))

C 1 WRITE (6, 2000) M, MCON, L, I, E(I,L), F(I,L), H(I,L), EP(I,L),
   FP(I,L), HP(I,L)


90 CONTINUE

100 CONTINUE

999 RETURN

END
C SUBROUTINE IWAGAK
COMMON/SHEAR/REYSTA, TAU
IF (REYSTA.LT.2.14) TAU = 0.14
   IF (REYSTA.GE.2.14 .AND. REYSTA.LE.54.2) TAU = 0.195 * REYSTA**(-7./16.)
   IF (REYSTA.GT.54.2 .AND. REYSTA.LE.162.7) TAU = 0.034
   IF (REYSTA.GT.162.7 .AND. REYSTA.LE.671.0) TAU = 8.45E-03 * REYSTA**(-3./11.)
   IF (REYSTA.GT.671.0) TAU = 0.05
RETURN
END
SUBROUTINE DAARMO (ACF, ACF1, PT, DSG, CDEP, PTT, VOLOUT, WIDTH, SF,
  D50R, THBED, PTA, NBEL, TALWGI, PBED, Q, RH, DARM, ELI, ARM, PAC,
  TDELD, ARMP, II, LTYPE, NRIN)

THIS SUBROUTINE CALCULATES ARMORING OF BED SURFACE

IBLR = INDEX VARIABLE FOR INCLUDING BED LAYER IN SEDIMENT
  CALCULATIONS; 0 IF BED LAYER IS NOT INCLUDED (IMPLIED
  USE OF ARMORING PROCEDURE); 1 IF BED LAYER IS
  CONSIDERED (ARMORING PROCEDURE NOT USED)
IARMOR = INDEX VARIABLE TO SPECIFY OR DETERMINE ARMORING
  SEDIMENT SIZE; IARMOR = 0, SPECIFY; =1 FOR
  DETERMINING INTERNALLY
MIND = FRACTION NUMBER FOR THE MINIMUM SEDIMENT SIZE WHICH
  (AND COARSER FRACTIONS) FORM ARMOR COAT
QMAX = MAXIMUM WATER DISCHARGE (CFS.) FOR DETERMINING NON-MOVING
  ARMORING FRACTIONS
IQMAX = INDEX VARIABLE FOR SPECIFYING WATER DISCHARGE FOR ARMORING
  CALCULATIONS; IQMAX = 0 FOR USING SPECIFIED CONSTANT
  QMAX IN EACH TIME STEP AND REACH; =1 FOR USING WATER
  DISCHARGE FROM SPECIFIED HYDROGRAPH
KARM = INDEX VARIABLE FOR MODIFYING THE ARMORING COEFFICIENT
  (CARM); 0 FOR USING SPECIFIED VALUES; 1 FOR MODIFYING
  CARM USING GESSLER'S RELATION; 2 FOR USING BED-LOAD
  METHOD; 3 FOR USING BOTH GESSLER'S AND BED-LOAD METHODS;
  4 FOR USING DUNE-HEIGHT METHOD; 5 FOR USING BOTH
  GESSLER'S AND DUNE-HEIGHT METHODS
IACF = INDEX VARIABLE FOR SPECIFYING INITIAL ARMORING; 0 FOR NO
  INITIAL ARMORED AREA; 1 IF ARMORED COAT (PARTIAL OR FULL)
  EXISTS AT THE BEGINNING

DIMENSION DSG(N1), PT(IMAX, N1P1, LINKS), PTT(IMAX, N1P1, LINKS),
  CDEP(IMAX, LINKS), VOLOUT(IMAX, LINKS), ACF(IMAX, LINKS), WIDTH(IMAX,
  LINKS), SF(IMAX, LINKS), D50R(IMAX1, LINKS), THBED(IMAX1, LINKS),
  PTA(IMAX1, N1, LINKS), NBEL(IMAX1, LINKS), TALWGI(IMAX, LINKS),
  PBED(IMAX1, N1, MAXBED, LINKS), Q(IMAX, LINKS), RH(IMAX, LINKS),
  DARM(IMAX, LINKS), ELI(IMAX, LINKS), ARM(IMAX, N1, LINKS), PAC(IMAX,
  N1, LINKS), TDELD(IMAX, N1, LINKS), ARMP(IMAX, N1, LINKS), ACF1(IMAX,
  N1, LINKS), II(LINKS), LTYPE(LINKS)

LOGICAL FIRCAL
COMMON/DIMS/NODES, KMAX, LINKS, IMAX, MEMO, NODESI, NTRIB, N1, IMAXM1
  1, N1P1, NGROUP, MAXG, IMLAST, NSECS, NLEVMAX, ERR, IMAR, 2
  MAXBED, NITOUT
COMMON/SCALR/GRAV, POROS, SGRAV, VIS, THETA, IT, IDELT
COMMON/TLTMCF/TLTM1, TLTM2, TLTM3, TLTM4, TLTM5, TLTM6, TLTM7, TLTM8,
  1, TLTM9
COMMON/ARM/MIND, QMAX, IARMOR, IQMAX
COMMON/ARM1/IBLR
COMMON/SHD/REYN, SHIPAR
COMMON/MODSH/ISHEAR, YALIN
COMMON/SHEAR/REYSTA, TAUCh
COMMON/MIXL/DELNOR

READ INDEX VAR. FOR USE OF BED LAYER
GSM1=GRAV*(SGRAV-1.0)
IBLR=0
IF (IBLR.EQ.0) WRITE(6,41)
IF (IBLR.EQ.1) WRITE(6,42)
41 FORMAT('//,10X,'BED LAYER IS NOT CONSIDERED (ARMORING PROCEDURE',
1 'USED')',//,10X,53(')'),/
42 FORMAT('//,10X,'BED LAYER IS CONSIDERED (ARMORING PROCEDURE NOT',
1 'USED')',//,10X,53(')'),/
IF (IBLR.EQ.1) GO TO 4000
C
C READ ARMORING INPUT PARAMETERS DURING PREPARATORY PHASE
OF RUN.
C
READ(5,1000) IARMOR,MIND,QMAX,QMAXM1,IACF,KARM,C1,CARM
1000 FORMAT(2I5,F10.0,3I5,2F10.0)
DARMOR=0.
IF (IARMOR.EQ.0) DARMOR=DSG(MIND)*304.8
WRITE(6,43) IARMOR,MIND,QMAX,QMAXM1,DARMOR,IACF,KARM,C1,CARM
43 FORMAT('//,T10, 'BED ARMORING PARAMETERS: IARMOR=',I2, '
1 I3, 'QMAX=',F10.2, ' IQMAX=',I2, ' DARMOR=',F10.3,
2 2X, 'IACF=',I2,2X, 'KARM=',I2,2X, 'C1=',F6.3,://,T36, 'CARM=',F6.3,/
3 T10,24(1H-))
C
IF (NRIN.GT.0) GO TO 5000
IF (IACF.EQ.1) GO TO 2000
DO 1010 L=1,LINKS
IF (LTYPE(L).NE.0) GO TO 1010
ILAST=II(L)-1
DO 1010 II=1,ILAST
DO 1010 K1=1,N1
ARMM(II,K1,L)=0.0
1010 CONTINUE
GO TO 2500
2000 DO 2010 L=1,LINKS
IF (LTYPE(L).NE.0) GO TO 2010
ILAST=II(L)-1
DO 2010 II=1,ILAST
READ(5,101) (ARM(II,K1,L),K1=1,N1)
WRITE(6,110)
WRITE(6,120) (ARMM(II,K1,L),K1=1,N1)
2010 CONTINUE
10 FORMAT(16F5.0)
10 FORMAT('//,T10,'INITIAL ARMOR-COVERED AREA (FRACTION) :',//)
120 FORMAT(T15,10F8.4)
2500 DO 3500 L=1,LINKS
IF (LTYPE(L).NE.0) GO TO 3500
ILAST=II(L)-1
- DO 3500 II=1,ILAST
ACF(II,L)=0.0
DO 3000 K1=1,N1
ACF(II,L)=ACF(II,L)+ARM(II,K1,L)
ARMP(II,K1,L)=ARMM(II,K1,L)
3000 CONTINUE
3500 CONTINUE
4000 IF (IBLR.EQ.0) GO TO 5000
DO 4050 L=1,LINKS
ILAST=II(L)-1
DO 4050 II=1,ILAST
ACF(I1,L)=0.0
4050 CONTINUE
5000 RETURN
C***********************************************************************
ENTRY ARMOR(IAR,LAR,FIRCAL)
C***********************************************************************
C
I=IAR
L=LAR
IF(IBLR.EQ.1) GO TO 800
C
105 S1=(SF(I,L)+SF(I+1,L))/2.0
C
C IF IARMOR=0 MIND IS FIXED
C
100 IF(IARMOR.EQ.0) GO TO 200
C
C COMPUTE THE ARMORING SEDIMENT SIZE
C
170 IF(IQMAX.EQ.1) USTAR=SQRT(32.2*(RH(I,L)+RH(I+1,L))/2.0*S1)
DO 180 J=1,N1
REYN=USTAR*DSG(J)/VIS
IF(ISHEAR.EQ.0) GO TO 161
REYSTA=SQRT(GSM1)*DSG(J)**1.5/VIS
CALL IWAGAK
SHIPAR=TAUC
GO TO 162
C
161 CALL SHIELD
162 USC=SQRT(SHIPAR*32.2*1.65*DSG(J))
IF(USC.GT.USTAR) GO TO 185
180 CONTINUE
185 MIND=J
IF(USC.LT.USTAR) MIND=N1+1
IF(MIND.LE.N1) DARMOR=DSG(MIND)*304.8
IF(MIND.GT.N1) DARMOR=2.0*DSG(N1)*304.8
IF(IBUG.EQ.1) WRITE(6,16) MIND,DARMOR,I,I
16 FORMAT(10X,'MIND=',I2,3X,'DMIN=',F8.3,'MM.',3X,'IT=',I4,4X,
@ 'I=',I3 )
200 CONTINUE
C
C ADJUSTING SIZE DISTRIBUTION OF ARMORING FRACTIONS IN CASE OF
C VERTICAL VARIATION OF BED MATERIAL (NOT USED NOW)
C
BEDEL=TALWGI(I,L)
IF(IBED.EQ.0) GO TO 410
IF (NBEL(I,L).EQ.0) GO TO 410
IF (DARM(I,L).LE.0) GO TO 410
IF (I.EQ.1) CDEPP=CDEPP(I,L)
IF (I.GT.1) CDEPP=(CDEPP(I,L)+CDEPP(I-1,L))/2.0
T1=TALWGI(I,L)-THBED(I,L)+CDEPP
IF (T1.LE.BEDEL) GO TO 410
IF (T1.GT.BEDEL) GO TO 208
DO 205 J=MIND,N1
   205 PTA(I,J,L)=PTT(I,J,L)
   N=NBEL(I,L)
   DO 210 M=1,NB
      210 T1=TALWGI(I,L)-M*THBED(I,L)+CDEPP
      IF (T1.GT.BEDEL) GO TO 215
      CONTINUE
   M=NB
   DO 260 J=MIND,N1
      ELL=TALWGI(I,L)-THBED(I,L)*M+CDEPP
      PIN=PTT(I,J,L)*THBED(I,L)+PBED(I,J,M,L)*((ELL-BEDEL)
      M2=M-1
      IF (IBUG.EQ.1) WRITE(6,94) J,M2
      9 4 FORMAT(5X,'J=',I3,2X,'L2=',I6)
      IF (M2.EQ.0) GO TO 255
      DO 245 MA=1,M2
      245 PIN=PIN+PBED(I,J,MA,L)*THBED(I,L)
      255 PTA(I,J,L)=PIN/DARM(I,L)
      CONTINUE
   IF (IBUG.EQ.1) WRITE(6,81) PTA(I,J,L),I,J,L
   8 1 FORMAT(5X,'PTA=',F10.6,2X,'I=',I3,2X,'J=',I2,'L=',I2).

COMPUTING FRACTION OF ARMORED AREA

IF (IBED.EQ.1) GO TO 450
   4 10 DO 420 J=MIND,N1
   4 20 PTA(I,J,L)=PTT(I,J,L)
   4 50 CONTINUE

KARM=0, CA=CA0; READ
KARM=1, CA=CA0*QK
KARM=2, CA=CA0*QS
KARM=3, CA=CA0*QS*QK
KARM=4, CA=CA0*ALPHA
KARM=5, CA=CA0*ALPHA*QK
QK: GESELLER'S PROBABILITY CURVE
QS: (QB/QT)**C1 BED LOAD METHOD
ALPHA: ALLEN DUNE HEIGHT PARAMETER

MODIFICATION OF CARM BY BED-LOAD METHOD

CARM=CARM
IF (KARM.EQ.0.OR.KARM.EQ.1) GO TO 460

CALCULATION OF TOTAL SED. DISCH. (EQ.1 IN IJHR REPORT NO.267)

DEP=(RH(I,L)+RH(I+1,L))/2.0
VEL=Q(I,L)/((WIDTH(I,L)+WIDTH(I+1,L))*0.50)/DEP
A3=ALOG10(DEP/D50R(I,L))
A12=ALOG10(ABS(VEL)/SQRT(32.2*1.65*D50R(I,L)))
USTAR=SQR(T(32.2*DEP*S1))
REYN=USTAR*D50R(I,L)/VIS
IF(ISHEAR.EQ.0) GO TO 171
REYSTA=SQR(T(GSM1)*DSG(J)**1.5/VIS
CALL IWAGAK
SHIPAR=TAUC
GO TO 172

CALL SHIELD

USTC=SQR(T(SHIPAR*32.2*1.65*D50R(I,L))
IF(KARM.GE.4) GO TO 455
TEMP=USTAR-USTC
IF(TEMP.LE.0.0) TEMP=0.001
A17=ALOG10(TEMP/SQR(T(32.2*1.65*D50R(I,L))))
QS =10.0**(TTLM1+AL2*TLTM2+A12*A17*TLTM3+A3*A17*TLTM4)
QT=QS*SQR(T(32.2*1.65*(D50R(I,L)**3))

C
CALCULATION OF BED-LOAD DISCH. (BY SBTM)

C
A4=ALOG10(S1*1000.0)
F11=36.0*VIS**2/(32.2*1.65*(D50R(I,L)**3))
F1=SQR(T(2.3+F11)-SQR(T(F11))
W=F1*SQR(T(32.2*1.65*D50R(I,L))
A6=ALOG10(USTAR/W)
A10=ALOG10(W*D50R(I,L)/VIS)
CB=10.0**(-3.7518+A12*2.6279+A4*0.4595+A6*(-2.5055)+
@ A10*(-0.0392)+A17*0.7395)
ETAAB=(D50R(I,L)*USTAR/USTC)/DEP
F=8.0*32.2*DEP*S1/(VEL**2)
FN=0.40*SQR(T(8.0/F)
WU=W/USTAR
CF=1.00
IF(WU.GT.1.00) CF=1.0/SQR(T(WU))
QB=CB*DEP*VEL*(ETAAB**((1./FN+1.))*CF
QBQT=QB/QT
PQBQT=QBQT**C1
CARM1=CARM*PQBQT

C
MODIFICATION OF CARM BY DUNE-HEIGHT METHOD

C
(EQ.20 IN IIHR REPORT 269)

C
IF(IYALN.NE.0) GO TO 456
THETAB=DEP*S1/(1.65*D50R(I,L))
THETAC=USTC**2/(32.2*1.65*D50R(I,L))
IF(THETAB.LE.1.10) PDH=(1.10-THETAB)/(1.10-THETAC)
IF(THETAB.GT.1.10) PDH=(THETAB-1.10)/(1.50-1.10)
IF(PDH.GT.1.00) PDH=1.00
CARM1=CARM*PDH
IF(IBUG.EQ.1) WRITE(6,54) THETAB,THETAC,PDH,CAR I
54 FORMAT(5X,'THETAB=',F6.3,2X,'THETAC=',F6.3,2X,'PDH=',F6.3,
@ 2X,'CARM1=',F6.3,2X,'I=',I4)
GO TO 460

456 PDH=1.0-DEINOR
CARM1=CARM*PDH

C

C
460 IF(MIND.GT.N1) GO TO 525
DO 500 IA=MIND,N1
IF(KARM.EQ.0.OR.KARM.EQ.2) GO TO 498
IF(KARM.EQ.4) GO TO 498

MODIFICATION OF CARM BY GESSLER'S PROBABILITY CURVE
(EQ.1 IN IJHR REPORT 269)

REYN=USTAR*DSG(IA)/VIS
IF(ISHEAR.EQ.0) GO TO 181
REYSTA=SQRT(GSM1)*DSG(J)**1.5/VIS
CALL IWAGAK
SHIPAR=TAUC
GO TO 182

L 81 CALL SHIELD
L 82 USC=SQRT(SHIPAR*32.2*1.65*DSG(IA))
TCTO=(USC/USTAR)**2
XX=(TCTO-1.0)/(SQRT(2.0)*0.57)
FGESS=0.50+0.50*ERF(XX)
CARM1=CARM*PGESS
IF(KARM.EQ.1) GO TO 498
IF(KARM.EQ.3) CARM1=CARM*PGESS*PQBT
IF(KARM.EQ.5) CARM1=CARM*PGESS*PDH

IF(IBUG.EQ.1) WRITE(6,55) TCTO,PGESS,QBQT,PQBT,PDH,CAR IT,I,IA
5 5 FORMAT(5X,'TCTO=',F6.3,2X,'PGESS=',F6.3,2X,'QBQT=',F6.3,2X,'PDH=',F6.3,2X,'IT=',I4,2X,
2 'I=',I4,2X,'K=',I2)
ARM(I,IA,L)=ARM(I,IA,L)+CARM1*VOLOUT(I,L)*(1.0-POROS)*
@ PTA(I,IA,L)/DSG(IA)
ARM(I,IA,L)=AMAX1(ARM(I,IA,L),0.0)

CONTINUE

ACF(I,L)=0.0
DO 560 IA=1,N1
IF(IA.LT.MIND) ARM(I,IA,L)=0.0
ACF(I,L)=ACF(I,L)+ARM(I,IA,L)

CONTINUE

C

IF(IBUG.EQ.1) WRITE(6,83) I,ACF(I,L),PTA(I,MIND,L),PTA(I,N1,L),
@ VOLOUT(I,L)
5 50 IF(ACF(I,L).GT.1.00) ACF(I,L)=1.00
IF(ACF(I,L).LT.0.0) ACF(I,L)=0.0
IF(PIRCAL) GO TO 600
IF(DARM(I,L).GE.0.0.AND.ACF(I,L).EQ.0.0) GO TO 600
C

IF(ACF(I,L).LT.ACF1(I,L).AND.KDREJ.EQ.0) ACF(I,L)=ACF1(I,L)
6 00 ACF1(I,L)=ACF(I,L)

IF(IBUG.EQ.1) WRITE(6,82) ACF(I,L),I
8 2 FORMAT(5X,'ACF=',F10.4,2X,'I=',I3)
8 3 FORMAT(5X,'I=',I3,2X,'ACF=',E14.6,2X,'PT(MIND)=',
8   'E14.6,2X,'PT(N1)=',E14.6,2X,'VOLOUT=',E14.6)
C

8 00 IF(IBLR.EQ.0) GO TO 6000

CALCULATION OF BED-LAYER SIZE DISTRIBUTION

S1=(SF(I,L)+SF(I+1,L))/2.0
DEP=(RH(I,L)+RH(I+1,L))/2.0
UST=SQRT(32.2*DEP*S1)
REYN=UST*DSGR(I,L)/VIS
IF(ISHEAR.EQ.0) GO TO 191
REYSTA=SQR(SGM1) * DSG(J) ** 1.5 / VIS
CALL IWAGAK
SHIPAR=TAUC
GO TO 192
191 CALL SHIELD
192 USC=SQR(SHIPAR * 32.2 * 1.65 * D50R(I,L))
TACL=D50R(I,L) * UST/USC
VREM=0
DO 810 K1=1,N1
T1=TACL * PAC(I,K1,L) - TDELD(I,K1,L)
IF (T1.LT.0.) T1=0.0
VREM=VREM+T1
810 CONTINUE
DO 850 K1=1,N1
T1=TACL * PAC(I,K1,L) - TDELD(I,K1,L)
IF (T1.LT.0.) T1=0.0
PAC(I,K1,L)=(T1+(TACL-VREM) * PT(I,K1,L)) / TACL
IF (VREM.GT.TACL) PAC(I,K1,L)=PT(I,K1,L)
850 CONTINUE
6000 RETURN
END
SUBROUTINE HYSORT

THIS SUBROUTINE RECOMPUTES BED-MATERIAL SIZE DISTRIBUTION DUE TO DEGRADATION/AGGRADATION IN EACH TIME PERIOD

SUBROUTINE DAHYSO(VOLIN, TALWEG, DS0R, PT, PTT, QS, SF, ACF,
1 RH, B2, TEDLED, VOLOUT, LLIM, DELT, TI, TH1, PTP, EL1, EL2,
2 PTU, BML, TB, NBEL, THBED, PBED, CDEP, DSG, LKNAM)

DIMENSION VOLIN(IMAX,N1,LINKS), TALWEG(IMAX,LINKS), DS0R(IMAXM1, 1 LINKS), PT(IMAX, N1P1, LINKS), PTT(IMAX, N1P1, LINKS), QS(IMAX, N1, 2 LINKS), ACF(IMAX, LINKS), RH(IMAX, LINKS), B2(IMAX, N1, LINKS),
3 TEDLED(IMAX, N1, LINKS), SF(IMAX, LINKS),
4 VOLOUT(IMAX, LINKS), LLIM(IMAX, LINKS), DELT(IMAX, N1, LINKS),
5 TI(IMAX, N1, LINKS), TH(IMAX, LINKS), PTP(IMAX, N1P1, LINKS),
6 EL1(IMAX, LINKS), EL2(IMAX, LINKS), PTU(IMAX, N1P1, LINKS),
7 BML(IMAX, LINKS), TB(IMAX, N1, LINKS), NBEL(IMAXM1, LINKS),
8 LLIM(IMAXM1, LINKS), PBED(IMAXM1, N1, MAXBED, LINKS), CDEP(IMAX,
9 LINKS), DSG(N1), TH1(IMAX, LINKS), LKNAM(LINKS)
LOGICAL FIRCAL
COMMON/DIMS/NODES, KMAX, LINKS, IMAX, MEMO, NODESI, NTRIB, N1, IMAXM1
1 , N1P1, NGROUP, MAXG, IMLAST, NSECS, NLEVMAX, IERR, IWAR,
2 MAXBED, NITOUT
COMMON/SCALR/GRAV, POROS, SGRAV, VIS, THETA, IT, IDEFLT, ITIME, PHI, EPS
1 , FDELTB, FFIMP, ALIMP, BEIMP, THETAS
COMMON/SHD/REYN, SHIPAR
COMMON/MODSHD/ISHPEAR, IYALIN
COMMON/SHERE/REYSTA, TAUC
COMMON/MIXL/DENOR

RETURN
************
ENTRY HYSORT(I,L,FIRCAL)
************

WARNING: ARMORING FACTOR APPROACHING UNITY

IF (ACF(I,L) .GT. 0.98) CALL ERRWAR(1,8,IT,LKNAM(L),I,ACF(I,L))
ACF(I,L) = AMIN1(0.98, ACF(I,L))
IF (VOLOUT(I,L) .EQ. 0.0) GO TO 900
IADJ=0
VOLOUT(I,L) = 0.
TH(I,L) = 0.
TOTAL=0.
LLIM(I,L) = 0.
DM = (RH(I,L) + RH(I+1,L)) * 0.5
SM = (SF(I,L) + SF(I+1,L)) * 0.5
SM = AMIN1(SM, 0.01)
WRITE(6, 2020) D50R(I,L)
FORMAT(T5, 'D50R=', 'F10.4')
THA = DM*SM/(1.65*D50R(I,L))
THA = THA*0.33333

MIXED LAYER THICKNESS COMPUTED BY EQ. 6, IIHR 250

TM = DM*(0.079865+2.23897*THA-18.1264*THA**2+70.90*THA**3
# -88.3293*THA**2*THA**2)*0.50*FMIX
IF(IYALIN.EQ.0) GO TO 11
USTAR = SQRT(GRAV*DM*SM)
REYN = USTAR*D50R(I,L)/VIS
IF(ISHEAR.EQ.0) GO TO 161
REYSTA = SQRT(GSM1)*DSG(J)**1.5/VIS
CALL IWAGAK
SHIPAR = TAU C
GO TO 162

161 CALL SHIELD

162 USTARC = SQRT(SHIPAR)*SQRT(GSM1*D50R(I,L))
TEMP = USTARC*USTAR/(USTARC*USTARC) - 1.0
ZZ = DM/D50R(I,L)
IF(ZZ.LT.20.0.OR.TEMP.LE.0.0) GO TO 11
WAVL = 2.3.1416*RH(I,L)
IF(ZZ.GE.20.0.AND.ZZ.LE.30.0) XBAR = 2.03
IF(ZZ.GT.30.0.AND.ZZ.LE.40.0) XBAR = 2.03+(3.85-2.03)*(ZZ-30.0)*0.1
IF(ZZ.GE.40.0.AND.ZZ.LE.50.0) XBAR = 3.85
IF(ZZ.GT.50.0.AND.ZZ.LE.65.0) XBAR = 3.85+(5.78-3.85)*(ZZ-50.0)/15.
IF(ZZ.GE.65.0.AND.ZZ.LE.75.0) XBAR = 5.78
IF(ZZ.GT.75.0.AND.ZZ.LE.100.0) XBAR = 5.78+(12.84-5.78)*(ZZ-75.0)/25.
IF(ZZ.GE.100.0) XBAR = 12.84
IF(ZZ.LT.25.0) WAVL = 20.*DM
TM = WAVL*0.0127*TEMP*EXP(-TEMP/XBAR)
DELNOR = TEMP/XBAR*EXP(1.0-TEMP/XBAAR)

11 DMM = DM*0.15
C
DMM = 2.0
IF(TM.LT.0.0) TM = DMM
FR1 = TM/DM
IF(IBUG.EQ.1) WRITE(6, 12) I, TM, DM, FR1
FORMAT(5X, 'I=', '1, I4, 2X, 'TM=', 'E14.6, 2X, 'DM=', 'E14.6, 2X, 'H/D=', ', F6.3')

12 C
C
ADJUSTMENT OF SIZE DIST. IF MIXED-LAYER THICKNESS IS
MORE THAN THE TOP-LAYER SEDIMENT BED THICKNESS
(INCONSISTENT WITH GLOBAL ITERATIONS)

IF(IEBED.EQ.0.OR.IT.GT.2) GO TO 315
IF(NBEL(I,L)).EQ.0) GO TO 315
IF(TM.LE.THBED(I,L)) GO TO 315
NSL = NBEL(I,L)
DO 300 M = 1, NSL
T1 = THBED(I,L)*M
IF(TM.GT.T1) GO TO 305

300 CONTINUE
M = NSL
305 M2 = M - 1
DO 310 J = 1, N1
PT(I,J,L)=PT(I,J,L)*THBED(L,I,L)/TM+(TM-THBED(L,I,L)*M)/TM
*PBED(I,J,M,L)
IF(M2.EQ.0) GO TO 310
DO 306 M1=1,M2
306 PT(I,J,L)=PT(I,J,L)+THBED(I,L)/TM*PBED(I,J,M1,L)
310 CONTINUE
315 CONTINUE
C C
DO 75 J=1,N1
DELT(I,J,L)=0.
IFT(FIRCAL) PTU(I,J,L)=PTP(I,J,L)
75 TOTAL=TOTAL+TDELD(I,J,L)
DO 100 J=1,N1
TI(I,J,L)=TM*(1.0-POROS)*PT(I,J,L)
TB(I,J,L)=TI(I,J,L)*(1.-ABETA*ACF(I,L))
100 CONTINUE
IF(IBUG.EQ.1) WRITE(6,56) I,J,L,TB(I,J,L),TDELD(I,J,L)
56 FORMAT((/10X,'TB(',I2,',',I2,')','I=','E14.6,2X,'TDELD=','E14.6)
TB(I,J,L)=AMAX1(0.,TB(I,J,L))
TH(I,L)=TH(I,L)+TB(I,J,L)
IF(TDELD(I,J,L).LT.0.0) GO TO 76
IF(IADJ.EQ.0) GO TO 72
C C
IF(FIRCAL.AND.TDELD(I,J,L).GT.TB(I,J,L)) QS(I,J,L)=
72 CONTINUE
IF(FIRCAL.AND.TDELD(I,J,L).GT.TB(I,J,L)) LLIM(I,L)=1
IF(FIRCAL.AND.TDELD(I,J,L).NE.0)
K#ELT(I,J,L)=IDELT*
* TB(I,J,L)/TDELD(I,J,L)
IF(TDELD(I,J,L).EQ.0) DELT(I,J,L)=900.0
DELT(I,J,L)=AMIN1(DELT(I,J,L),9000.)
IF(FIRCAL.AND.TDELD(I,J,L).GT.TB(I,J,L)) TDELD(I,J,L)=TB(I,J,L)
IF(FIRCAL) GO TO 90
ABC=TH(I,L)*PTP(I,J,L)
IF(IADJ.EQ.0) GO TO 74
74 CONTINUE
IF(TDELD(I,J,L).GT.ABC) LLIM(I,L)=1
IF(TDELD(I,J,L).NE.0) DELT(I,J,L)=IDELT*ABC/TDELD(I,J,L)
DELT(I,J,L)=AMIN1(DELT(I,J,L),9000.)
TDELD(I,J,L)=AMIN1(TDELD(I,J,L),ABC)
IF(TDELD(I,J,L).GE.0.0) GO TO 90
76 CONTINUE
IF(TDELD(I,J,L).LE.0.0) DELT(I,J,L)=900.0
DELT(I,J,L)=AMIN1(DELT(I,J,L),9000.)
90 VOLOUT(I,L)=VOLOUT(I,L)+TDELD(I,J,L)
100 CONTINUE
IF(VOLOUT(I,L).EQ.0.0) GO TO 900
IF(IADJ.EQ.0) GO TO 125
C C
C TOQS(I,L)=0.
DO 120 J=1,N1
C120 TOQS(I,L)=TOQS(I,L)+QS(I,J,L)
120 CONTINUE
IF(VOLOUT(I,L).LT.0) GO TO 800
C C
CC=0.
IF(FIRCAL) TH1(I,L)=TH(I,L)
DIN=TH(I,L)+VOLOUT(I,L)-TH1(I,L)
ELL1=TALWEG(I,L)-TH1(I,L)
EL2I=ELL1-DIN
BEL=BML(I,L)
IF(FIRCAL) BEL=EL2I
DO 200 J=1,N1

C LINDEX=0
LDEP=0
C IF(IBED.EQ.1) CALL VSORT(BEL,ELL1,EL2I,DIN,PTT,PT,PTU,VOLIN,
C # NBEL,THBED,PBED,LINDEX,TALWG,CDEP,LDEP)
C
C IF(LINDEX.EQ.1) GO TO 135
IF(FIRCAL) GO TO 130
IF(EL2I.GT.ELL1) GO TO 130
IF(BEL.GE.ELL1) VOLIN(I,J,L)=DIN*PTT(I,J,L)
IF(ELL1.GE.BEL.AND.BEL.GT.EL2I) VOLIN(I,J,L)=(ELL1-BEL)
# *PTT(I,J,L)+(BEL-EL2I)*PTT(I,J,L)
IF(EL2I.GT.BEL) VOLIN(I,J,L)=DIN*PTT(I,J,L)
IF(FIRCAL) VOLIN(I,J,L)=DIN*PTT(I,J,L)
IF(EL2I.GT.ELL1) VOLIN(I,J,L)=DIN*PTT(I,J,L)
130 CONTINUE
C VOLIN(I,J,L)=AMAX1(VOLIN(I,J,L),0.0)
BZ(I,J,L) = TH1(I,L)*PTP(I,J,L)-TDELD(I,J,L)+VOLIN(I,J,L)
C WRITE(6,3000) I,J,L,TH1(I,L),PTP(I,J,L),TDELD(I,J,L),VOLIN(I,J,L)
C 1,BZ(I,J,L)
3000 FORMAT(5X,3I5,5F10.5)
BZ(I,J,L) =AMAX1(BZ(I,J,L),0.0)
200 CCC=CCC+BZ(I,J,L)
ELL1(I,L)=ELL1
EL2I(I,L)=EL2I
EMIN=ELL1
IF(EL2I.LT.ELL1) EMIN=EL2I
BEL=AMIN1(BEL,EMIN)
TH1(I,L)=0.
DO 220 J=1,N1
149 TH1(I,L)=TH1(I,L)+TB(I,J,L)
C WRITE(6,2021) CCC
2021 FORMAT(T5,'CCC=',F10.4)
C IF(CCC.EQ.0.AND.IT.EQ.8) C
C 1 WRITE(6,3001) IT,I,L,TH1(I,L),TH(I,L),TM,BZ(I,J,L)
3001 FORMAT(1X,3I5,5G10.3)
C IF(CCC.EQ.0.0) CCC=0.1
IF(CCC.NE.0.0) PT(I,J,L)=BZ(I,J,L)/CCC
PTCK=PT(I,J,L)
C IF(LNKNNAM(L).EQ.479) WRITE(6,HYSCHK)
220 CONTINUE
BML(I,L)=BEL
GO TO 900
800 CCl=0
IF(FIRCAL) TH1(I,L)=TH(I,L)
DIN=TH1(I,L)-VOLOUT(I,L)-TH(I,L)
ELL1=TALWEG(I,L)-TH1(I,L)
EL2I=ELL1+DIN
BEL=BML(I,L)
IF(FIRCAL) BEL=ELL1
DO 850 J=1,N1
C
LINDEX=0
LDEP=1

C IF(IBEQ.EQ.1) CALL VSORT(BEL,EL1,ELEL,DIN,P0T,PT,PTU,VTOLIN,
# NBEL,THBED,PBED,LINDEX,TALWG,CDEP,LDEP)

IF(LINDEX.EQ.1) VOLIN(I,J,L) = -VOLIN(I,J,L)
IF(LINDEX.EQ.1) GO TO 832
IF(FIRCAL) GO TO 830
IF(ELELT.EQ.EL1) VOLIN(I,J,L) = D*PTT(I,J,L)
IF(EL1.EQ.EL1A) VOLIN(I,J,L) = D*PTU(I,J,L)

# *PTT(I,J,L)+((BEL-EL2)PTT(I,J,L))
IF(ELELT.EQ.EL1) VOLIN(I,J,L) = D*PTU(I,J,L)

830 IF(FIRCAL) VOLIN(I,J,L) = D*PTT(I,J,L)
IF(ELELT.EQ.EL1) VOLIN(I,J,L) = D*PTP(I,J,L)

832 CONTINUE
VOLIN(I,J,L) = AMAX1(VOLIN(I,J,L), 0.0)
BZ(I,J,L) = TH1(I,L) * PTP(I,J,L) - TDEL(I,J,L) - VOLIN(I,J,L)
BZ(I,J,L) = AMAX1(BZ(I,J,L), 0.0)

850 CC1 = CC1 + BZ(I,J,L)
EL1(I,L) = EL1
EL2(I,L) = EL2
EMIN = EL1
IF(ELELT.EQ.EL1) EMIN = EL2
IF(EMIN.EQ.EL) BEL = EMIN
TH1(I,L) = 0.
DO 860 J = 1,N1
858 TH1(I,L) = TH1(I,L) + TB(I,J,L)

C IF(IT.EQ.8.AND.CC1.EQ.0.0)
C 1 WRITE(6,3001) IT,I,L,TH1(I,L),TH(I,L),TM,BZ(I,J,L)
C IF(CC1.EQ.0.0) CC1 = 0.1
C IF(CC1.NE.0.0) PT(I,J,L) = BZ(I,J,L)/CC1
PTCK = PT(I,J,L)
C IF(LNKAM(L).EQ.479) WRITE(6,HSCHK)

860 CONTINUE
BML(I,L) = BEL

900 RETURN
END
FIRST CARD OF POINTS

SUBROUTINE POINTS

THIS PROGRAM READS POINTS' DATA
AND ALLOWS TO CHANGE NSEC, RM AND TALWEG
BUT NOT NSED FOR THE RESTARTED RUN

COMMON/DIMS/NODES, KMAX, LINKS, IMAX, MEMO, NODSES1, NTRIB, N1, IMAXM1
1 , NIP1, NGROUP, MAXG, IMLAST, NSEC, NLEVMX, IERR, IWAR,
2 MAXBED, NITOUT, NBDT, IEND, NODES2
COMMON/ITCON/ITTOT, ITHYD, EPSHYD, EPSQ, MITMAT, MITHYD, DYNMAX
1 , DQMAX, DRYQ, IPLINK, IPNODE, IPOINT, ISECT
COMMON/SCALR/GRAV, POROS, SGRAV, VIS, THETA, IT, IDELT, ITIME, PHI, EPS
1 , FDELTBF, FFIMP, ALIMP, BEIMP

READ ALL DATA FOR POINTS

IF(NRIN.LE.0) CALL RA2(FFACT, IMAX*LINKS)
IF(IPOINT.NE.0) WRITE(6,2000)
2000 FORMAT(1HL,T30,'POINT PROPERTIES',/T30,18(1H-),/T02,
1 'LINK',T10,'PT.',T12,'NSEC',T17,'NSED',T25,'RM',
2 T35,'TALWG',T40,'FACT',T45,'APHA',T50,'BETA',T60,'Y',T70,
3 'Q',/T2,75(1H-))

5 READ(5,1000) LNAME, I, NSEC, NNSEC, NSED, RR, TALWGE, YY, QQ, FFFACT,
1 AALPHA, BBETA, BBANK
IF(LNAME.EQ.-9999) GO TO 999

DO 50 L=1, LINKS
   IF(IABS(LNAME).EQ.LINKNAM(L)) GO TO 60
50 CONTINUE
   CALL ERRWAR(2, 8, 0, LNAME, 0, 0.0)
GO TO 70

60 NSEC(I,L)=NNSEC
   NSED(I,L)=NSED
   RM(I,L)=RR
   TALWEG(I,L)=TALWGE
   BANK(I,L)=BBANK
   IF(NRIN.LE.0) TALWGI(I,L)=TALWGE
IF(NRIN.LE.0) Y(I,L)=YY
IF(NRIN.LE.0) Q(I,L)=QQ

25.04.85
IF(NRNIN.LE.0) FFACT(I,L)=FFFACT
ALPHA(I,L)=AALPHA
BETA(I,L)=BBETA

C
IF(FFACT(I,L).EQ.0.) FFACT(I,L)=FFIMP
IF(ALPHA(I,L).EQ.0.) ALPHA(I,L)=ALIMP
IF(BETA(I,L).EQ.0.) BETA(I,L)=BEIMP
IF(LTYPE(I).EQ.0.AND.BETA(I,L).LT.0.5) CALL ERRWAR(1,3,0,
1 I,LNKNAM(I),BETA(I,L))

1.000 FORMAT(4(I5,4F10.0,4F5.0))
IF(IPINT.NE.0)
WRITE(6,2001) LNAME,I,NSEC(I,L),NSED(I,L),RM(I,L),TALWEG(I,L),
1 FFACT(I,L),ALPHA(I,L),BETA(I,L),Y(I,L),Q(I,L)

2:001 FORMAT(4(I5,2F10.3,3F5.2,2F10.3)
NSEC(I,L)=-NSEC(I,L)

70 IF(LNAME.GT.0) GO TO 5

AVERAGE NODAL W/S LEVEL

DO 350 M=1,NODES
KKK=KK(M)
YSUM=0.0
DO 305 K=1,KKK
L=IABS(LL(M,K))
I=II(L)
IF(LL(M,K).LT.0) I=1
IF(K.EQ.1) YYY=Y(I,L)
IF(YYY-Y(I,L).NE.0.0) CALL ERRWAR(1,4,0,NODNAM(M),
1 1) LNKNAM(L),Y(I,L))
YSUM=YSUM+Y(I,L)

305 CONTINUE
YAVG=YSUM/KKK
DO 310 K=1,KKK
L=IABS(LL(M,K))
I=II(L)
IF(LL(M,K).LT.0) I=1
Y(I,L)=YAVG

310 CONTINUE

DETECT THE NODES ATTACHED WITH TWO LINKS
HAVING THE DIFFERENT CROSS SECTION TYPE

IF(KKK.NE.2) GO TO 350
NSEC1=NSEC(1,IABS(LL(M,1)))
NSEC1=NSEC(II(LL(M,1)),LL(M,1))
NSEC2=NSEC(1,IABS(LL(M,2)))
NSEC2=NSEC(II(LL(M,2)),LL(M,2))
IF(NSEC1.NE.NSEC2) CALL ERRWAR(1,2,0,NODNAM(M),0,0.0)

350 CONTINUE
GO TO 999

READ SEDIMENT CHARACTERISTICS FOR CUURENT POINTS

******************************
ENTRY SEDINP(PT,DS,D50R,PTYP)

******************************
READ STANDARD SEDIMENT DISTRIBUTIONS AND
LOAD IN APPROPRIATE POINT ARRAYS

NOTE: ARRAY E TEMPORARILY USED FOR NSED
ARRAY QS TEMPORARILY USED FOR PTYP

IF(NRIN.LE.0) CALL RAZ(D50R,IMAXM1*LINKS)
WRITE(6,2004)
2004 FORMAT(1H1,T30,'BED SEDIMENT DISTRIBUTIONS',/,'T30,28(1H-),/
100 READ(5,1002) NSEDTT,(PTYP(J),J=1,N1P1)
1002 FORMAT(I5,(T6,15F5.0))
NSED=IABS(NSEDTT)
WRITE(6,2002) NSEDTT,(PTYP(J),J=1,N1P1)
2002 FORMAT(/,T5,'SEDIMENT TYPE:',I5,' CDF:',(T30,15F6.3))

COMPUTE D50 FROM CDF

DO 10 J=1,N1P1
   IF(PTYP(J).GT.0.5) GO TO 20
10 CONTINUE
J=N1P1
20 D50TYP=DS(J-1)+(DS(J)-DS(J-1))*(0.5-PTYP(J-1))
   /((PTYP(J)-PTYP(J-1))

TRANSFORM INTO PDF

DO 30 J=1,N1
   PTYP(J)=PTYP(J+1)-PTYP(J)
   IF(PTYP(J).LT.0) CALL ERRWAR(23,2,0,J,0,PTYP(J))
30 CONTINUE
WRITE(6,2003) D50TYP,(PTYP(J),J=1,N1)
2003 FORMAT(T10, 'D50R=',F5.3, ' PDF:', (T32,15F6.3))
IF(NRIN.GT.0) GO TO 220
DO 200 L=1,LINKS
   ILAST=II(L)-1
   DO 200 I=1,ILAST
      IF(NSED(I,L).NE.NSED) GO TO 200
      DO 300 J=1,N1
         PT(I,J,L)=PTYP(J)
300 CONTINUE
   D50R(I,L)=D50TYP
200 CONTINUE
220 IF(NSEDTT.GT.0) GO TO 100
C RETURN

ENTRY SEDTRB

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SEDTRB READS SEDIMENT SIZE DISTRIBUTION
FOR TRIBUTARY INFLOW TO NODES

WRITE(6,2005)
2005 FORMAT(/,T30,'TRIBUTARY SEDIMENT DISTRIBUTION',/,'T30,40(1H-),/)

000 READ(5,3000) NODNM,NODSTT,(PTYP(J),J=1,N1P1)
300 FORMAT(2I5,(T11,14F5.0))
   IF(NODNM.EQ.-9999) GO TO 999
   NODNMM=IABS(NODNM)
   WRITE(6,2006) NODNMM,NODSTT,(PTYP(J),J=1,N1P1)
2006 FORMAT(/,T5,'NODNAM:','I5',' TYPE:','I5',' CDF:','(T30,15F6.3))
   DO 500 J=1,N1P1
      IF(PTYP(J).GT.0.5) GO TO 510
500 CONTINUE
   J=N1P1
510   D50TYP=DS(J-1)+(DS(J)-DS(J-1))*(0.5-PTYP(J-1))/(PTYP(J)-PTYP(J-1))
   DO 520 J=1,N1
      PTYP(J)=PTYP(J+1)-PTYP(J)
520 CONTINUE
   WRITE(6,2007) D50TYP,(PTYP(J),J=1,N1)
2007 FORMAT(T10,'D50R=','F5.3',' PDF=','(T32,15F6.3))
   DO 530 M=1,NODES
      IF(NODNAM(M).EQ.NODNMM) GO TO 540
530 CONTINUE
   CALL ERRWAR(2,24,0,NODNMM,0,0.0)
540 NODSED(M)=NODNMM
   IF(NODSED(M).NE.0.AND.NINQS(M).EQ.0)
1   CALL ERRWAR(2,26,0,M,NODNMM,0.0)
   DO 550 J=1,N1
      PTRIB(J,M)=PTYP(J)
550 CONTINUE
   IF(NODNM.GT.0) GO TO 600
999 RETURN
END
SUBROUTINE USTLTM

THIS SUBROUTINE CALCULATE UPSTREAM BOUNDARY CONDITION

DIMENSION D50P(IMAX,LINKS), AREA(IMAX,LINKS), VEL(IMAX,LINKS), Q(IMAX,LINKS), FFACT(IMAX,LINKS), RH(IMAX,LINKS), Y(IMAX,LINKS), D(IMAX,LINKS), QSTR(NODES), ACF(IMAX,LINKS), WIDTH(IMAX,LINKS), REACH(IMAX1,LINKS), TALWEG(IMAX,LINKS), SF(IMAX,LINKS), TALWGP(IMAX,LINKS), VOLOUT(IMAX,LINKS), QSTOT(IMAX,LINKS), II(LINKS), LL(NODES,KMAX), LNKNam(LINKS), DRYBED(LINKS)

COMMON/DIMS/NODES,KMAX,LINKS,IMAX,MEMO,NODES1,NTRIB,N1,IMAXM1

COMMON/USB/ADJRE

COMMON/SCALR/GRAY, POROS, SGRAY, VIS, THETA, IT, IDELT, ITIME, PHI, EPS

COMMON/TLMCF/TLM1, TLM2, TLM3, TLM4, TLM5, TLM6, TLM7, TLM8,

TLTM9

COMMON/SHD/REYN, SHIPAR

COMMON/MODSHD/ISHEAR

COMMON/SHEAR/REYSTA, TAUC

NAMELIST/USBC/IT, L, ITBC, V1, V2, V6, V8, UST, USC, SHF, QSIMP, FD, FDP, DELD

L, DW, ADJRE, AVDEP, TALM, DELT2, DELOST, CTOL, QSN, BNP, DWAT, V8P, TLM3T, TEMP

LOGICAL DRYBED, FIRCAL

VOLMAX=1.0
RETURN

ENTRY USTLTM(M,FIRCAL)

COMPUTE UPSTREAM BED LEVEL BY REQUIRING

QS(TLM)=QS(IMPOSED)

THETS1=1.0 - THETAS
C=ADJRE*5280./30.
L=IABS(LL(M,1)).
I=II(L)
IF(ABS(Q(I,L)).LT.DRYQ OR ABS(Q(I-1,L)).LT.DRYQ) GO TO 999
IF(ACF(I,L).LT.1.0) GO TO 710
VOLOUT(I-1,L)=0.0
GO TO 999

710

BUFF=C*IDELE*TCONST/REACH(I-1,L)/86400.
IF(BUFF.EQ.0.5) BUFF=0.5
ITBC=0
VAR1=SQR(32.17*1.65*D50R(I-1,L))
DEP=Y(I,L) - TALWGP(I,L)
CALL SECPRO(L,I)
IF(NOT.DRYBED(L)) GO TO 730
CALL ERRWAR(1,9,IT,LNKNAM(L),I,Q(I,L))
TALWEG(I,L)=TALWGP(I,L)
VOLOUT(I-1,L)=0.0
GO TO 999

MANAGEMENT OF NEWTON RAGHSON ITERATION

20 ITBC=ITBC+1
D(I,L)=AREA(I,L)/WIDTH(I,L)
VEL(I,L)=ABS(Q(I,L))/AREA(I,L)
SF(I,L)=FFACT(I,L)*VEL(I,L)*VEL(I,L)/(8.32.17*RH(I,L))
SFF=AMIN1(SF(I,L),0.01)
V1=VEL(I,L)/VAR1
V2=D(I,L)/D50R(I-1,L)
UST=SQRT(32.17*D(I,L)*SFF)
REYN=UST*D50R(I-1,L)/VIS
IF(ISHEAR.EQ.0) GO TO 161
REYSTA=SQRT(GSM1)*D50R(I-1,L)**1.5/VIS
CALL IWAGAK
SHIPAR=TAUC
GO TO 162

CALL SHIELD

USC=SQRT(SHIPAR)*VAR1
TEMP=AMAX1(0.001,UST-USC)
V6=TEMP/VAR1
TLTM3=TLTM3
IF(V1.LT.1.0.AND.V6.LT.1.0) TLM3T=0.0
QSIMP=AMAX1(0.0001,QSTR(M))/EXP(-ACF(I,L)*2.99573)/WIDTH(I,L)
DELTZ=Y(I,L)-DEP-TALWGP(I,L)
V8=(QSIMP-BUFF*REACH(I-1,L)*(1.-POROS)*
@ (Y(I,L)-DEP-TALWGP(I,L))/(IDELT*CONST*EXP(-ACF(I,L)*2.99573)))/
@ (VAR1*D50R(I-1,L))
IF(V8.LE.0.) GO TO 9
FD=ALOG10(V8)-TLTM2-TLM3*ALOG10(V1)-TLTM3*ALOG10(V6)
@ALOG10(V6)-TLTM4*ALOG10(V2)*ALOG10(V6)
FDP=(BUFF*REACH(I-1,L)*(1.-POROS)/(IDELT*CONST*EXP(-ACF(I,L)*
@2.99573)))*VAR1*D50R(I-1,L)
V8=TLTM2/AREA(I,L)+TLTM3/UST/WIDTH(I,L)/
@ (VAR1*V6/AREA(I,L))*ALOG10(V1)+TLTM4/UST/WIDTH(I,L)*ALOG10(V6)/
@ (AREA(I,L)+TLTM4/UST/WIDTH(I,L)/(VAR1*V6/AREA(I,L))*ALOG10(V2)-
@ @TLTM4*ALOG10(V6)/D(I,L))/2.303
DELP=-FD/FDP
GO TO 12
DELP=0.
TALWEG(I,L)=Y(I,L)-DEPP
WIDTH(I,L)=WIDP
V8=V8P
GO TO 13

DEPP=DEP
WIDP=WIDTH(I,L)
V8P=V8
DEP=DEP+DELP
TALWEG(I,L)=Y(I,L)-DEP

13 IF(ABS(DELP).GT.0.001*DEP.AND.ITBC.LT.50) GO TO 720

END OF ITERATION
C
IF (ABS (TALWEG (I, L) - TALWGP (I, L)) .LE. VOLMAX) GO TO 15
CALL ERRWAR (1, 10, IT, LNKNAM (L), I, VOLMAX)
TALWEG (I, L) = TALWGP (I, L) + SIGN (VOLMAX, TALWEG (I, L) - TALWGP (I, L))
15 IF (.NOT. FIRCAL) GO TO 10
QSN = QSTR (M) / EXP (-ACF (I, L) * 2.99573) / WIDTH (I, L)
CTOC = QSN
CTOP = CTOC
QSNP = QSN
10 QSN = VAR1 * D50R (I-1, L) * V8
C
CTOC = QSTOT (I-1, L) / WIDTH (I-1, L)
DELDST = THETAS * (QSN - CTOC) + THETS1 * (QSNP - CTOP)
DELDST = IDELT * TCONST * DELDST / ((1. - PORCS) * (1. - BUFF) * REACH (I-1, L))
VOLOUT (I-1, L) = -DELDST
IF (QSTR (M) .LE. 0.0. AND. TALWGP (I, L) .LT. TALWEG (I, L)) GO TO 20
GO TO 30
20 TALWEG (I, L) = TALWGP (I, L)
VOLOUT (I-1, L) = 0.0
30 IF (ABS (VOLOUT (I-1, L)) .LT. VOLMAX) GO TO 999
CALL ERRWAR (1, 10, IT, LNKNAM (L), I, VOLOUT (I-1, L))
VOLOUT (I-1, L) = SIGN (VOLMAX, VOLOUT (I-1, L))
999 RETURN
END
C**************************************** FIRST CARD OF NODSD **************************************************

NODAL SEDIMENT CONTINUITY PROCEDURES

SUBROUTINE NODSD(KK, LL, DRYBED, Q, LTYPE, REACH, WIDTH, QSTOT, D50R,
1 D50P, PT, CDF, DS, PTPT, TALWEG, TALWGP, CDF1, NODNAM, II, QS,
2 PTRIB, NINQS, NODSED, QTR, TDELD, NINQ, ACF, FFACHT, RH, SF, DSG, W, QSJNOD,
3 WASHLO, LKMNAM, VOLOUT, DEGLO, VEL, QSCAP, QSOUTF)
DIMENSION KK(NODES), LL(NODES, KMAX), DRYBED(LINKS), Q(IMAX, LINKS),
1 LTYPE(LINKS), REACH(IMAXML, LINKS), WIDTH(IMAX, LINKS), QSTOT(IMAX,
2 LINKS), D50R(IMAXML, LINKS), D50P(IMAX, LINKS), PT(IMAX, N1P1, LINKS),
3 CDF(N1P1), DS(N1P1), PTPT(IMAX, N1P1, LINKS), TALWEG(IMAX, LINKS),
4 TALWGP(IMAX, LINKS), CDF1(N1P1), NODNAM(NODES), II(LINKS),
5 QS(IMAX, N1, LINKS), PTRIB(N1, NODES), NINQS(NODES2), LKMNAM(LINKS),
6 NODSED(NODES), QTR(NODES2), TDELD(IMAX, N1, LINKS), NINQ(NODES2)
7 , ACF(IMAX, LINKS), FFACHT(IMAX, LINKS), RH(IMAX, LINKS),
8 SF(IMAX, LINKS), DSG(N1), W(N1), QSJNOD(N1), WASHLO(N1, QSOUTF(N1)),

VOLOUT(IMAX, LINKS), DEGLO(N1), VEL(IMAX, LINKS), QSCAP(IMAX, N1, LINKS)
COMMON/DIMS/NODES, KMAX, LINKS, IMAX, MEMO, NODES, NTRIB, N1, IMAXM1
1 , N1P1, NGROUP, MAXG, IMLAST, NSECS, NLEVMX, IERR, IWAR
2 , MAXBED, NITOUT, NBDT, IEND, NODES2
COMMON/SCALR/GRAV, POROS, SGRAV, VIS, THETA, IT, IDELT, ITIME, PHI, EPS
1 , FDELTB, FFIMP, ALIMP, BEIMP, THETAS, TCONST
COMMON/ITCON/ITTOT, ITHYD, EPSHYD, EPSQ, MITMAT, MITHYD, DYNMAX
1 , QMx, DRYQ, IPLINK, IPNODE, IPPOINT, IPSECT
COMMON/EXNI/ISORT
COMMON/TLTENH/QSTLTM, USTC, QBQT, USTWJ

A

NAMELIST/NODchk/ISEQ,M,KKK,NIQS
LOGICAL DRYBED,WASHLO,DEGLO
VOLMAX=1.0
GSAM1=GRAV*(SGRAV-1.0)
CNOD=40000.
RETURN

-----------------------------------

ENTRY NODSD1

-----------------------------------

DO 200 M=1,NODES
    ASUM=0.0
    QSUM=0.0
    KKK=KK(M)

    IGNORE THIS PROCEDURES FOR U/S AND D/S NODES

    IF(KKK.EQ.1.0.OR.NINQ(M).LT.0) GO TO 200
    IF(KKK.EQ.2.AND.(LTYPE(IABS(LL(M,1))).GT.0.OR.LTYPE(IABS(LL(M,2))).GT.0)) GO TO 200
    QSINF=0.0
    QINF=0.0
    QSUM=0.0
    CALL RAZ(CDF,N1)

200   CONTINUE

RETURN
CALL RAZ(QS,JNOD,N1)
DO 150 K=1,KKK

C COMPUTE THE NODAL AREA SM

L=IABS(LL(M,K))
IF (DRYBED(L) .OR. LTYPE(L) .GT. 0) GO TO 150
I=II(L)
IV=I-1
DELX=REACH(I-1,L)
WIDI=WIDTH(I,L)
WIDII=WIDTH(I-1,L)
IF(LL(M,K) .GT. 0) GO TO 146
I=1
DELX=REACH(I,L)
WIDI=WIDTH(I,L)
WIDII=WIDTH(I+1,L)
146 IF (ABS(Q(I,L)) .LT. DRYQ) GO TO 150
BAVG=0.5*(WIDI+WIDII)
IF(Q(I,L)*LL(M,K) .GT. 0) GO TO 148
QINF=QINF+ABS(Q(I,L))
QSUM=QSUM+ABS(Q(I,L))

C COMPUTE SUM OF PTPT*QSTOT FOR EACH SIZE FRACTION

C AT NODES

148 ASUM=ASUM+CNODE*BAVG
DO 149 J=1,N1
WASHLO(J)=.FALSE.
DEGLO(J)=.FALSE.

C NO NODAL SEDIMENT INFLOW WHEN

C NINGS=0 OR NODSED=0

135 IF(NINGS(M) .LE. 0 .OR. NODSED(M) .LE. 0) GO TO 135
QSJNOD(J)=QSJNOD(J)+QTR(NINGS(M))*PTL(J,M)
QSJNOD(J)=QSJNOD(J)-QS(I,J,L)*ISIGN(1,LL(M,K))
135 CONTINUE
149 CONTINUE

C PARTICLES ARE NOT ALLOWED TO DEPOSIT
C WHEN USTWJ > 1.0 IS TRUE FOR ONE OF
C D/S LINKS AT NODES

DO 120 K=1,KKK
L=IABS(LL(M,K))
1 IF (DRYBED(L) .OR. LTYPE(L) .NE. 0) GO TO 120
I=II(L)
IF(LL(M,K) .LT. 0) I=1
IF(ABS(Q(I,L)) .LE. DRYQ .OR. Q(I,L)*LL(M,K) .LT. 0 .AND. 0) GO TO 120
DO 110 J=1,N1
CALL CRIT2(I,J,L)
IF(QS(JNOD(J) .GT. 0 .AND. USTWJ .GT. 0.8) WASHLO(J)=.TRUE.
IF(QS(JNOD(J) .LT. 0 .AND. USTC .GT. 1.0) DEGLO(J)=.TRUE.
110 CONTINUE
120 CONTINUE
DO 90 J=1,N1
IF(QSJNOD(J).LT.0.0) GO TO 125
IF(WASLHO(J)) QSJNOD(J)=0.0
GO TO 126
IF(.NOT.DEGLO(J)) QSJNOD(J)=0.0

126
QSUM=QSUM+QSJNOD(J)
90 CONTINUE

COMPUTE NODAL BED CHANGE

IF(ASUM.EQ.0.0) GO TO 200
TALAVG=QSUM*QDELT*TCONST/ASUM/(1.-POROS)
IF(ABS(TALAVG).LT.0.001) TALAVG=0.0
IF(ABS(TALAVG).GT.VOLMAX) CALL ERRWAR(1,1,IT,NODNAM(M),0,
                         TALAVG)
             TALAVG=AMIN1(VOLMAX,ABS(TALAVG))*SIGN(1.0,TALAVG)

C C
C C
C
IF(ISORT.EQ.0) GO TO 152
DO 170 K=1,KKK
    L=IABS(LL(M,K))
    IF(DRYBED(L).OR.LTYPE(L).NE.0) GO TO 170
    I=II(L)
    IF(LL(M,K).LT.0) I=1
    IF(ABS(Q(I,L)).LE.DRYQ) GO TO 170
    IF(Q(I,L)*LL(M,K).GT.0.0) GO TO 170
    DO 176 J=1,N1
        IF(WASHLO(J)) GO TO 176
        IF(NINQS(M).LE.0.OR.NODSED(M).LE.0) GO TO 177
        QSINF=QSINF+PDIRB(J,M)*ABS(QTR(NINQS(M)))
        CDF(J)=CDF(J)+PDIRB(J,M)*ABS(QTR(NINQS(M)))
        QSINF=QSINF+PTPT(I,J,L)*ABS(QSTOT(I,L))
        CDF(J)=CDF(J)+PTPT(I,J,L)*ABS(QSTOT(I,L))
176 CONTINUE
170 CONTINUE
152 DO 160 K=1,KKK
    L=IABS(LL(M,K))
    IF(DRYBED(L).OR.LTYPE(L).GT.0) GO TO 160
    I=II(L)
    IF(LL(M,K).LT.0) I=1
    IF(ABS(Q(I,L)).LE.DRYQ) GO TO 160

C C
C
IF(ISORT.EQ.0) GO TO 157
IF(QSINF.LE.0.0) GO TO 157
IF(Q(I,L)*LL(M,K).LT.0.0) GO TO 157
DO 156 J=1,N1
    PTPT(I,J,L)=CDF(J)/QSINF
156 CONTINUE
CDF1(I)=0.0
DO 159 J=2,NIP1
    CDF1(J)=CDF1(J-1)+PTPT(I,J-1,L)
    IF(CDF1(J).GE.0.5) GO TO 161
159 CONTINUE
DO 600 M=1,NODES
QINF=0.0
QOUTF=0.0
KKK=KK(M)
IF(KKK.EQ.1) GO TO 600
CALL RAZ(CDF,NIP1)
CALL RAZ(QSOUTF,N1)
DO 601 J=1,N1
   WASHLO(J)=.FALSE.
   DEGLO(J)=.FALSE.
601 CONTINUE
IF(NINQS(M).LE.0) GO TO 603
DO 602 J=1,N1
   CDF(J)=CDF(J)+QTR(NINQS(M))*PTRIB(J,M)
602 CONTINUE
603 DO 610 K=1,KKK
   L=IABS(LL(M,K))
   IF(DRYBED(L).OR.LTYPE(L).GT.0)
      GO TO 610
   I=II(L)
   IF(LL(M,K).LT.0) I=1
   IO=I
   IF(ABS(Q(I,L)).LE.DRYQ) GO TO 610
   IF(Q(I,L)*LL(M,K).GT.0.0) GO TO 611
   QINF=QINF+ABS(Q(I,L))
   DO 631 J=1,N1
      CDF(J)=CDF(J)+ABS(QS(I,J,L))
631 CONTINUE
   GO TO 610
611 QOUTF=QOUTF+ABS(Q(I,L))
   IO=I+1
   IF(LL(M,K).GT.0) IO=I-1
   DO 630 J=1,N1
      QSOUTF(J)=QSOUTF(J)+ABS(QSCAP(IO,J,L))
630 CONTINUE
610 CONTINUE
DO 700 K=1,KKK
L=IABS(LL(M,K))
IF(DRYBED(L).OR.LTYPE(L).NE.0)
   GO TO 700
I=II(L)
IF(LL(M,K).LT.0) I=1
IF(ABS(Q(I,L)).LE.DRYQ.OR.Q(I,L)*LL(M,K).LT.0.0) GO TO 700
IO=I+1
IF(LL(M,K).GT.0) IO=I-1
GO TO 700

DO 710 J=1,N1
   CALL CRIT2(IO,J,L)
   IF(M.EQ.6) WRITE(6,6005) M,K,IO,I,J,L,USTWJ,USTC,CDF(J)
   FORMAT(5X,'ISEQ4',6IS,3F10.4)
   IF(CDF(J).GT.0.0.AND.USTWJ.GT.0.8) WASHLO(J)=.TRUE.
   IF(CDF(J).LT.0.0.AND.USTC.GT.1.0) DEGLO(J)=.TRUE.
7 10 CONTINUE
7 40 CONTINUE
DO 650 K=1,KKK
   L=IABS(LL(M,K))
   IF(DRYBED(L).OR.LTYPE(L).GT.0)
      GO TO 650
   I=II(L)
   II=I-1
   IO=II
   IF(LL(M,K).LT.0) GO TO 660
   DELX=REACH(II,L)
   WIDI=WIDTH(II,L)
   WIDI1=WIDTH(I,L)
   GO TO 665
6 60 I=1
   II=I
   IO=II+1
   DELX=REACH(I,L)
   WIDI=WIDTH(I,L)
   WIDI1=WIDTH(I+1,L)
   BAVG=0.5*(WIDI+WIDI1)
   IF(ABS(Q(I,L)).LE.DRYQ) GO TO 650
   IF(Q(I,L)*LL(M,K).GT.0.0) GO TO 670
6 65 GO TO 650

UPDATE TDELSD OF THE FIRST REACH OF OUTFLOW CHANNELS BY NODAL SEDIMENT CONTINUITY

6 70 DO 690 J=1,N1
   IF(QSOUTF(J).NE.0.0) GO TO 691
   QSD=-CDF(J)
   GO TO 692
6 91 QSD=QS(IO,J,L)-CDF(J)*QSCAP(IO,J,L)/QSOUTF(J)
6 92 TDELSD(II,J,L)=QSD*IDELT*TCNST/DELX
   /BAVG/(1.-POROS)
C GO TO 690
   CALL CRIT2(IO,J,L)
   IF(QSD.LT.0.0.AND.USTWJ.GT.1.0) TDELSD(II,J,L)=
   TDELSD(II,J,L)*QBQT
   IF(QSD.GT.0.0.AND.USTC.LT.1.0) TDELSD(II,J,L)=0.0
6 90 CONTINUE
CONTINUE
RETURN

ENTRY NODSD3

DO 400 M=1,NODES
    KKK=KK(M)
    IF(KKK.EQ.1) GO TO 400
    DZSUM=0.0
    DXSUM=0.0
    DO 430 K=1,KKK
        L=IABS(LL(M,K))
        I=II(L)-1
        IF(LL(M,K).LT.0) I=1
        IF(LTYPE(L).NE.0) GO TO 430
        DZSUM=DZSUM+VOLTOUT(I,L)*REACH(I,L)
        DXSUM=DXSUM+REACH(I,L)
    430      CONTINUE
    DZAVG=DZSUM/DXSUM
    DO 440 K=1,KKK
        L=IABS(LL(M,K))
        IF(LTYPE(L).NE.0) GO TO 440
        I=II(L)
        IF(LL(M,K).LT.0) I=1
        TALWEG(I,L)=TALWGP(I,L)-DZAVG
    440      CONTINUE
    IF(KKK.NE.2) GO TO 400
    L1=IABS(LL(M,1))
    L2=IABS(LL(M,2))
    IF(LTYPE(L1).NE.0.OR.LTYPE(L2).NE.0) GO TO 400
    I1=II(L1)
    I2=I1
    IF(LL(M,1).GT.0) GO TO 410
    I1=1
    I2=II(L2)
    IF(NINQS(M).NE.0.OR.NINQ(M).LT.0) GO TO 400
    ACFAVG=(ACF(I1,L1)+ACF(I2,L2))/2.
    FFAVG=(FFACT(I1,L1)+FFACT(I2,L2))/2.
    ACF(I1,L1)=ACFAVG
    ACF(I2,L2)=ACFAVG
    FFACT(I1,L1)=FFAVG
    FFACT(I2,L2)=FFAVG
    D50AVG=(D50P(I1,L1)+D50P(I2,L2))*0.5
    D50P(I1,L1)=D50AVG
    D50P(I2,L2)=D50AVG
    DO 420 J=1,N1
        PTAVG=(PTPT(I1,J,L1)+PTPT(I2,J,L2))*0.5
        PTPT(I1,J,L1)=PTAVG
        PTPT(I2,J,L2)=PTAVG
    420      CONTINUE
400      CONTINUE
RETURN
END
SUBROUTINE DONODE(MU, MD, E, F, H, DYN, KK, Q, II, YN, NINQ, NINQ1,
1 QTRIB, QTR, TEMPF, NGSIZE, SMAT, RMAT, TMAT, VVECT, EMAT, FVECT,
2 MGROUP, MPPOS, EP, FP, HP, AC, BC, ITRIB, LL, SF)

REAL*8 SMAT(MAXG, MAXG), RMAT(MAXG, MAXG), TMAT(MAXG, MAXG),
1 VVECT(MAXG), EMAT(MAXG, MAXG, NGROUP), FVECT(MAXG, NGROUP)

DIMENSION MU(LINKS), MD(LINKS), E(IMAX, LINKS), F(IMAX, LINKS),
1 H(IMAX, LINKS), DYN(NODES), KK(NODES), Q(IMAX, LINKS), II(LINKS),
2 YN(NODES), NINQ(NODES2), NINQ1(NODES2), QTRIB(NODES2), QTR(NODES2),
3 NGSIZE(NGROUP), EP(IMAX, LINKS), FP(IMAX, LINKS), HP(IMAX, LINKS),
4 MGROUP(NODES), MPPOS(NODES), AC(NODES2), BC(NODES2), LL(NODES, KMAX),
5 SF(IMAX, LINKS)

COMMON/DIMS/NODES, KMAX, LINKS, IMAX, MEMO, NODESI, NTRIB, N1, IMAX1,
1 , NAIL, NGROUP, MAXG, IMAST, NSECS, NLEVX, IERR, IWAR
2 , MAXBED, NITOUT, NBDT, IEND, NODES2

COMMON/SCALR/GRAV, POROS, SGRAV, VIS, THETA, IT, IDELT, ITIME, PHI, EPS
COMMON/ITCON/ITOT, ITHYD, EPSHYD, EPSQ, MITMAT, MITHYD, DYMAX
COMMON/STABLE/EPSYB, EPSY, DYMAX, ITERM

D E L Y M = 1.0

LRSTV = (3*MAXG*MAXG+MAXG)*2
GO TO 999

ENTRY NODES1(DETER)

LOAD BOUNDARY DATA

CALL INFLOW(YDOWN, QTRIB, QTR, TEMPF, NINQ, AC, BC, ITRIB, NINQ1)

LOOP ON NODE GROUPS

MEND = 0

DO 100 NG = 1, NGROUP
  MBEG = MEND + 1
  MEND = MBEG + NGSIZE(NG) - 1
  NGL = 0
  NGR = 0
  NGC = NGSIZE(NG)
  IF (NG.GT.1) NGL = NGSIZE(NG - 1)
  IF (NG.LT.NGROUP) NGR = NGSIZE(NG + 1)
  WRITE(6, MATERR)

  INITIALIZE MATRICES TO ZERO

  CALL RAZ(RMAT, LRSTV)

  LOAD DOWNSTREAM BOUNDARY CONDITION (THIS REQUIRES THAT D.S. POINT BE FIRST NODE IN
FIRST GROUP)

CALL LODMAT TO LOAD RMAT,SMAT,TMAT,VVECT
FOR CONTINUITY EQUATIONS
AT ALL NODES IN GROUP NG EQUATION(1)

CALL LODMA1(RMAT,SMAT,TMAT,VVECT,NGL,NGC,NGR,MBEG,MEND,NG)

INITIALIZE EMAT,FVECT

IF(NG.GT.1) GO TO 30

CALL INVERT(SMAT,NGC,DETER)
IF(DETER.EQ.0.) GO TO 400

CALL MATMLT(SMAT,TMAT,EMAT(1,1,1),NGC,NGC,NGR)
CALL SCAMAT(-1.0D00,EMAT(1,1,1),EMAT(1,1,1),NGC,NGR)

CALL MATVEC(SMAT,VVECT,FVECT(1,1),NGC,NGC)
WRITE(6,2K+MAT,FVECT
GO TO 100

REGRESSION CALCULATION FOR EMAT,FVECT EQUATION(4)

CALL MATMLT(RMAT,EMAT(1,1,NG-1),EMAT(1,1,NG),NGC,NGL,NGC)

CALL MATADD(EMAT(1,1,NG),SMAT,NGC,NGC)

CALL INVERT(SMAT,NGC,DETER)
IF(DETER.EQ.0.) GO TO 400

IF(NG.LT.NGROUP) CALL MATMLT(SMAT,TMAT,EMAT(1,1,NG),NGC,NGC,
1.0D00,EMAT(1,1,NG),EMAT(1,1,NG),
 1,NGC,NGR)

CALL MATVEC(RMAT,FVECT(1,NG-1),FVECT(1,NG),NGC,NGL)
-CALL MATSUB(FVECT(1,NG),FVECT,NGC,1)

CALL MATVEC(SMAT,VVECT,FVECT(1,NG),NGC,NGC)
CALL SCAVEC(-1.0D00,FVECT(1,NG),FVECT(1,NG),NGC)
WRITE(6,2000) EMAT,FVECT

CONTINUE

RETURN MATRIX SWEEP

DO 200 NG1=2,NGROUP
NG=NGROUP-NG1+1
NGC=NGSIZE(NG)
NGR=NGSIZE(NG+1)

    COMPUTE DYN VECTORS BY EQUATION (2),
    STORE IN FFVECT

    CALL MATVEC(EMAT(1,1,NG),FVECT(1,NG+1),VVECT,NGC,NGR)
    CALL MATADD(VVECT,FVECT(1,NG),FVECT(1,NG),NGC,1)

200 CONTINUE

TRANSFER DYN VALUES FROM RELATIVE POSITION
    (AS STORED IN FVECT) TO ABSOLUTE POSITIONS
    (AS STORED IN DYN)

    DYMAX=0.0
    DO 300 M=1,NODES
    DYN(M)=FVECT(MPOS(M),MGROUP(M))
    DYN(M)=SIGN(AMIN1(ABS(DYN(M)),DELYM),DYN(M))
25.04.85
    YN(M)=YN(M)+DYN(M)
    WRITE(6,2001) M,MPOS(M),MGROUP(M),DYN(M),YN(M)
2003 FORMAT(/,1X,3I5,',',DYN=','2F10.3)
    DYMAX=AMAX1(ABS(DYN(M)),DYMAX)
300 CONTINUE
    IF(IHYD.EQ.MHYD)
1    WRITE(6,2001) IT,IHYD,DYN
2001 FORMAT(/,T5,'NODE-LEVEL CORRECTIONS AT IT=',I5,1
1      ' IHYD=',I5,/,T05,2SF5.1))
    GO TO 999
400 CALL ERRWAR(2,2,IT,NG,0,DETER)
    WRITE(6,MATERR)
999 RETURN
END
C************** FIRST CARD OF ENHAN *********************
C
C
C
C THIS PROGRAM COMPUTES SEDIMENT LOAD BY
C ENGELUND HANSEN FORMULA

C
C SUBROUTINE ENHAN(LTYPE, II, LL, KK, LKNAM, RH, WIDTH, SF, VEL, Q, DSG,
1 D50P, PTPT, QS, QSTOT, ACF, DRYBED, QSCAP)
C
C DIMENSION LTYPE(LINKS), II(LINKS), QSTOT(IMAX, LINKS),
1 RH(IMAX, LINKS), SF(IMAX, LINKS), DSG(N1), LKNAM(LINKS),
C
2 D50P(IMAX, LINKS), PTPT(IMAX, N1P1, LINKS), QS(IMAX, N1, LINKS),
3 Q(IMAX, LINKS), LL(NODES, KMAX), KK(NODES), ACF(IMAX, LINKS),
4 WIDTH(IMAX, LINKS), VEL(IMAX, LINKS), DRYBED(LINKS),
5 QSCAP(IMAX, N1, LINKS)
C
C LOGICAL DRYBED
C COMMON/DIMS/NODES, KMAX, LINKS, IMAX, MEMO, NODESI, NTRIB, N1, IMAXM1
1 , N1P1
C COMMON/ITCON/ITTOT, ITHX, EPSHYD, EPSQ, MITHX, MITHYD, DYNMAX
1 , DQMAX, DRYQ
C COMMON/SCALR/GRAV, POROS, SGRAV, VIS, THETA, IT, IDELT, ITIME
C COMMON/EXNI/ISORT, WKB0, WKB1
C COMMON/SHD/REYN, SHIPAR
C COMMON/TLENH/QSTLTM, USTC, QBQT, USTWJ
C
C GSM1=GRAV*(SGRAV-1)
GAMA=1.94*GRAV
GAMAS=GAMA*(SGRAV-1)
C
C GO TO 999
C
C ENTRY ENHAN1
C
C
C-------------------------------------
C
C
C DO 200 I=1, LINKS
C ILAST=II(I)
C CALL RA2(QSTOT(1, I), ILAST)
C IF(DRYBED(L).OR.LTYPE(L).NE.0)
1 GO TO 200
C
C DO 150 I=1, ILAST
C IF(ABS(Q(I, L)).LT.DRYQ) GO TO 150
C VEL2=VEL(I, L)*VEL(I, L)
C USTAR=SQRT(GRAV*RH(I, L)*SF(I, L))
B1=0.26*SQRT(RH(I, L)/D50P(I, L))
B1=AMIN1(B1, 70.0)
C IF(WKB1.NE.0.0) B1=WKB1
C TAU0=GAMA*RH(I, L)*SF(I, L)
C DO 100 J=1, N1
C QS(I, J, L)=0.0
C VAR1=SQRT(GSM1*DSG(J))
C REYN=USTAR*DSG(J)/VIS
C CALL SHIELD
C TAUSTA=TAU0/(GAMAS*DSG(J))
C
C
C 200 CONTINUE
C
C
C 150 CONTINUE
C
C 100 CONTINUE
C
C
WK = (DSG(J)/D50P(I,L)) ** B1 * WKB0
WK = AMIN1(WK, 1.0)
QSCAP(I,J,L) = 0.05*VEL2*Sqrt(DSG(J)/GSM1)*TAUSTA**1.5
QS(I,J,L) = QSCAP(I,J,L) * WIDTH(I,L)
QSTLTM = QS(I,J,L) / WIDTH(I,L)
QS(I,J,L) = QS(I,J,L) * PTPT(I,J,L) * WK*EXP(-ACF(I,L) *
1  2.99573)*SIGN(1.0, Q(I,L))
QSTOT(I,L) = QSTOT(I,L) + QS(I,J,L)
1  00  CONTINUE
1  50  CONTINUE
2  00  CONTINUE
9  99  RETURN
END
FIRST CARD OF USENHA

SUBROUTINE USENHA

THIS SUBROUTINE CALCULATE UPSTREAM BOUNDARY CONDITION

SUBROUTINE USENHA(D50P, AREA, VEL, Q, FFACT, RH, Y, D, QSTR, ACF,
1 WIDTH, REACH, TALWEG, TALWG2, SF, VOLOUT,
2 QSTOT, II, LL, LNKNAME, DRYBED)

DIMENSION D50P(IMAX, LINKS), AREA(IMAX, LINKS), VEL(IMAX, LINKS),
1 Q(IMAX, LINKS), FFACT(IMAX, LINKS), RH(IMAX, LINKS), Y(IMAX, LINKS),
2 D(IMAX, LINKS), QSTR(NODES), ACF(IMAX, LINKS), WIDTH(IMAX, LINKS),
3 REACH(IMAX1, LINKS), TALWEG(IMAX, LINKS), SF(IMAX, LINKS),
4 TALWG2(IMAX, LINKS), VOLOUT(IMAX, LINKS), QSTOT(IMAX, LINKS),
5 II(LINKS), LL(NODES, KMAX), LNKNAME(LINKS), DRYBED(LINKS)

COMMON/DIMS/NODES, KMAX, LINKS, IMEM, NODES1, NTRIB, N1, IMAXM1
1 

COMMON/ITCON/ITTOT, ITHYD, EPSHYD, EPSQ, MITMAT, MTHYD, DYNMAX
1 , DQMAX, DRYQ, IPLINK, IPNODE, IPOINT, IPSECT

COMMON/USB/ADJRE

COMMON/SCALR/GRAV, FOGR, SGRAY, VIS, THETA, IT, IDELT, ITIME, PHI, EPS
1 , FDELTB, FFIME, ALIMF, BEIMF, THETAS, TCONST

COMMON/TLTMCF/TLTM1, TLTM2, TLTM3, TLTM4, TLTM5, TLTM6, TLTM7, TLTM8,
1 TLTM9

COMMON/SYH/REYN, SHIPAR

LOGICAL DRYBED, FICAL

TO BE IN ERROR BY AT MOST 'EPSUS*DEP'
IN NEWTON'S METHOD

EPSUS=0.0001
VOLMAX=1.0
GSML=GRAV*(SGRAV-1)
GAMA=1.94*GRAV
GAMAS=GAMA*(SGRAV-1)
RETURN

ENTRY USENHL(M, FICAL)

COMPUTE UPSTREAM BED LEVEL BY REQUIRING
QS(ENGHAN)=QS(IMPOSED)

THETS1=1.-THETAS
C=ADJRE*5280./30.
L=IABS(LL(M,1))
I=II(L)
IF(AABS(Q(I,L)).LT.DRYQ.OR.ABS(Q(I-1,L)).LT.DRYQ) GO TO 999
IF(ACF(I,L).NE.1.0) GO TO 710
VOLOUT(I-1,L) = 0.0
GO TO 999

C
710 BETA1 = C*IDELT*TCONST/REACH(I-1,L)/86400.
IF (BETA1 .GE. 0.5) BETA1 = 0.5
ITBC = 0
VAR1 = SQRT(GSM1*D50P(I,L))
DEF = Y(I,L) - TALWGP(I,L)

BEGIN OF NEWTON ITERATION

C
C
720 CALL SECPRO(L,I)
IF (.NOT. DRYBED(L)) GO TO 730
CALL ERRWAR(1, 9, IT, LNKNAME(L), I, Q(I,L))
TALWEG(I,L) = TALWGP(I,L)
VOLOUT(I-1,L) = 0.0
GO TO 999
C
730 ITBC = ITBC + 1
C
AREA2 = AREA(I,L)*AREA(I,L)
D(I,L) = AREA(I,L)/WIDTH(I,L)
VEL(I,L) = ABS(Q(I,L))/AREA(I,L)
VEL2 = VEL(I,L)*VEL(I,L)
SF(I,L) = FFACT(I,L)*VEL(I,L)*VEL(I,L)/(8.*GRAV*RH(I,L))
C
QSIMP = QSTR(M)/EXP(-ACF(I,L)*2.99573)/WIDTH(I,L)
DELTZ = Y(I,L) - DEF - TALWGP(I,L)
QSOBJ = QSIMP - BETA1*REACH(I-1,L)*(1.-POROS)*
@ DELTZ/(IDELT*TCONST*EXP(-ACF(I,L)*2.99573))
C
FD = QSOBJ - 0.05*VEL2*SQRT(D50P(I,L)/GSM1)*
@ (GAMA*RH(I,L)*SF(I,L)/(GAMAS*D50P(I,L)))**1.5
C
C
TAKE DEPLET"DEP"=DELEN"D"=DELEN"RH" WHEN TAKING DERIVATIVE

C
C
FD = BETA1*REACH(I-1,L)*(1.-POROS)/(IDELT*TCONST*EXP(-ACF(I,L)*
@ 2.99573))
0 + 0.05*SQRT(D50P(I,L)/GSM1)*(GAMA*RH(I,L)*SF(I,L)/
@ (GAMAS*D50P(I,L)))**1.5*VEL2*5./D(I,L)
DELD = -FD/FD
DEF = DEF + DELD
TALWEG(I,L) = Y(I,L) - DEF
C
C
END OF NEWTON ITERATION

C
C
IF (ABS(DELD) .GT. EPS*DEP_AND. ITBC .LT. 50) GO TO 720
IF (ABS(TALWEG(I,L) - TALWGP(I,L)) .LE. VOLMAX) GO TO 15
CALL ERRWAR(1, 10, IT, LNKNAME(L), I, VOLMAX)
TALWEG(I,L) = TALWGP(I,L) + SIGN(VOLMAX, TALWEG(I,L) - TALWGP(I,L))
C
C
TAKE THETAS = 1 IN EQ. (II-103)

15 DELDST = QSOBJ - QSTOT(I-1,L)/WIDTH(I-1,L)
DELDST = IDELT*TCONST*DELDST/((1.-POROS)*(1.-BETA1)*
@ REACH(I-1,L))
VOLOUT(I-1,L) = -DELDST
IF (QSTR(M) .LE. 0.0 AND. TALWGP(I,L) .LT. TALWEG(I,L)) GO TO 20
GO TO 30
20 TALWEG(I,L) = TALWGP(I,L)
   VOLOUT(I-1,L) = 0.0
30 IF (ABS(VOLOUT(I-1,L)).LT.VOLMAX) GO TO 999
   CALL ERRWAR(1,10,IT,LINKAM(L),I,VOLOUT(I-1,L))
   VOLOUT(I-1,L) = SIGN(VOLMAX, VOLOUT(I-1,L))
999 RETURN
END
SUBROUTINE CROISS

SUBROUTINE CROISS (TAB, NBV, CORR, ISHIFT)

(FROM CARIMA)
CLASS IN RAISING ORDER PAIRS IN A TABLE
BY THE FIRST MEMBER OF THE PAIR
CORRECTION OF THE FIRST OR OF THE SECOND MEMBER
BY CORR

DIMENSION TAB(NBV)
DO 50 I=1,NBV,2
   TAB(I+ISHIFT)=TAB(I+ISHIFT)+CORR
50 CONTINUE

IFIN=NBV-2
DO 100 I=1,IFIN,2
   IP2=I+2
   DO 80 J=IP2,NBV,2
      IF(TAB(I).LE.TAB(J)) GOTO 80
      DUM=TAB(I)
      TAB(I)=TAB(J)
      TAB(J)=DUM
      DUM=TAB(I+1)
      TAB(I+1)=TAB(J+1)
      TAB(J+1)=DUM
80 CONTINUE
100 CONTINUE
RETURN
END
C******************************************** FIRST CARD OF SEXION ********************************************
C************************************************************************************************************
C
SUBROUTINE SEXION(TALWEG, AREA, RH, FFACT, WIDTH, Y, NSEC, ISECAD,
1 SEGEOM, ISSEGO, TWORK, DRYBED, LNKNAM, II, RK, RPK, RKPEP, RPKP, AREAP)
C
DIMENSION TALWEG(IMAX, LINKS), AREA(IMAX, LINKS), RH(IMAX, LINKS),
1 FFACT(IMAX, LINKS), WIDTH(IMAX, LINKS), Y(IMAX, LINKS), NSEC(IMAX, LINKS),
2 LINKS, ISECAD(NSECS), SEGEOM(1), ISSEGO(IMAX, LINKS),
3 TWORK(INE), DRYBED(LINKS), LNKNAM(LINKS), II(LINKS), TITLE(15),
4 RK(IMAX, LINKS), RPK(IMAX, LINKS), RKPEP(IMAX, LINKS), RPKP(IMAX, LINKS)
LOGICAL BCNST, DRYBED, FIRCAH, WET
COMMON/DIMS/NODES, KMAX, LINKS, IMAX, MEMO, NODESI, NTRIB, N1, IMAXM1
1 , N1P1, NGROUP, MAXG, IMLAST, NSECS, NLEVXM, IERR, IWAR,
2 MAXBED, NITOUT, NBDT, IEND
COMMON/SCALR/GRAV, POROS, SGRAV, VIS, THETA, IT, IDELT, ITIME, PHI, EPS
1 , FDELTB, FFIMP, ALIMP, BEIMP, THETAS, TCONST, STRK
COMMON/ITCON/ITTOT, ITHYD, EPSHYD, EPSQ, MITMAT, MITHYD, DYNMAX
1 , DQMAX, DRYQ, IFLINK, IPNODE, IPOINT, IPSECT, FIRCAH, ISTRK
NAMELIST/SECH2C/IT, I, I, ISFEC, NLEVEL, DH, DEPTH, IL, FINT, SQRTF,
1 NSCEIL
FIRCAH = .TRUE.
DEPMAX = 500.
C
READ SECTION DATA AND LOAD AREA-CONVEYANCE
TABLES
LOOP ON NUMBER OF SECTION-TYPES, NSECS
C
ISECA = 1
IF (IPSECT.NE.0) WRITE(6,2000)
2000 FORMAT(1H1, // , T20, 'SECTION DEFINITION
1', // T20, 18(IH-))
DO 100 NS = 1, NSECS
C-------------------------------------------------------------
C
IMPUT RECORD 15
C-------------------------------------------------------------
C
READ (5,1000) NUMSEC, NLEVEL, DH, TITLE
1000 FORMAT (2I5, F10.0, 15A4)
C
-------------------------------------------------------------
C
READ (5, 1002) ISEC, NSBEC
1002 FORMAT (10I5)
* THEN
WRITE (6, 2007) NUMSEC, ISEC
2007 FORMAT (1X, 'NUMSEC=', I3, ' ISEC=', I2, ' !!! CONTROL !!!',
1 * ' ISEC MUST BE 0 OR 1, ISEC=0 ASSUMED')
ISEC = 0
END IF
IF (NLEVXM = NLEVEL.LT.0) CALL ERRWAR(3, 27, NLEVXM, NLEVEL, 0.0)
IF (IPSECT.NE.0) WRITE (6, 2001)
NUMSEC, NLEVEL, ISEC, NSBEC, DH, TITLE
2001 FORMAT (//, T10, 'SECTION NUMBER', I5, ' NLEVEL=', I3,
1 ' ISEC=', I2, ' NSBEC=', I3, ' DH=', F10.2, 15A4, //, T10, 40(IH-))
IF (ISEC.EQ.0) WRITE (6, 2011)
2011 FORMAT (T15, 'LEVEL-WIDTH PAIRS:')
IF (ISEC.EQ.1) WRITE (6, 2012)
2012 FORMAT (T15, 'DISTANCE-LEVEL PAIRS:')
MEMOIR=4*NSEC
IF(MOD(NSEC, 4).NE.0) MEMOIR=MEMOIR+2*(4-MOD(NSEC, 4))
IF(MEMOIR.GE.IMSLAST) CALL ERRWAR(3, 0, NUMSEC, MEMOIR, 0.0)
CALL RA2(TWORK, MEMOIR-IMSLAST)
IWORK=0
C
CREAD LEVEL-WIDTH OR DISTANCE-LEVEL PAIRS
CINPUT RECORD 17 (4 PAIRS PER RECORD) &18
C
C20 CONTINUE
READ(5, 1001) (TWORK(I+IWORK), I=1, 8)
1001 FORMAT(8F10.0)
IF(TWORK(1+IWORK).LT.0.0) GO TO 25
ZLAST=TWORK(1+IWORK)
IF(IPSECT.NE.0) WRITE(6, 2002) (TWORK(I+IWORK), I=1, 8)
2002 FORMAT(T35, 4F10.2, 3X)
IWORK=IWORK+8
C
C
C
C
CGO TO 20
C
C25 CONTINUE
IF(ISEC.EQ.0) GOTO 30
C
C
C
C
CTRANSFORMATION OF DISTANCE-LEVEL PAIRS
INTO LEVEL-WIDTH PAIRS (CARIMA PROCEDURE)
C
C
CNBVS=NSEC*2
IDEB1=1
IDEB2=3
IFIN=IDEB1+NBVS-1
NBV=NBVS
C
C
C
C
FOR EACH LEVEL IN THE TABLE (DISTANCE-LEVEL),
A WIDTH IS COMPUTED, THEN THE PAIR (LEVEL,WIDTH)
IS STORED AT THE SAME PLACE IN TWORK TABLE.
C
CGIVE A SLIGHT SLOPE TO EACH HORIZONTAL SUBSECTION
C
C
C
CDO 155 I=IDEB2, IFIN, 2
IF(TWORK(I+1).NE.TWORK(I-1)) GO TO 155
IF(I.EQ.IDEB2) TWORK(I+1)=TWORK(I+1)-0.001
IF(I.NE.IDEB2) TWORK(I+1)=TWORK(I+1)+
*  SIGN(0.001, (TWORK(I-1)-TWORK(I-3)))
155 CONTINUE
C
C
C
CDO 190 I=IDEB1, IFIN, 2
COTE=TWORK(I+1)
191 FORMAT(1X, 'I = ', I2, ' COTE = ', F10.4)
B=0.0
WET=.FALSE.
IF(COTE.GE.TWORK(IDEB1+1)) WET=.TRUE.
C
C
C
CDO 185 J=IDEB2, IFIN, 2
IF(.NOT.WET) GOTO 170
C
C
CPREVIOUS POINT WET
C
REF=TWORK(J)
IF(TWORK(J+1).LE.COTE) GOTO 165
REF=REF-(TWORK(J)-TWORK(J-2))*(TWORK(J+1)-COTE)
*       /(TWORK(J+1)-TWORK(J-1))
165     WET=.FALSE.
       B=B+REF-TWORK(J-2)
       GOTO 185
C
C
PREVIOUS POINT DRY
C
170    IF(TWORK(J+1).GT.COTE) GOTO 185
175    IF(TWORK(J+1).EQ.COTE) GOTO 177
       REF=TWORK(J-2)+(TWORK(J)-TWORK(J-2))*(TWORK(J-1)-COTE)
*       /(TWORK(J-1)-TWORK(J+1))
177    B=B+TWORK(J)-REF
185    CONTINUE
C
STORE (LEVEL,WIDTH) PAIRS IN TWORK TABLE
C
TWORK(NBV+1)=COTE
TWORK(NBV+2)=B
NBV=NBV+2
190    CONTINUE
DO 195 I=1,NBVS
       TWORK(I)=TWORK(I+NBVS)
       TWORK(I+NBVS)=0.
195    CONTINUE
C
CALL CROISS(TWORK(1),NBVS,0.0,0)
C
DO 196 I=3,NBVS,2
    IF((TWORK(I)-TWORK(1)).EQ.0) TWORK(I)=TWORK(I)+0.0005
196    CONTINUE
C
ALL LEVEL-WIDTH PAIRS READ FOR SECTION.
C PROJECT (Z,B) VALUES ONTO REGULAR GRID-STORE
C IN ZONE WHICH WILL ULTIMATELY HOLD AREAS
C
WRITE(6,6006) (TWORK(I),I=1,NBVS)
6006  FORMAT(1X,'TRANSFORMED PAIRS',/8(1X,F10.3))
30    ISECAD(NS)=ISECA
TWORK(IWORK+1)=0.0
ISEGEO(ISECA)=NUMSEC
ISEGEO(ISECA+1)=NLEVEL
SEGEOM(ISECA+2)=DH
ZHI=TWORK(I)
DO 197 I=1,NBVS,2
       TWORK(I)=TWORK(I)-ZHI
197    CONTINUE
ZHI=0.0
C****** MIN BED WIDTH ZERO FOR FLUME SIMULATIONS, JULY 87
BHI=AMIAX1(00.0,TWORK(2))
SEGEOM(ISECA+3)=BHI
IF (NBVS.GE.4)
*       THEN
       IF((TWORK(3)-TWORK(1)).LT.0.0011)
* SEGEOM(ISECA+3)=AMAX1(0.0,TWORK(4))
END IF
IWORK=1
BCONST=.FALSE.
C
DO 40 IL=2,NLEVEL
   DEPTH=DH*(IL-1)
32  IF(DEPTH.LT.ZHI.OR.BCONST) GO TO 35
   IWORK=IWORK+2
   IF(TWORK(IWORK).EQ.0.0) BCONST=.TRUE.
   IF(BCONST) BLO=BHI
   IF(BCONST) GO TO 35
   ZLO=ZHI
   BLO=BHI
   ZHI=TWORK(IWORK)
C *********** MIN BED WIDTH ZERO FOR FLUME SIMULATIONS JULY 87
   BHI=AMAX1(00.0,TWORK(IWORK+1))
   IF(ZHI.LT.ZLO.OR.(BHI-BLO).LT.-0.001)
1    CALL ERRWAR(2,1,0,NUMSEC,IWORK,BHI)
   GO TO 32
   SEGEOM(ISECA+IL+2)=BLO
   IF(BHI.NE.BLO)
1    SEGEOM(ISECA+IL+2)=BLO+(BHI-BLO)*(DEPTH-ZLO)/(ZHI-ZLO)
40  CONTINUE
C
PERFORM TRAPEZOIDAL INTEGRATION TO LOAD AREAS,
CONVEYANCES, HYDRAULIC RADII ON REGULAR GRID
C
IF(IPSECT.NE.0) WRITE(6,2003)
   A=0.
   BHI=SEGEOM(ISECA+3)
   P=BHI
DO 50 IL=1,NLEVEL
   DEPTH=IL*DH
   BLO=BHI
   IF(IL.LT.NLEVEL) BHI=SEGEOM(ISECA+IL+3)
   BAVG=0.5*(BLO+BHI)
   A=A+DH*BAVG
   P=P+SQRT(DH*DH*4+(BHI-BLO)*(BHI-BLO))
   R=A/P
   SEGEOM(ISECA+IL+2)=A
   SEGEOM(ISECA+IL+2+NLEVEL)=A*SQRT(8.0*GRAV*R)
   IF(ISTRK.EQ.1) SEGEOM(ISECA+IL+2+NLEVEL)=
1    1.486*STRK*A*R**(2./3.)
   SEGEOM(ISECA+IL+2+NLEVEL+NLEVEL)=R
   IF(IPSECT.NE.0)
1    WRITE(6,2004) IL,DEPTH,A,BAVG,SEGEOM(ISECA+IL+2+NLEVEL),
1     R
50  CONTINUE
IF(ISTRK.EQ.1)WRITE(6,2005)
IF(ISTRK.NE.1)WRITE(6,2006)
ISECA=ISECA+3+3*NLEVEL
2003 FORMAT(/,'T40,'LEVEL',T50,'DEPTH',T60,'AREA',T70,'WIDTH',
1       T80,'CONVEYANCE',T92,'HYD. RAD.',/,'T40,60(1H-1))
2004 FORMAT(T40,I5,3F10.3,F15.3,F10.3)
2005 FORMAT(T3,'STRICKLER COEFFICIENT USED TO COMPUTE CONVEYANCE')
2006 FORMAT(T3,'FRICITION FACTOR USED TO COMPUTE CONVEYANCE')
C
REPLACE REFERENCES TO SECTION NAME BY
REFERENCES TO SECTION SEQUENCE NUMBER, NS

DO 60 L=1,LINKS
   ILAST=II(L)
   DO 60 I=1,ILAST
      IF(-NSEC(I,L).EQ.NUMSEC) NSEC(I,L)=NS
   60 CONTINUE

100 CONTINUE
   GO TO 999

**********
ENTRY SECPRO(LS,IS)

**********
Determine relative position in area-conveyance table for appropriate section

L=LS
I=IS
ISECA=ISECAD(NSEC(I,L))
NSECIL=NSEC(I,L)
NLEVEL=ISEGEQ(ISECA+1)
DH=SEGEQ(ISECA+2)
DEPTH=Y(I,L)-TALWEG(I,L)
IL=DEPTH/DH+0.001
IF(IL.GE.1) GO TO 510

SMALL DEPTH

DRYBED(L)=.TRUE.
   IL=1
   DEPTH=DH
510 IF(IL.LT.NLEVEL) GO TO 520

LARGE DEPTH
   IF(ITIME.GE.0.OR.DEPTH.GT.DEPMAX) CALL ERRWAR(1,6,IT,
   1 LNKNAM(L),I,DEPTH)
   IF(DEPTH.GE.DEPMAX) CALL ERRWAR(3,22,IT,LNKNAM(L),I,DEPTH)
   IL=NLEVEL-1

   CALL INTERPOLATION FACTOR

520 FIN=(DEPTH-DH*IL)/DH
   IL=IL+2+ISECA
   AREA(I,L)=SEGEQ(IL)+FIN*(SEGEQ(IL+1)-SEGEQ(IL))
   COMPUTE WIDTH
   WIDTH(I,L)=(SEGEQ(IL+1)-SEGEQ(IL))/DH
   COMPUTE CONVEYANCE, K PRIME

   IL=IL+NLEVEL
IF(ISTRK.EQ.1) GO TO 400
SQRTF=SQRT(FFACT(I,L))
RK(I,L)=SEGEOM(IL)+FINT*(SEGEOM(IL+1)-SEGEOM(IL))/SQRTF
RPK(I,L)=(SEGEOM(IL+1)-SEGEOM(IL))/(DH*SQRTF)
GO TO 410
400 RK(I,L)=SEGEOM(IL)+FINT*(SEGEOM(IL+1)-SEGEOM(IL))
RPK(I,L)=(SEGEOM(IL+1)-SEGEOM(IL))/DH
410 IF(FIRCAH) GO TO 317
GO TO 318
317 RKP(I,L)=RK(I,L)
RPKP(I,L)=RPK(I,L)
AREAP(I,L)=AREA(I,L)
C
C COMPUTE HYDRAULIC RADIUS
C
318 IL=IL+NLEVEL
RH(I,L)=SEGEOM(IL)+FINT*(SEGEOM(IL+1)-SEGEOM(IL))
C IF(IT.LE.2) WRITE(6,SECHEC)
999 RETURN
END
SUBROUTINE FLOCA

SUBROUTINE FLOCA (MU, MD, LL, E, F, H, EP, FP, HP, Y, YP, Q, QP, DYN, AREA,
1 AREAP, VEL, RH, WIDTH, II, REACH, LTYPE, ALPHA, YN,
2 BETA, SF, TALWEG, DRYBED, LNKNAM, RM, RK, RKP, RPK, RPKF,
3 RL, RMM, RN, KK, NINQ, NINQS, QTRIB, QTR, TEMPF,
4 NGSIZE, SMAT, RMAT, TMAT, VVECT, EMAT, FVECT, MGROUP, MPOS,
5 D50P)

REAL*8 SMAT (MAXG, MAXG), RMAT (MAXG, MAXG), TMAT (MAXG, MAXG),
4 VVECT (MAXG), EMAT (MAXG, MAXG, NGROUP), FVECT (MAXG, NGROUP)

DIMENSION KK (NODES),
1 NINQ (NODES2), NINQS (NODES2), QTRIB (NODES2), QTR (NODES2),
2 NGSIZE (NGROUP),
3 MGROUP (NODES), MPOS (NODES)

DIMENSION MU (LINKS), MD (LINKS), LL (NODES, KMAX), E (IMAX, LINKS),
1 F (IMAX, LINKS), H (IMAX, LINKS), EP (IMAX, LINKS), FP (IMAX, LINKS),
2 HP (IMAX, LINKS), Y (IMAX, LINKS), YP (IMAX, LINKS), Q (IMAX, LINKS),
3 QP (IMAX, LINKS), DYN (NODES), AREA (IMAX, LINKS), AREAP (IMAX, LINKS),
4 VEL (IMAX, LINKS), RH (IMAX, LINKS), WIDTH (IMAX, LINKS), II (LINKS),
5 REACH (IMAXM1, LINKS), LTYPE (LINKS), ALPHA (IMAX, LINKS), BETA (IMAX,
6 LINKS), TALWEG (IMAX, LINKS), DRYBED (LINKS), LNKNAM (LINKS), RM (IMAX,
7 LINKS), SF (IMAX, LINKS), RR (IMAX, LINKS), RKP (IMAX, LINKS),
8 RPK (IMAX, LINKS), RPKF (IMAX, LINKS), YN (NODES), D50P (IMAX, LINKS)

COMMON/SCALR/GRAV, POROS, SGRAV, VIS, THETA, IT, IDDEL, ITIME, PHI, EPS
1 , FDELTB
COMMON/ITCON/ITTOT, ITHYD, EPSHYD, EPSQ, MITMAT, MITHYD, DYNMAX
1 , DQMAX, DRYQ, IPLINK, IPNODE, IPOINT, IPSECT
COMMON/STABLE/EPSYB, EPSY, DYMAG, ITERMX, ICYCLET, DQNMAX
COMMON/DIMS/NODES, KMAX, LINKS, IMAX, MEMO, NODSET, NTRIB, N1, IMAXM1
1 , NIP1, NGROUP, MAXG, IMLAST, NSECS, NLEVMX, IERR, IWAR
2 , MAXBED, NITOUT, NBDT, IEND, NODES2
COMMON/TMPHAS/IDT, IDTT, ITGLOB, IUNST, DELTB, ITGLMX, IDTMX, IDTTMX
1 , IFFACT, PRINT

LOGICAL DRYBED, FIRCAL, PRINT

IDT=0
IDTT=0
ITGLOB=0
ITER=0
EPSQIT=0.5

GO TO 999
---------

ENTRY FLOCA1 (DETER, FIRCAL)
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---------

UNSTEADY FLOW
---------
IF(IUNST.NE.0) DELTB=IDELT
IF(IUNST.NE.0.AND.UNITIME.GT.0) THEN

MANAGEMENT OF ITERATION FOR ITERATIVE FORM
OF DE SAINT VENANT EQUATION (LINEARIZATION
ITERATION LEVEL 1)

ITER=ITER+1

PROCEED FORWARD SWEEP

CALL LINKS1

CALL NODES1(DETER)

IF(DETER.EQ.0.0) GO TO 999

PROCEED BACKWARD SWEEP

CALL LINKS2

IF(ITER.LT.ITERMX.AND.DYMAX.GT.EPSHYD.AND.DQMAX.GT.EPSQIT) GO TO 300

ITER=0

THE END OF ITERATION LEVEL 1

DETERMINE THE MAXIMUM CHANGE IN DISCHARGE AND WS
ELEVATION

DQNMAX=0.0
DYNMAX=0.0
DO 350 L=1,LINKS
   ILAST=II(L)
   DO 350 I=1,ILAST
      DQNMAX=AMAX1(DQNMAX,ABS(Q(I,L)-QP(I,L)))
      DYNMAX=AMAX1(DYNMAX,ABS(Y(I,L)-YP(I,L)))
   CONTINUE

SET PREVIOUS VALUES FROM PRESENT VALUES AND COMPUTE
ENERGY SLOPE FOR NORMAL FLUVIAL LINKS

DO 150 L=1,LINKS
   ILAST=II(L)
   DO 150 I=1,ILAST
      AREAP(I,L)=AREA(I,L)
      YP(I,L)=Y(I,L)
      QP(I,L)=Q(I,L)
      RK(I,L)=RK(I,L)
      RPKP(I,L)=RPK(I,L)
      IF(LTYPE(I).EQ.0) SF(I,L)=Q(I,L)**2 / RK(I,L)**2
   CONTINUE

ELSE

STEADY FLOW

--------------
PROCEED STABILIZATION PROCEDURES IF NEEDED

STBTIM=0.0
ICYCLE=0

MANAGEMENT OF STABILIZATION ITERATION
(REAL TIME MARCHING)

IDT=IDT+1
IF(IDT.GT.IDTMX) IDTT=IDTT+1
CALL TMCHG1

MANAGEMENT OF ITERATION WITHIN ONE INCREMENT
TIME (ITERATION LEVEL 2)

ITGLOB=ITGLOB+1

PROCEED FORWARD SWEEP

CALL LINKS1

CALL NODES1(DETER)

IF(DETER.EQ.0.0) GO TO 999

PROCEED BACKWARD SWEEP

CALL LINKS2

Determine the maximum change in discharge and ws
elevation between present and previous iterations

DQNMAX=0.0
DYNMAX=0.0

DO 450 I=1,LINKS
   ILAST=II(L)
   DO 450 I=1,ILAST
      DQNMAX=AMAX1(DQNMAX,ABS(Q(I,L)-QP(I,L)))
      DYNMAX=AMAX1(DYNMAX,ABS(Y(I,L)-YP(I,L)))
   CONTINUE

SET PREVIOUS VALUES AS PRESENT VALUES AND COMPUTE
ENERGY SLOPE FOR FLUVIAL LINKS

DO 550 I=1,LINKS
   ILAST=II(L)
   DO 550 I=1,ILAST
      AREAP(I,L)=AREA(I,L)
      YP(I,L)=Y(I,L)
      QP(I,L)=Q(I,L)
      RK(I,L)=RK(I,L)
      RPKP(I,L)=RPK(I,L)

      RK: CONVANCE (Q=RK * SF**.5)

(IF(LTYPE(L).EQ.0) SF(I,L)= Q(I,L)**2 / RK(I,L)**2

CONTINUE
STABILIZATION TIME IN MINUTES

```
STBTIM=STBTIM+DELTB/60.0
ICYCLE=ICYCLE+1
IF(PRINT) WRITE(6,2000) IDT,IDTT,ITGLOB,DELTB,EPSY,DYNMAX,
     DQNNMAX,STBTIM,ICYCLE
2000
     FORMAT(13,T3,'IDT=',',I5,T25,'IDTT=',
            ',I5,T50,'ITGLOB=',',I5,///,
            ',T3,'DELTB=' ',F10.5,T25,'EPSY=' ',F10.5,T50,'DYNMAX='
            ',E10.3,///,T3,'DQNNMAX=' ',E10.3,T25,'STBTIM=' ',F10.5,
            T50,'CYCLE=' ',I5)
     CALL FRICT1 WILL AUTOMATICALLY COMPUTE f
```

IF(FIRCAL.AND.IFFACT.GT.0) CALL FRICT1
IF(ITGLOB.LT.ITGLMX.AND.DYNMAX.GT.EPSY) GO TO 250

```
ITGLOB=0
```

THE END OF ITERATION LEVEL 2

```
IF(IDT.LT.IDTLMX.OR.(DYNMAX.GT.EPSHYD.AND.DQNNMASS.GE.EPSQ))
     GO TO 50
IF(IDTT.LT.IDTTMX) GO TO 50
```

THE END OF STABILIZATION PROCEDURE

```
IDT=0
IDTT=0
END IF
```

CALL FRICT1 WILL AUTOMATICALLY COMPUTE f

```
IF(IFFACT.GT.0) CALL FRICT1
```

RETURN
END

SUBROUTINE TOSHI
RETURN
END
SUBROUTINE ACKERS

** SUBROUTINE ACKERS (LTYPE, II, QSTOT, RH, SF, DSG, D50P, PTPT, QS, Q, LL, KK, WIDTH, VEL, DRYBED, ACF, LNKNAM, QSCAP) **

DIMENSION LTYPE(LINKS), II(LINKS), QSTOT(IMAX, LINKS),
       RH(IMAX, LINKS), SF(IMAX, LINKS), DSG(N1), LNKNAM(LINKS),
       D50P(IMAX, LINKS), PTPT(IMAX, N1P1, LINKS), QS(IMAX, N1, LINKS),
       Q(IMAX, LINKS), LL(NODES, KMAX), KK(NODES), ACF(IMAX, LINKS),
       WIDTH(IMAX, LINKS), VEL(IMAX, LINKS), DRYBED(LINKS),
       QSCAP(IMAX, N1, LINKS)

LOGICAL DRYBED
COMMON/DIMS/NODES, KMAX, LINKS, IMAX, MEMO, NODESI, NTRIB, N1, IMAXM1
1    , N1P1
COMMON/SCALR/GRAV, POROS, SGRAV, VIS, THETA, IT, IDELT, ITIME
COMMON/TLTMCF, TLTM1, TLTM2, TLTM3, TLTM4, TLTM5, TLTM6, TLTM7, TLTM8,
1    TLTM9
COMMON/EXNI/ISORT, WKB0, WKB1
COMMON/SHD/REYN, SHIPAR
COMMON/ITCON/ITTOT, ITHYD, EPSHYD, EPSQ, MITMAT, MITHYD, DYNMAX
1    , DQMAX, DRYQ
COMMON/TLTENH/QSTLTM, USTC, QBQT, USTWJ
GSM1=GRAV*(SGRAV-1.)
GRTHS=GRAV/1000.
ATEG=8.0*GRAV
GO TO 999

ENTRY ACKQS

DO 105 L=1, LINKS
    LNKNM=LNKNAM(L)
    ILAST=II(L)
    IJ=ILAST*N1
    CALL RAZ(QS(1,1,L), IJ)
    CALL RAZ(QSTOT(1,L), ILAST)
    IF (DRYBED(L).OR.1-)
    LTYPE(L).NE.0) GO TO 105
DO 100 I=1, ILAST
    IF (ABS(Q(I,L)).LT.DRYQ) GO TO 100
    IF (VEL(I,L).EQ.0.) GO TO 100
    USTAR=SQR(T(GRAV*RH(I,L)*SF(I,L))

C

DEF=RH(I,L)
D50PF=D50P(I,L)
DO 100 J=1, N1
    QS(I,J,L)=0.0
ACKER AND WHITE'S METHOD

\[ \text{DSTAR} = \frac{\text{GSM1}}{(\text{VIS} \times \text{VIS})} \times (1.3) \times \text{DSG}(J) \]

IF (DSTAR.GT.60.) GO TO 300

\[ \text{C1} = 1.0 - 0.56 \times \text{ALOG10}(\text{DSTAR}) \]
\[ \text{C2} = 10.0 \times \text{ALOG10}(\text{DSTAR}) - 2.86 \times \text{ALOG10}(\text{DSTAR})^2 - 3.53 \]
\[ \text{C3} = 0.23 / \text{SQRT}(\text{DSTAR}) + 0.14 \]
\[ \text{C4} = 9.66 / \text{DSTAR} + 1.34 \]

GO TO 400

300

\[ \text{C1} = 0.0 \]
\[ \text{C2} = 0.025 \]
\[ \text{C3} = 0.17 \]
\[ \text{C4} = 1.5 \]

400

\[ \text{F1} = \text{USTAR}^2 / \text{SQRT}(\text{GSM1} \times \text{DSG}(J)) \times (\text{VEL}(I,L) / (\text{SQRT}(32.)))^2 \times \text{ALOG10}(10.0 \times \text{DEP} / \text{DSG}(J)))^2 \times (1.0 - \text{C1}) \]

\[ \text{DSR} = \frac{\text{DSG}(J)}{D50PP} \]

EPI: HIDING OR EXPOSURE FACTOR (Eq.II.27)

IF (DSR.GE.3.7) EPI=1.3

IF (DSR.GE.0.075.AND.DSR.LT.3.7) EPI=0.53 \times \text{ALOG10}(\text{DSR}) + 1.0

IF (DSR.LT.0.075) EPI=0.4

\[ \text{F1} = \text{EPI} \times \text{F1} \]

401

IF (F1/C3.LE.1.0) THEN

\[ \text{QSCAP}(I,J,L) = 0.0 \]

ELSE

\[ \text{QSCAP}(I,J,L) = \text{SGRAV} \times \text{DSG}(J) \times C2 \times (F1/C3 - 1.0) \times (\text{USTAR} \times \text{VEL}(I,L))^2 \times \text{C1} \times \text{DEP} \]

END IF

\[ \text{QSCAP}(I,J,L) = \text{QSCAP}(I,J,L) \times \text{VEL}(I,L) \times \text{DEP} / (2.65) \]

\[ \text{QS}(I,J,L) = \text{QSCAP}(I,J,L) \times \text{WIDTH}(I,L) \]

\[ \text{QS}(I,J,L) = (\text{QS}(I,J,L) \times \text{PTPT}(I,J,L)) \times \exp(-\text{ACF}(I,L) \times 2.99573) \times \text{SIGN}(1.0, \text{Q}(I,L)) \]

\[ \text{QSTOT}(I,L) = \text{QSTOT}(I,L) + \text{QS}(I,J,L) \]

100 CONTINUE

105 CONTINUE

999 RETURN

END
SUBROUTINE USACK

THIS SUBROUTINE CALCULATE UPSTREAM BOUNDARY CONDITION
FOR ACKERS-WHITE TRANSPORT FORMULA.

SUBROUTINE USACK (D50R, D50P, AREA, VEL, Q, FFACT, RH, Y, D, QSTR, ACF,
1      WIDTH, REACH, TALWEG, TALWGP, SF, VOLOUT,
2      QSTOT, II, LL, LNKNAM, DRYBED)

DIMENSION D50P (IMAX, LINKS), AREA (IMAX, LINKS), VEL (IMAX, LINKS),
1      Q (IMAX, LINKS), FFACT (IMAX, LINKS), RH (IMAX, LINKS), Y (IMAX, LINKS),
2      D (IMAX, LINKS), QSTR (NODES), ACF (IMAX, LINKS), WIDTH (IMAX, LINKS),
3      REACH (IMAX1, LINKS), TALWEG (IMAX, LINKS), SF (IMAX, LINKS),
4      TALWGP (IMAX, LINKS), VOLOUT (IMAX, LINKS), QSTOT (IMAX, LINKS),
5      II (LINKS), LL (NODES, KMAX), LNKNAM (LINKS), DRYBED (LINKS)
6      , D50R (IMAX, LINKS)

COMMON /DIMS/NODES, KMAX, LINKS, IMAX, MEMO, NODESI, NTRIB, N1, IMAXM1
1      , NIP1
2      COMMON /USB/ADJRE, A, B, UC
3      COMMON /ITCON/ITTOT, ITHYD, EPSHYD, EPSQ, MITMAT, MITHYD, DYNMAX
4      , DQMAX, DRYQ, IPLIT, INODE, IPOINT, ISPCT
5      COMMON /SCALE/GRAV, POROS, SGRAV, VIS, THETA, IT, ITDEL, ITIME, PHI, EPS
6      , FDELTB, FFIMP, ALIMP, BEIMP, THETAS, TCONST
7      COMMON /TLTMCF/TLTM1, TLTM2, TLTM3, TLTM4, TLTM5, TLTM6, TLTM7, TLTM8,
8      , TLTM9
9      COMMON /SHD/REYN, SHIPAR

LOGICAL DRYBED, FIRCAL

NAMELIST /PWS/IT, I, L, ITIME, ITBC, THETAS, C, DRYQ, BETAI, TCONST,
1      DEP, QSIMP, DELT2, QSOBJ, FD, FDP, DED, UC

TO BE IN ERROR BY AT MOST 'EPSUS*DEP'
IN NEWTON'S METHOD

EPSUS=0.0001
VOLMAX=1.0
GSM1=GRAV*(SGRAV-1)
GAMA=1.94*GRAV
GAMAS=GAMA*(SGRAV-1)
RETURN

ENTRY USACK1 (M, FIRCAL)

COMPUTE UPSTREAM BED LEVEL BY REQUIRING
QS (ACKER-WHITE) = QS (IMPOSED)

THETS1=1.-THETAS
C=ADJRE*5280./30.
L=IABS (LL (M, 1))
I=II(L)
IF(ABS(Q(I,L)).LT.DRYQ.OR.ABS(Q(I-1,L)).LT.DRYQ) GO TO 999
IF(ACF(I,L).NE.1.0) GO TO 710
VOLOUT(I-1,L)=0.0
GO TO 999

C
710 BETA1=C*IDELT*TCONST/REACH(I-1,L)/86400.
IF(BETA1.GE.0.5) BETA1=0.5
ITBC=0
DEP=Y(I,L)-TALWGP(I,L)

C
C
BEGIN OF NEWTON ITERATION
C
C
720 CALL SECPRO(L,I)
IF(.NOT.DRYBED(L)) GO TO 730
CALL ERRWAR(1,9,IT,LNKNAM(L),I,Q(I,L))
TALWEG(I,L)=TALWGP(I,L)
VOLOUT(I-1,L)=0.0
GO TO 999
C
C
730 ITBC=ITBC+1
D(I,L)=AREA(I,L)/WIDTH(I,L)
DEPP=D(I,L)
VEL(I,L)=ABS(Q(I,L))/AREA(I,L)
V=VEL(I,L)
DV=-V/D(I,L)
USTAR=SQRT(GRAV*RH(I,L)*SF(I,L))
DUSTAR=USTAR/D(I,L)
DS=DS0P(I,L)

C
C
ACKERS-WHATE METHOD
C

DS0P=DS0P(I,L)
DSTAR=(GSM1/(VIS*VIS))**(1./3.)*DS
IF(DSTAR.GT.60.) GO TO 300
C1=1.0-0.56*ALOG10(DSTAR)
C2=10.0**(2.86*ALOG10(DSTAR)-ALOG10(DSTAR)**2-3.53)
C3=0.23/SQRT(DSTAR)+0.14
C4=9.66/DSTAR+1.34
GO TO 400

300
C1=0.0
C2=0.025
C3=0.17
C4=1.5

400
F1=USTAR**C1/SQRT(GSM1*DS)*(VEL(I,L)/(SQRT(32.)*
ALOG10(10.*DEPP/DS)))**(1.0-C1)
DSR=DS/DS0P
-IF(DSR.GE.3.7) EPI=1.3
IF(DSR.GE.0.075.AND.DSR.LT.3.7) EPI=0.53*ALOG10(DSR)+1.0
IF(DSR.LT.0.075) EPI=0.4
F1=EPI*F1

C
UST=USTAR
DF1=EPI/SQRT(GSM1*DS)*(
@C1*UST**(C1-1.)*DUSTAR*(V/(SQRT(32.)*ALOG10(10.*DEPP/DS)))**(1.
@-C1)+
@UST**C1*(1.-C1)/V**C1*DV/(SQRT(32.)*ALOG10(10.*DEPP/DS))**(1.-C1)
@+UST**C1*V**(1.-C1)*(C1-1.)*(SQRT(32.)*ALOG10(10.*DEPP/DS))**
@ (C1 - 2.) * SQRT (32.) / 2.303/DEPF)
C
QSIMP = QSTRI(M) / EXP (-ACF(I,L) * 2.99573) / WIDTH(I,L)
DELTZ = Y(I,L) - DEP - TALWGP(I,L)
QSOBJ = QSIMP - BETA1 * REACH(I-1,L) * (1.-POROS) *
C
DELTZ / (IDEFT*TCONST*EXP (-ACF(I,L) * 2.99573))
C
F1C3 = MAX (0., F1/C3 - 1.)
C
QSAK = DS*C2*(F1C3)**C4*V**((1.+C1)/USTAR*C1
FD = QSOBJ - QSAK
DQSAK = DS*C2*
C4*(F1C3)**(C4-1.)*DF1/C3**V**((1.+C1)/USTAR*C1
C
(1.)*C4*(1.+C1)*V**C1*DV/USTAR*C1
C
DQSAK = DS*C2*(F1C3)**(C4-1.)*DF1/C3**V**((1.+C1)/USTAR*C1
C
FD = BETA1 * REACH(I-1,L) * (1.-POROS) / (IDEFT*TCONST*EXP (-ACF(I,L) * 2.99573)) - DQSAK
C
DELD = -FD/FDP
DEP = DEP + DELD
TALWEG(I,L) = Y(I,L) - DEP
C
END OF NEWTON ITERATION
C
IF (ABS(DELD) .GT. EPS*DEP.AND. ITBC.LT.50) GO TO 720
IF (ABS(TALWEG(I,L) - TALWGP(I,L)) .LE. VOLMAX) GO TO 15
CALL ERRWAR(1,10,IT,INKNAM(L),I,VOLMAX)
TALWEG(I,L) = TALWGP(I,L) + SIGN (VOLMAX, TALWEG(I,L) - TALWGP(I,L))
C
TAKE THETAS=1 IN EQ.(II-103)
C
15 DELDST = QSOBJ - QSTOT(I-1,L)/WIDTH(I-1,L)
DELDST = IDEFT*TCONST*DELDST / ((1.-POROS)*(1.-BETA1) *
C
REACH(I-1,L))
VOLOUT(I-1,L) = -DELDST
IF (QSTRI(M) .LE. 0.0 AND. TALWGP(I,L).LT.TALWEG(I,L)) GO TO 20
GO TO 30
20 TALWEG(I,L) = TALWGP(I,L)
VOLOUT(I-1,L) = 0.0
30 IF (ABS(VOLOUT(I-1,L)) .LT. VOLMAX) GO TO 999
CALL ERRWAR(1,10,IT,INKNAM(L),I,VOLOUT(I-1,L))
VOLOUT(I-1,L) = SIGN (VOLMAX, VOLOUT(I-1,L))
999 RETURN
END
SUBROUTINE INFLOW (YDOWNS, QTRIB, QTR, TEPF, NINQ, AC, BC, ITRIB, & NINQS)

DIMENSION QTRIB(NODES2), QTR(NODES2), NINQ(NODES2), AC(NODES2),
1 BC(NODES2), NINQS(NODES2)

COMMON/DIMS/NODES, KMAX, LINKS, IMAX, MEMO, NODESI, NTRIB, N1, IMAXM1
1 , N1P1, NGROUP, MAXG, IMLAST, NSECS, NLEVMX, IERR, IWAR
2 , MAXBED, NITOUT, NBDT, IEND, NODES2
COMMON/SCALR/GRAV, POROS, SGRAV, VIS, THETA, IT, IDELT, ITIME
INTEGER ITDAT/-9999/

READ NEW INFLOWS IF NEEDED

25 IF (ITIME.LT. ITDAT) GO TO 100
30 CONTINUE
DO 30 LT=1, NTRIB
30 CONTINUE
QTR(LT) = QTRIB(LT)
TEMPF = TFREAD

THE RECORD POSITION FOR YDOWNS NOW IS USED
2 AS Y(U/S) (i.e. upstream water surface
ele.
) IN SUPERCRITICAL FLOW CASE. (AUG. '89)

YDOWNS = YREAD
YTIMEP = ITDAT

INPUT RECORD 23

READ (5,1000,END=900) ITDAT, TFREAD, YREAD, (QTRIB(LT), LT=1, NTRIB)
IF (ITRIB.LT.0) GO TO 300

DO 200 M=1, NODES

ABS(NINQ) = seq. posN

NINQ>0 FOR Q input
NINQ<0 FOR Y input
NINQ=0 FOR nothing (inter-nodes)

I=NINQ(M)

ABS(NINQS) = seq. pos. in QTRIB:
NINQS=0 : NO Qs inflow
NINQS>0 : Qs input from imposed data
NINQS<0 : Qs input = a*Q**b

IF (NINQS(M).GT.0) GO TO 200
IF (I.LE.0) GO TO 200

IF NINQS(M).LE.0.AND. DISCHARGE
ALPI=0.0
BET=1.0-BETA(I,L)
IF (Q(I,L)*X(I1,L)-Y(I,L)) .LE. 0.0 .OR. Q(I1,L)*(Y(I1,L)-Y(I,L))
1 .LE. 0.0) BET=0.5
IF (Q(I,L).LT.0.0 .AND. Q(I1,L).LT.0.0) BET=1.0-BET
DELX=-REACH(I,L)
WRITE(6,CFCHK)

COMPUTE A, B, C, ------------Etc.

A=PHI*WIDTH(I1,L)/DELX
B=THETA/DELX
C=-(1.-PHI)*WIDTH(I,L)/DELX
D=B
G=PHI/DELTS*(AREI1-AREPI1)-(1-PHI)/DELTS*(AREI-AREPI)-
1 THETA/DELX*(Q1I-Q1I)-((1-THETA)/DELX*(QPI-QPI)+
1 (1-THETA)/DELX*(QPI-QPI))=ALPI*THETA*WIDTH(I1,L)/DELX*
2 (THETA/4*(QI/AREI+Q1I/AREI1)**2+(1-THETA)/4*(QI/AREI+Q1I/AREI1+*
3 AREPI)**2)+ALPI*THETA*WIDTH(I+1,L)/2/AREI1S*Q1I*Q1I/AREI+
4 Q1I/AREI1) * ((THETA/DELX*(AREI1-AREI)+(1-THETA)/DELX*(AREI1-*
5 AREPI)) +THETA*GRAV/DELX*(THETA/2*(AREI+AREI1) + (1-THETA)/2*
6 (AREPI+AREPI1)) +THETA*GRAV*WIDTH(I+1,L)/2*(THETA/DELX*(YI1-YI)+
7 -(1-THETA)/DELX*(YP1-YPI)) -THETA*GRAV*(1-BET)*RPKI1/RKI1C*Q1I*
8 ABS(Q1I)*2*(1-THETA)*((AREI+AREI1)+(1-THETA)*((AREPI1-AREPI1))
AP=AP+THETA*GRAV*WIDTH(I+1,L)/2*(THETA*(BET*QI*ABS(QI)/RKIS+*
1 (1-BET)*Q1I*ABS(Q1I)/RKIS1) +(1-THETA)*Q1I*ABS(QPI)/RKPI1)+*
2 (1-BET)*QPI*ABS(QPI)/RKPI1))
BP=PHI/DELTS*(THETA/DELX*ALPI*(THETA/2*(2*QI/AREI+2*Q1I/*
1 AREI1)+(1-THETA)/2*(2*QI/AREI+2*QPI/AREPI1))
1 +ALPI*THETA/AREI1*(THETA/DELX*(Q1I-Q1I)+(1-THETA)/DELX*
2 ((Q1I-QPI)) -ALPI*THETA/2*AREI1*
2 (QI/AREI+Q1I/AREI1)*(THETA/DELX*
3 (AREI1-AREI)+(1-THETA)/DELX*
3 (AREPI1-AREPI) + GRAV*THETA*(1-BET)*
4 ABS(Q1)/RK1S*(THETA*(AREI+AREI1)+(1-THETA)*(AREPI+AREPI1))
   CP=-ALPI*THETA*WIDTH(I,L)*QI/AREIS*(THETA/DELX*(QI1-QI)+(1-THETA)) /
1 DELX*(QPI1-QPI) + ALPI*THETA*WIDTH(I,L)/DELX*(THETA/4*(QI/AREI+
2 QI1/AREI1)**2+(1-THETA)/(QPI/AREPI+QPI1/AREPI1)**2)+ALPI*
3 THETA/2*(WIDTH(I,L)*QIS/AREIC+WIDTH(I,L)*QI*QI1/(AREI1*AREIS)) *
4 (THETA/DELX*(AREI1-AREI)+
4 (1-THETA)/DELX*(AREPI1-AREPI)) - THETA*
5 GRAV/DELX*(THETA/2*(AREI+AREI1)+(1-THETA)/2*(AREPI+AREPI1))+
6 THETA*GRAV*WIDTH(I,L)/2/DELX*(THETA*(YI1-YI)+(1-THETA)*(YPI1-
7 YPI)) - GRAV*THETA*BET*RPKI*QI*ABS(QI)/RKIC*(THETA*(AREI+AREI1)+
8 (1-THETA))*(AREPI+AREPI1))
CP=CP+THETA*GRAV*WIDTH(I,L)/2*(THETA*(BET*QI*ABS(QI)/RKIS+*
1 (1-BET)*QI1*ABS(QI)/RKI1S)+(1-THETA)*(BET*QPI*ABS(QPI)/
2 RKPI+*(1-BET)*QPI1*ABS(QPI1)/RKPI1S))
CP=-CP
DP=(1-PHI)/DELTIS+(-THETA/DELX*ALPI*(THETA*(QI/AREI+QI1/
1 AREI1)+(1-THETA)*(QPI/AREPI+QPI1/AREPI1)) + ALPI*
1 QPI1/AREPI1)) + (THETA/DELX*(QI1-QI)+(1-THETA)/
2 DELX*(QPI1-QPI)) - ALPI*THETA/2/AREI*(QI/AREI+QI1/AREI1)*
3 (THETA/DELX*(AREI1-AREI)+
3 (1-THETA)/DELX*(AREPI1-AREPI)) +
4 GRAV*THETA*BET*ABS(QI)/RKIS*(THETA*(AREI+AREI1)+(1-THETA)*
5 (AREPI+AREPI1))
DP=-DP
GP=PHI/DELTIS*(QI1-QPI1)+(1-PHI)/DELTIS*(QI-QPI)+ALPI*(
1 THETA*(QI/AREI+QI1/AREI1)+(1-THETA)*(QPI/AREPI+
2 QPI1/AREPI1)) + (THETA/DELX*(QI1-QI)+(1-THETA)/DELX*(
3 QPI1-QPI)) - ALPI*(THETA/4*(QI/AREI+QI1/AREI1)**2*+
4 (1-THETA)/4*(QPI/AREPI+QPI1/AREPI1)**2)*(THETA/DELX*
5 (AREI1-AREI)+(1-THETA)/DELX*
5 (AREPI1-AREPI)) + GRAV*
6 (THETA/2*(AREI+AREI1)+(1-THETA)/2*(AREPI+AREPI1)) *
7 (THETA/DELX*(YI1-YI)+(1-THETA)/DELX*(YPI1-YPI))
GP=GP+ GRAV*(THETA/2*(AREI+AREI1)+(1-THETA)/2*(AREPI+AREPI1)) *
1 (THETA*(BET*QI*ABS(QI)/RKIS+*(1-BET)*QI1*ABS(QI1)/RKI1S)+
2 (1-THETA)*(BET*QPI*ABS(QPI)/RKPI+(1-BET)*QPI1*ABS(QPI1)/
3 RKPI1S))
GP=GP
C WRITE(6,CFCHK1)
999 RETURN
END
C*********************************************************** FIRST LINE OF HYSOR2 (VERSION 3/88)***********************************************************

C THIS SUBROUTINE RECOMPUTES BED-MATERIAL SIZE DISTRIBUTION DUE TO DEGRADATION/AGgradation IN EACH TIME PERIOD

******************************************************************************

**************

SUBROUTINE HYSOR2(I, LNKNAM, ACF, RH, VOLOUT, SF, D50R,
C*** 1 TDELDP, PT, PTT, WIDTH, WIDTHP, TALWGP, TALWGP,
C
C WE DO NOT HAVE WIDTHP IN SECPR0 NOW
C USE WIDTHP-WIDTH IN HY502 FOR THE TIME
BEGING
C
1 TDELDP, PT, PTT, WIDTH, TALWGP, TALWGP,
2 PT, REACH, QS, QSFP, EL1, TMP, DSG)
C
**************

VERSION 3/88 - SEDICOUP EQUIVALENT

-----------------------------------------------------------------------

C

DIMENSION DSG(N1), RH(IMAX), SF(IMAX), TDELDP(IMAX,N1),
1 PT(IMAX,N1P1), WIDTH(IMAX), QS(IMAX,N1),
2 TALWGP(IMAX), TALWGP(IMAX), PTP(IMAX,N1P1), QSFP(IMAX,N1),
3 PTT(IMAX,N1)
4 WIDTHP(IMAX)

COMMON/DIMS/NODES, KMAX, LINKS, IMAX, MEMO, NODESI, NTRIB, N1, IMAXM1
1 , N1P1, NGROUP, MAXG, IMLAST, NSEC, NLEVMAX, IERR, IWAT, 2
MAXBED, NITOUT

COMMON/SCALR/GRV, POROS, SGRV, VIS, THETA, IT, IDEL, ITIME, PHI, EPS
1 , FDELTB, FFIMP, ALIMP, BEIMP, THETAS, TCONST

COMMON/SHD/REYN, SHIR, SHIPAR
COMMON/MODSH/ISHAR, IYALIN
COMMON/SHEAR/REYSTA, TAUC
NAMELIST/CHK1/IT, IK, DM, SM, TALWMP, TALWM, THA, TM, TMP, VOLNP1
1 , VOLN, BM, FIRRIS, FACTOR, THETA, DTM, DTALW, VOL
NAMELIST/CHK2/IK, J, VOLOD, BEDLIN, PTLRP, VOLNEW, PTIJ, PTSM
1 , PTPIJ, PTTIJ, DQS, DQSP

C

WARNING 8 : ARMORING FACTOR CAPPED BELOW 1.0 (POINT VALUES)

IF (ACF.GT.0.98) CALL ERRWAR(1, 8, IT, LNKNAM, I, ACF)
ACF=AMIN1(0.98, ACF)

- NO SORTING FOR INACTIVE REACH

IF(VOLOUT.EQ.0.0) GO TO 999

C

COMPUTE MIXED-AYER THICKNESS FOR REACH
(EQ.II.35)

C

DM=(RH(I)+RH(I+1))*0.5
SM=(SF(I)+SF(I+1))*0.5
SM=AMIN1(SM, 0.01)
TALWMP=0.5*(TALWGP(I)+TALWGP(I+1))
TALWM=TALWMP-VOLOUT
WM=0.5*(WIDTH(I)+WIDTH(I+1))

WE DO NOT HAVE WIDTHP IN SECPRO NOW
USE WIDTHP=WIDTH IN HYSO2 FOR THE TIME
BEING

WMP=0.5*(WIDTH(I)+WIDTH(I+1))
WMP=WM

C*** TEST(12/1/1989) TO FIX TM AS A CONSTANT
C%% IF(IT.LE.3) THEN
THA=DM*SM/(1.65*D50R)
THA=THA*0.33333

TM : MIXING LAYER THICKNESS

TM=DM*(0.079865+2.23897*THA-18.1264*THA**2+70.9001*THA**3
# -88.3293*THA**2*THA**2)*0.50

IF(IYALIN.EQ.0) GO TO 11

ALLOW MIXED-LAYER THICKNESS
TO BE NO SMALLER THAN 15 PERCENT
OF DEPTH

11 TM=AMAX1(TM, 0.15*DM)

ARMORING-FACTOR REDUCTION
OF MIXED-LAYER THICKNESS

TM=TM*(1.-ACF)

INCREMENT MIXED-LAYER THICKNESS,
IF NECESSARY, TO ENSURE AVAILABILITY
OF ALL SCoured MATERIAL AS REQUIRED
BY ENER COMPUTATION (EXPLICIT
DETERMINATION)
WANT : TM * PT(J) >= TDELD(J) / (1-P)

DO 50 J=1,N1
   TM=AMAX1(TM, TDELD(I,J)/(1.-POROS)/PT(I,J))

50 CONTINUE

C**TEST-5 LINES
C%% ELSE
C%% TM=TMP
C%% END IF
C

IF(IT.LE.3) TMP= TM

WARNING: ADJUSTED MIXED-LAYER
THICKNESS APPEARS EXCESSIVELY LARGE

IF(TM.GT.0.15*DM) CALL ERRWAR(1,3,IT,LNKNAI,I,TM)

COMPUTE SIZE-CLASS-INDEPENDENT
FACTOR
VOLNP1 = (1. - POROS) * WM * TM
VOLN = (1. - POROS) * WMP * TMP
BM = THETA * WM + (1. - THETA) * WMP

C%
C FLOR1: OLD FLOOR ELE.
C FLOR2: NEW FLOOR ELE.
C FLRRIS > 0: FLOOR RISING
C FLRRIS < 0: FLOOR DESCENDING
C%
C THETAM = 1.0
C IF (FLRRIS.LT.0.) THEN
C FACTOR = VOLNP1
C ELSE
C FACTOR = VOLNP1 + THETAM * BM * FLRRIS * (1. - POROS)
C END IF

C CHECK PRINTOUT FOR DEBUGGING

C IK = I
C TMPF = TMP
C DTM = TM - TMP
C DTALW = TALW - TALWMP
C VOL = VOLOUT
C IF (IT.GT.3) WRITE (6, CHK1)

C COMPUTE NEW FRACTIONAL SIZE-CLASS
C REPRESENTATION FOR EACH CLASS

C PTSUM = 0.0
C DO 100 J = 1, NL
C VOLOLD = VOLN * PTP (I, J)

C BEDLIN = IDELT * TCONST * (THETA * (QS (I+1, J) - QS (I, J))
C \hspace{1cm} + (1. - THETA) * (QSP (I+1, J) - QSP (I, J))) / REACH
C TO BE CONSISTENT WITH EXNER1 IN SEDIMENT CONTINUITY (REACH), USE TDELD INSTEAD OF QS
C
C BEDLIN = - TDELD (I, J) * BM * (1. - POROS)
C SULOUT = 0.5 * IDELT * TCONST * (THETA * (0.0 + 0.0) + (1. - THETA)
C \hspace{1cm} * (0.0 + 0.0))
C ASSIGN APPROPRIATE COMPOSITION
C TO MATERIAL FLUX ACROSS FLOOR OF MIXED LAYER AT TIME \( n \)

C IF (FLRRIS.LT.0.) THEN
C PTLRN = PTT (I, J)
C ELSE
C PTLRN = PTP (I, J) * (1. - THETAM)
C END IF

100 CONTINUE
COMPUTE CONTRIBUTIONS TO
SORTING EQUATION NOT INVOLVING
NEW PT AT TIME N+1

VOLNEW = VOLUM+ BEDLIN- SULOUT- BM* FLRRIS* (1.-POROS) * PTFLRN
PT(I,J) = VOLNEW/ FACTOR
PTSUM = PTSUM + PT(I,J)

C** IF(I.GE.10) THEN
C      PTIIJ = PT(I,J)
C      PTPIJ = PTP(I,J)
C      PTTIJ = PTT(I,J)
C      D QS = QS(I+1,J) - QS(I,J)
C      D QSP = QSP(I+1,J) - QSP(I,J)
C      IF(IT.GT.3) WRITE(6,CHK2)
C      END IF

100 CONTINUE

WARNING : SUM OF SIZE-CLASS
FRACTIONS NOT UNITY

C   IF (ABS(PTSUM-1.0).GT.0.05) CALL ERRWAR(1,4,IT,LNKNAM,I,PTSUM)
C
999 RETURN
C
END
SUBROUTINE CRITER(RH, SF, DSG, W, VEL)

DIMENSION RH(IMAX, LINKS), SF(IMAX, LINKS), DSG(N1), W(N1),
VEL(IMAX, LINKS)

COMMON/DIMS/NODES, KMAX, LINKS, IMAX, MEMO, NODESI, NTRIB, N1, IMAXM1
1 , N1P1, NGROUP, MAXG, IMLAST, NSEC, NLVNX, IERR, IWAR
2 , MAXBED, NITOUT, NBDT, IEND
COMMON/SCALAR/GRAV, POROS, SGRAV, VIS, THETA, IT, IDELT, ITIME, PHI, EPS
1 , FDELTB, FFIMP, ALIMP, BEIMP, THETAS
COMMON/SHD/REYN, SHIPAR
COMMON/MODSH/ISHEAR
COMMON/SHEAR/REYSTA, TAUC
COMMON/TLENH/QSTLTM, USTC, QBQT, USTWJ
COMMON/TLMCF/TLM1, TLM2, TLM3, TLM4, TLM5, TLM6, TLM7, TLM8,
1 TLM9
NAMELIST/CRIT/I1, J1, L1, RRH, SFF, DSGG, REYN, SHIPAR, VAR1, USTC, USTWJ,
1 TEMP, QSTL, CB, QB, QBQT
GSM1=GRAV*(SGRAV-1.0)
GO TO 999

---------
ENTRY CRIT2(I, J, L)
---------

I1=I
J1=J
L1=L

USE REACH VALUE INSTEAD OF POINT VALUE
(MARKO 12/26/89)

RRH=(RH(I,L)+RH(I+1,L))/2.
SFF=(SF(I,L)+SF(I+1,L))/2.
VEL=(VEL(I,L)+VEL(I+1,L))/2.
DSGG=DSG(J)
USTAR=SQRT(GRAV*RRH*SFF)
VAR1=SQRT(GSM1*DSG(J))
REYN=USTAR*DSG(J)/VIS

IF(ISHEAR.EQ.0) GO TO 161
REYSTA=SQRT(GSM1)*DSG(J)**1.5/VIS
CALL IWGAK
SHIPAR=TAUC
GO TO 162
161 CALL SHIELD
162 USTARC=SQRT(SHIPAR)*VAR1

USTC=USTARC/USTARC
F11=36.0*VIS**2/(GSM1*DSG(J)**3)
F1=SQRT(2.0/3.0+F11)-SQRT(F11)

Particle Fall Velocity by Rubey eq.(1933),
see pp.169 SEDIMENTATION (ASCE Manual)
W(J)=F1*VAR1
USTWJ=USTAR/W(J)
V1= ALOG10(ABS(VELL)/VAR1)
V2= ALOG10(RRH/DSG(J))
TEMP= AMAX1(USTAR-USTARC,0.00001)
V3= ALOG10(TEMP/VAR1)

QSTL: Total Load per width by the TLTM,
eq (II.21)

QSTL=10.0*(TLTM1+V1*TLTM2+V1*V3*TLTM3+V2*V3*TLTM4)
QSTL= QSTL* VAR1* DSG(J)
V4= ALOG10(USTAR/W(J))
V5= ALOG10(W(J)*DSG(J)/VIS)
V6= ALOG10(SFF*1000.0)

Old Regression formula

CB=10.0*(-3.7518+V1*2.6279+V6*0.4595+V4*(-2.5055)+
V5*(-0.0932)+V3*0.7395)

New Formula revised by MARKO (12/28/89)

CB=10.0*(-4.44+3.57*V1+1.23*V6-2.87*V4+1.58*V2*V3-
1.40*V1*V5+1.041*V2*V5-0.85*V6*V4*V5+0.65*V2*V6*V3-
5.43*V1*V4*V3+
2.19*V2*V4*V3-1.27*V1*V2*V3)

YB = DSG(J)*(USTAR/USTARC)
ETA2 = YB/RRH
F=8.0*32.2*RRH*SFF/(ABS(VELL)**2)

USE Kappa = 0.4

FN=0.4*SQRT(8.0/F)
WU=W(J)/USTAR
CF=1.0
IF(WU.GT.1.0) CF=1.0/SQRT(WU)


QB=CB*RRH*ABS(VELL)*(ETA2**((1.+1./FN)))*CF
QBQT=QB/QSTL
IF(QBQT.GT.1.0) QBQT=1.0
IF(L.EQ.5) WRITE(6,CRT)
999 RETURN
END
C*************************************************************************
C                      FIRST CARD OF POWFCT                         
C*************************************************************************
C
SUBROUTINE POWFCT(LTYPE, II, LL, KK, LNKNAME, RH, WIDTH, SF, VEL, Q, DSG, 
  1     D50P, PTPT, QS, QSTOT, ACF, DRYBED, QSCAP)
C
DIMENSION LTYPE(LINKS), II( LINKS), QSTOT(IMAX, LINKS), 
  1     RH(IMAX, LINKS), SF(IMAX, LINKS), DSG(N1), LNKNAME(LINKS), 
  2     D50P(IMAX, LINKS), PTPT(IMAX, N1P1, LINKS), QS(IMAX, N1, LINKS)
  3     Q(IMAX, LINKS), LL(NODES, KMAX), KK(NODES), ACF(IMAX, LINKS), 
  4     WIDTH(IMAX, LINKS), VEL(IMAX, LINKS), DRYBED(LINKS)
  5     QSCAP(IMAX, N1, LINKS)
C
LOGICAL DRYBED
COMMON/USB/ADJRE,A,B,UC
COMMON/DIMS/NODES,KMAX,LINKS,IMAX,MEMO,NODESI,NTRIB,N1,IMAXM1 
  1     ,N1P1
COMMON/SCALAR/GRAV,POROS,SGRAV,VIS,THETA,IT,IDELT,ITIME,PHI,EPS 
  1     ,FDELTB,FFIMP,ALIMP,BEIMP,THETAS,TCONST
COMMON/TLTMCF/TLTM1,TLTM2,TLTM3,TLTM4,TLTM5,TLTM6,TLTM7, 
  1     TLTM9
COMMON/EXNI/ISORT,WKB0,WKB1
COMMON/SHD/REYN,SHIPAR
COMMON/MODSHP/ISHEAR
COMMON/SHEAR/REYSTA,TAUC
COMMON/ITCON/ITTOT,ITHYD,EPSHYD,EPSQ,MITMAT,MITHYD,DYNMAX 
  1     ,DQMAY,DRYQ
COMMON/TLTENH/QSTLTM,USTC,QBQT,USTWJ
C
GSM1=GRAV*(SGRAV-1)
GAMA=1.94*GRAV
GAMAS=GAMA*(SGRAV-1)
A=1.608E-2

C*************************************************************************
C   IF INDOOR RUN-0421,0128 THEN CHANGE THE "A" VALUE
C*************************************************************************
CCC

A= A*2.201

B=5.97

GO TO 999

ENTRY POWFQS

DO 200 L=1,LINKS
  ILAST=II(L)
  IJ=ILAST*N1
  CALL RA2(QS(1,1,L),IJ)
  CALL RA2(QSTOT(1,L),ILAST)
  IF (DRYBED(L).OR.LTYPE(L).NE.0)
    GO TO 200
  DO 150 I=1,ILAST
    VEL2=VEL(I,L)*VEL(I,L)
    USTAR=SQRT(GRAV*RH(I,L)*SF(I,L))
$B_1 = 0.26 \cdot \sqrt{R_H(I, L) / D_{50P}(I, L)}$

$B_1 = \text{AMIN1}(B_1, 70.0)$

IF(WKB1 .NE. 0.0) B1=WKB1

TAU0=GAMA*RH(I, L)*SF(I, L)

DO 100 J=1,N1

Eq. (2.121) in 'SEDIMENTATION ENGINEERING'

UC=0.5*SQRT(SGRAV-1.)*(DSG(J)*304.8)**(4./9.)

QS(I, J, L) = 0.0

Use the above empirical formula instead of Shield's curve for NTU flume case

REYN=USTAR*DSG(J)/VIS

IF(ISHEAR.EQ.0) GO TO 161

REYSTA=SQRT(GSM1)*DSG(J)**1.5/VIS

CALL IWAGAK

SHIPAR=TAUC

GO TO 162

C161

CALL SHIELD

USTARC=SQRT(SHIPAR)*SQRT(GSM1*DSG(J))

TAUC=USTARC*USTARC*1.934

WK=(DSG(J)/D_{50P}(I, L))**B1*WKB0

WK=AMIN1(WK, 1.0)

IF(VEL(I, L).LE.UC) THEN

QSCAP(I, J, L) = 0.

ELSE

".3048": CONVERSION FACTOR BETWEEN METRIC UNIT AND ENGLISH UNIT

QSCAP(I, J, L) = A/(.3048)**2 *( (VEL(I, L)-UC) *.3048 )**B

This power law formula use Metric unit

G(g/sec) = 1187.6 * (u-uc) (m/sec)**5.97

ENDIF

QS(I, J, L) = QSCAP(I, J, L)*WIDTH(I, L)

QS(I, J, L) = QS(I, J, L)*PTPT(I, J, L)*WK*EXP(-ACF(I, L)*

2.99573)*SIGN(1.0,Q(I, L))

QSTOT(I, L) = QSTOT(I, L) + QS(I, J, L)

100 CONTINUE

150 CONTINUE

200 CONTINUE

C

999 RETURN

END
SUBROUTINE TLTM

DIMENSION LTYPE(LINKS), II(LINKS), QSTOT(IMAX, LINKS),
       RH(IMAX, LINKS), SF(IMAX, LINKS), DSG(N1), LNKNAME(LINKS),
       D50p(IMAX, LINKS), PTPT(IMAX, NIP1, LINKS), QS(IMAX, N1, LINKS)

LOGICAL DRYBED

COMMON/DIMS/NODES, KMAX, LINKS, IMAX, MEMO, NODESI, NTRIB, N1, IMAXM1
       , NIP1
COMMON/SCALAR/GRAV, POROS, SGRAV, VIS, THETA, IT, IDELT, ITIME
COMMON/TLMCF/TLM1, TLM2, TLM3, TLM4, TLM5, TLM6, TLM7, TLM8,
       TLM9
COMMON/EXNI/ISORT, WKB0, WKB1
COMMON/SHD/REYN, SHIPAR
COMMON/MODSHD/ISHEAR
COMMON/SHEAR/REYSTA, TAUC
COMMON/ITCON/ITTOT, ITHYD, EPSHYD, EPSQ, MITMAT, MITHYD, DYNMAX
       , DQMAX, DRYQ
COMMON/TLMENH/QSTLM, USTC, QBQT, USTWJ
NAMELIST/DTLTM/IT, IDELT, ITIME, L, I, J, D50PP, VAR1, REYN, USTAR, USTARC,
       & TEMP
GSML=GRAV*(SGRAV-1.)
GRTHS=GRAV/1000.
ATEG=8.0*GRAV
GO TO 999

ENTRY TLMQS

DO 105 L=1, LINKS
   LINKNM=LNKNAME(L)
   ILAST=II(L)
   IJ=ILAST*N1
   CALL RA2(QS(1, I, L), IJ)
   CALL RA2(QSTOT(1, L), ILAST)
   IF(DRYBED(L).OR.
      & LTYPE(L).NE.0) GO TO 105
DO 100 I=1, ILAST
   IF(ABS(Q(I, L)).LT.DRYQ) GO TO 100
   IF(VEL(I, L).EQ.0.) GO TO 100
   SF(I, L)=AMIN1(SF(I, L), 0.01)
   USTAR=SQR(T(GRAV*RH(I, L)*SF(I, L)))
FIRST CARD OF USPOW

SUBROUTINE USPOW

THIS SUBROUTINE CALCULATE UPSTREAM BOUNDARY CONDITION FOR A POWER-LAW TRANSPORT FUNCTION.

SUBROUTINE USPOW(D50R, D50P, AREA, VEL, Q, FFACT, RH, Y, D, QSTR, ACF,
1    WIDTH, REACH, TALWEG, TALWGP, SF, VOLOUT,
2    QSTOT, II, LL, LNKNAM, DRYBED)

DIMENSION D50P(IMAX, LINKS), AREA(IMAX, LINKS), VEL(IMAX, LINKS),
1    Q(IMAX, LINKS), FFACT(IMAX, LINKS), RH(IMAX, LINKS), Y(IMAX, LINKS),
2    D(IMAX, LINKS), QSTR(NODES), ACF(IMAX, LINKS), WIDTH(IMAX, LINKS),
3    REACH(1MAX1, LINKS), TALWEG(IMAX, LINKS), SF(IMAX, LINKS),
4    TALWGP(IMAX, LINKS), VOLOUT(IMAX, LINKS), QSTOT(IMAX, LINKS),
5    II(LINKS), LL(NODES, KMAX), LNKNAM(LINKS), DRYBED(LINKS)
6    , D50R(IMAX, LINKS)
COMMON/DIMS/NODES, KMAX, LINKS, IMAX, MEMO, NODESI, NTRIB, N1, IMAXM1
1    , NIP1
COMMON/USB/ADJREV, A, B, UC
COMMON/ITCON/ITTOT, ITYHD, EPSHYD, EPSQ, MITMAT, MITHYD, DYNMAX
1    , DQMAX, DRYQ
COMMON/SCALR/GRAV, POROS, SCGRAV, VIS, THETA, IT, IDELT, ITIME, PHI, EPS
1    , FDELTB, FFIMP, ALIMP, BEIMP, THETAS, TCONST
COMMON/TLTCF/TLT1, TLT2, TLT3, TLT4, TLT5, TLT6, TLT7, TLT8,
1    TLM9
COMMON/SHD/REYN, SHIPAR

LOGICAL DRYBED, FIRCAL

NAMELIST/POWU/I, I, L, ITIME, ITBC, THETAS, C, DRYQ, BETA1, TCONST,
1    DFP, QSIMP, DELTZ, QSOBJ, FD, FDP, DELP, UC

TO BE IN ERROR BY AT MOST 'EPSUS*DEP'
IN NEWTON'S METHOD

EPSUS=0.0001
VOLMAX=1.0
RETURN

-------------
ENTRY USPOW1(M, FIRCAL)
-------------

COMPUTE UPSTREAM BED LEVEL BY REQUIRING QS (POWER LAW) = QS (IMPOSED)

THETSL=1.-THETAS
C=ADJREV*5280./30.
L=IABS(LL(M,1))
I=II(L)

Eq. (II.31-C)
```plaintext
C
UC=0.5*SQRT(SGRAV-1.)*(D50P(I,L)*304.8)**(4./9.)
C
WRITE(6,POWUS)
   IF(ABS(Q(I,L)).LT.DRYQ.OR.ABS(Q(I-1,L)).LT.DRYQ) GO TO 999
   IF(ACF(I,L).NE.1.0) GO TO 710
   VOLOUT(I-1,L)=0.0
   GO TO 999
C
710  BETA1=C*IDELT*TCONST/REACH(I-1,L)/86400.
   IF(BETA1.GE.0.5) BETA1=0.5
   IF(BETA1.LT.0.01) BETA1=0.01
C
CCCCC  PRINT*,\' BETA1 = \',BETA1
   ITBC=0
   DEP=Y(I,L)-TALWGP(I,L)
C
     BEGIN OF NEWTON ITERATION
C
720  CALL SECPRO(L,I)
   IF(.NOT.DRYBED(L)) GO TO 730
   CALL ERRWAR(1,9,IT,LNKNAM(L),I,Q(I,L))
   TALWEG(I,L)=TALWGP(I,L)
   VOLOUT(I-1,L)=0.0
   GO TO 999
730  ITBC=ITBC+1
   D(I,L)=AREA(I,L)/WIDTH(I,L)
   VEL(I,L)=ABS(Q(I,L))/AREA(I,L)
C
   QSIMP=QSTR(M)/EXP(-ACF(I,L)*2.99573)/WIDTH(I,L)
   DELTZ=Y(I,L)-DEP-TALWGP(I,L)
   QSOBJ=QSIMP-BETA1*REACH(I-1,L)*(1.-POROS)*
         *DELTZ/(IDELT*TCONST*EXP(-ACF(I,L)*2.99573))
C
   FD=QSOBJ- A/.3048**2 *((VEL(I,L)-UC)**.3048)**B
   FDP=BETA1*REACH(I-1,L)*(1.-POROS)/(IDELT*TCONST*EXP(-ACF(I,L)*
         *2.99573)) + A/.3048**2 *B*((VEL(I,L)-UC)**.3048)**(B-1.0)
   @
   DLED=-FD/FDP
   DEP=DEP+DLED
   TALWEG(I,L)=Y(I,L)-DEP
C
     END OF NEWTON ITERATION
C
C
IF(IT.GE.0.AND.IT.LE.99) WRITE(6,POWUS)
IF(ABS(DLED).GT.EPS*DEP.AND.ITBC.LT.50) GO TO 720
IF(ABS(TALWEG(I,L)-TALWGP(I,L)).LE.VOLMAX) GO TO 15
   CALL ERRWAR(1,10,IT,LNKNAM(L),I,VOLMAX)
   TALWEG(I,L)=TALWGP(I,L)+SIGN(VOLMAX,TALWEG(I,L)-TALWGP(I,L))
C
C
   TAKE THETAS=1 IN EQ.(11-103)
C
15  DELDST=QSOBJ-QSTOT(I-1,L)/WIDTH(I-1,L)
   DELDST=IDELT*TCONST*DLEDST/((1.-POROS)*(1.-BETA1)*
         *REACH(I-1,L))
   VOLOUT(I-1,L)==DELDST
IF(QSTR(M).LE.0.0.AND.TALWGP(I,L).LT.TALWEG(I,L)) GO TO 20
   GO TO 30
```
nlp1 = n1+1
imaxl = imax-1
nodesi = nodes+1
maxbedl = 1 (required values)
nseg = 3*nsecs*(1+nlevmx)

Note that these last 6 values are checked for consistency with the primitive values in MAIN. Note also that the first 11 values were previously read on input data record number 2.

Once the appropriate values are placed in the file PARAMS.INC, then the files MAIN.FOR and PILOT.FOR must be recompiled to take these values into account. The appropriate FORTRAN command is as follows:

    fl -c -Zl -AH -Gt main.for pilot.for

Once the compilation is completed (it takes about 15 minutes on an 8087 PC), then the new object files MAIN.OBJ and PILOT.OBJ are linked with the remaining ones in the object-module library CHARIMA.LIB and the FORTRAN library to form the new executable program CHARIMA.EXE. The required LINK command is as follows:

    link main+pilot /ST:4000 /NOE /E

In response to the request for the executable file, type
    'charima.exe'

In response to the request for a list file, just press ENTER

In response to the request for libraries, type:
    charima+libfore

The linker will then create the new CHARIMA.EXE program.

The PC version uses the following names for input and output files. These names are programmed, they cannot be changed at present.

Input data records:  CARDIN.DAT
Printer output:       PRINTER.DAT
Results output:      RESULTS.BIN
Restart input:       RESTART.BIN (a previous RESULTS.BIN
                      file, renamed.)
Addendum to CHARIMA User's Guide

Modifications for PC Version

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27 January 1990

For the PC adaptation, it has not been possible to maintain the full dynamic-allocation capability of CHARIMA. In particular, the MS FORTRAN 4.0 compiler will not accept the complexity of the expression in MAIN necessary for a single call to PILOT with all 111 array locations in table T.

As a temporary solution to this problem, all the arrays are allocated in PILOT. Although the MAIN goes through its usual routine of calculating array pointers in T, this actually serves no purpose. Input data record 2 is read only for the variables ISHEAR and IYALIN (columns 56-60 and 61-65, respectively); no other dimensioning variables are read on this record. Then a single call to PILOT transfers simple the run title read from record 1.

In PILOT, all the arrays are allocated using symbolic dimensioning parameters acquired from the parameter statement contained in the file PARAMS.INC. These parameters, equivalent to those previously read on input data record 2, are specific to each model; therefore both MAIN and PILOT must be recompiled anytime the model size specifications change. However it should be noted that most of the parameters set maximum limits on array sizes; only the number of nodes (NODES), the number of links (LINKS), the number of section types (NSECS), the number of sediment size classes (N1), and several parameters related to these (NODES1, NODES2, NGROUP, N1P1, NSEG) are really limiting. The number of printed output dates (NITOUT) and the number of time-step changes (NBDT) can be set to relatively large numbers, as long as the user is careful to supply the correct number of values of each.)

The required parameters in PARAMS.INC are as follows:

- nodes = exact number of nodes
- kmax = maximum number of links connected to one node
- links = exact number of links
- imax = maximum number of computational points on one link
- n1 = exact number of sediment size classes
- maxg = maximum number of nodes in a node group
- ngroup = exact number of node groups
- nsecs = exact number of section types
- nlevmx = maximum number of levels in any A-K-R table
- nitout = exact number of printed output dates
- nbdt = twice the number of time-step changes
- iend = length of working zone for section processing, in words. A value of about 200 is suggested.
  The program will print an error message if the length is insufficient.
- nodes2 = 2*nodes
Appendix H

PC IMPLEMENTATION OF CHARIMA
ENTRY EXNER2

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COMPUTE TALWEG AT EACH COMPUTATIONAL POINT

COMPUTE TOTAL DEGR/AGR DEPTH IN REACH I,
LINK L USING TDELD DEGRADATION DEPTHS
ADJUSTED IN HYSORT

DO 300 L=1,LINKS
   IF(DRYBED(L).OR.
      LTYPE(L).NE.0) GO TO 300
   ILAST=II(L)-1

   COMPUTE DEG/AGR DEPTH FOR THE U/S REACH
   OF BOUNDARY LINKS

   DO 200 I=1,ILAST
      TOTAL=0.
      DO 150 J=1,N1
         TOTAL=TOTAL+TDELD(I,J,L)
      CONTINUE
      IF(ABS(TOTAL).LE.VOLMAX) GO TO 155
      CALL ERRWAR(1,10,IT,LKNAM(L),I,TOTAL)
      TOTAL=SIGN(VOLMAX,TOTAL)
      155 VOLOUT(I,L)=TOTAL
      CDEP(I,L)=CDEPP(I,L)+VOLOUT(I,L)
      DARM(I,L)=CDEP(I,L)
   CONTINUE

   FOR LINKS WITH ONLY ONE REACH: GO TO 270

   IF(ILAST.LE.1) GO TO 270

   FOR INTERMEDIATE POINT : COMPUTED HERE

   DO 250 I=2,ILAST
      TALWEG(I,L)=TALWGP(I,L) - (REACH(I-1,L)*VOLOUT(I-1,L) + TALWGP(I,L)) / (REACH(I,L)+REACH(I-1,L))
   CONTINUE

   C** TALWEG(1,L)=TALWGP(1,L)-1.5*VOLOUT(1,L)+0.5*VOLOUT(2,L)
   TALWEG(1,L)=TALWGP(1,L)-VOLOUT(1,L)

   IF(IUSBC=0, PERFORM SIMPLE CONTINUITY
   ATTRIBUTION OF VOLOUT TO U/S TALWEG
   NO COMPUTATION FOR U/S TALWEG WHEN
   IUSBC .NE. 0

   IF(IUSBC.NE.0) GO TO 300

   C** TALWEG(II(L),L)=TALWGP(II(L),L)-1.5*VOLOUT(II(L)-1,L) +
   C*** 0.5*VOLOUT(II(L)-2,L)
   TALWEG(II(L),L)=TALWGP(II(L),L)-VOLOUT(II(L)-1,L)
   C*** IF(I.GT.37.AND.IT.GT.59.AND.IT.LT.80) WRITE(6,EXN)
       GO TO 300
   270 TALWEG(II(L),L)=TALWGP(II(L),L)-VOLOUT(1,L)
       TALWEG(1,L)=TALWGP(1,L)-VOLOUT(1,L)
   300 CONTINUE
C*** IF(ISHEAR.EQ.0) GO TO 161
C*** REYSTA=SQRRT(GSM1)*DSG(J)**1.5/VIS
C*** CALL IWAGAK.
C*** SHIPAR=TAUC.
C*** GO TO 162
C161     CALL SHIELD
C162     USTARC=SQRRT(SHIPAR)*VAR1
C-----------------------------------------------
111        QSDD=TETA*QSD+TETA1*QSDP
CCC**(6/6/90) IF(ABS(QSDD).LT.1.0E-14) GO TO 110
C        TDELD= delta(i,j) IN Eq.(II.103)
        TDELD(I,J,L)=IDELT*TCONST/(REACH(I,L)*(1.-FOROS))*
QSDD/((WIDTH(I,L)+WIDTH(I+1,L))/2.)
110        CONTINUE
C        BANK EROSION ADJUSTMENT
C        IF(BANK(I,L).EQ.0.0) GO TO 112
        WF=0.0
        IF(ABS(Q(I,L)).GT.QMIN) WF=1.0
        IF(J.GE.MIND) WF=0.0
        EROS=BANK(I,L)*IDELT*REACH(I,L)/5280./(1.-FOROS)*
1/((WIDTH(I,L)+WIDTH(I+1,L))*0.5*REACH(I,L))*WF
        TDELD(I,J,L)=TDELD(I,J,L)-EROS*PTT(I,J,L)
C        IF USTWJ > 0.8 NO PARTICLES CAN DEPOSIT
C        TEMPORARILY DEACTIVATED
C112        CALL CRIT2(I,J,L)
        IF(TDELD(I,J,L).LT.0.0.AND.USTWJ.GT.1.0) THEN
        TDELD(I,J,L)= TDELD(I,J,L)*QBQT
        PRINT *, ' Deposition but U*/w >1 ',J,I, QBQT
        END IF
        IF(TDELD(I,J,L).GT.0.0.AND.USTC.LT.1.0) THEN
        TDELD(I,J,L)= 0.0
        PRINT *, ' Scouring but U* < U*c ',J,I
        END IF
        VOLOUT(I,L)=TDELD(I,J,L)+VOLOUT(I,L)
DELD=VOLOUT(I,L)
90        CONTINUE
C        * THE COMMENT BELOW IS NO LONGER USED:
C        IF AGGR. OCCURS FOR SMALL PARTICLES AND
C        DEGR. OCCURS FOR LARGE PARTICLES
C        THEN VOLOUT=0.0
C        IF(ABS(DELD).LE.VOLMAX) GO TO 95
        CALL ERRWAR(1,10,IT,LNKNAM(L),I,DELD)
        DO 93 J=1,N1
        TDELD(I,J,L)=TDELD(I,J,L)*VOLMAX/ABS(DELD)
93        CONTINUE
95        CONTINUE
100        CONTINUE
C        RETURN
C        ------------------
IF(ABS(Q(I,L)).LT.DRYQ.OR.ABS(Q(I+1,L)).LT.DRYQ)
  GO TO 95
DELD=0.0

COMPUTE BED EVOLUTION BY SIZE FRACTION
THE BED IS DEGRADING WHEN QSD > 0.0
THE BED IS AGGRADING WHEN QSD < 0.0

DO 90 J=1,N1

THETAS= THETA for sediment
TETA=THETAS

For tidal flow (back & forth) use THETAS=
(fully implicit) temporarily in order to
be robust.

IF(QS(I,J,L)*QSP(I,J,L).LE.0.) TETA=1.
TETA1=1.-TETA
QSDP=QSP(I,J,L)-QSP(I+1,J,L)
QSD=QS(I,J,L)-QS(I+1,J,L)

Qs imposed at U/S point has been taken
of in PILOT (i.e. QS=QTR(NINQS(MU(L)))*
if IUSSC.EQ.0.AND.NINQS(MU(L)).NE.0)
No matter Conge's condition or Karim's
condition at U/S pt. U/S imposed sediment
is used as QS(II,J,L) to calculate
J,L) (Marko June'90)

M=KODSED(MU(L))
IF(M.EQ.0.OR.NOT.USLNK(L).OR.L.NE.ENTER) GO TO 111

MU(links): upstream node of a link
QTR(NINQS(MU(L))): Qs imposed at u/s pt.

QTRB=QTR(NINQS(MU(L)))
QSD=QS(I,J,L)-QTRB*PTRIB(J,MU(L))
QSDP=0.0

The following Qs(II,J,L) correction

accordi
suppress
ed.

-------------------------------------
C** USTAR=SQRT(GRAV*RH(I+1,L)*SF(I+1,L))
C** VAR1=SQRT(GSM1*DSG(J))
C** REYN=USTAR*DSG(J)/VIS
C#FIRST CARD OF EXNER########################################

SUBROUTINE EXNER

SUBROUTINE EXNER(QS, QSP, TDELD, REACH, CDEP, CDEPP, DARM, TALWEG,
1       TALWGP, VOLOUT, LTYPE, II, KK, LL, WIDTH, DRYBED,
2       Q, LNKNAM, DSG, W, RH, SF, MU, NODSED, VEL, QTR, NINQS, PTRIB,
3       PTT, BANK)

DIMENSION QS(IMAX, N1, LINKS), QSP(IMAX, N1, LINKS), TDELD(IMAX, N1, LINKS), REACH(IMAX1, LINKS), CDEP(IMAX, LINKS), DARM(IMAX, LINKS), TALWEG(IMAX, LINKS),
1       CDEPP(IMAX, LINKS), VOLOUT(IMAX, LINKS), LTYPE(LINKS),
2       II(LINKS), KK(NODES), LL(NODES, KMAX), WIDTH(IMAX, LINKS),
3       LNKNAM(LINKS), Q(IMAX), DSG(N1), W(N1), RH(IMAX, LINKS),
4       SF(IMAX, LINKS), USLNK(LINKS), MU(LINKS), NODSED(NODES)
5       , VEL(IMAX, LINKS), QTR(NODES), NINQS(NODES2), PTRIB(N1, NODES)
6       , PTT(IMAX, N1, LINKS), BANK(IMAX, LINKS)

LOGICAL DRYBED, FIRCAL, USLNK
COMMON/ITCON/ITTOT, ITHYD, EPSHYD, EPSQ, MITMAT, MITHYD, DYNMAX
1       , DQMAX, DRYQ, IPLINK, IPNODE, IPOINT, IPSECT, FIRCAL, ISTRK
2       , IDSCF, IUSBC
COMMON/DIMS/NODES, KMAX, LINKS, IMAX, MEMO, NODESI, NTRIB, N1, IMAXM1
1       , N1P1, NGROUP, MAXG, IMLAST, NSEGS, NLEVMAX, IERR, IWAR,
2       , MAXBED, NITOUT, NBDT, IEND, NODES2
COMMON/SCALAR/GRAV, POROS, SGRAV, VIS, THETA, IT, IDELT, ITIME, PHI, EPS
1       , FDELTB, FFIMP, ALIMP, BEIMP, THETAS, TCONST
COMMON/EXNI/ISORT
COMMON/TLTENH/QSTLTM, USTC, QBQT, USTWJ
COMMON/SHD/REYN, SHIPAR
COMMON/MOSHID/ISHPEAR
COMMON/SHEAR/REYSTA, TAUC
NAMELIST/EXN/L, I, J, QSDF, QSD, DDEL, TDD, QBQT, USTWJ, USTC, QSSD, QTRB,
1       M, IUSBC, USTAR
VOLMAX=1.0
QMIN=30000.
MIND=7
GSM1=GRAV*(SGRAV-1.0)

RETURN

---------------------
ENTRY EXNER1(FIRCAL, USLNK)
---------------------

CONTINUITY FOR EACH REACH

DO 100 L=1, LINKS
   ILAST=II(L)-1
   ILASTN=ILAST*N1
   CALL RAZ(TDELD(1, L), ILASTN)
   CALL RAZ(VOLOUT(1, L), ILAST)
   IF(DRYBED(L).OR.
1      .LTYPE(L).NE.0) GO TO 100
   DO 95 I=1, ILAST

95   CONTINUE

100  CONTINUE
20 TALWEG(I,L) = TALWGP(I,L)
   VOLOUT(I-1,L) = 0.0
30 IF(ABS(VOLOUT(I-1,L)).LT.VOLMAX) GO TO 999
   CALL ERRWAR(1,10,IT,LNKNAM(L),I,VOLOUT(I-1,L))
   VOLOUT(I-1,L) = SIGN(VOLMAX, VOLOUT(I-1,L))
999 RETURN
END
C************* IF (USTAR/USTARC.LT.1.0) QS(I,J,L) = 0.0
    QS(I,J,L) = (QS(I,J,L) * PTPT(I,J,L) * WK) * EXP(-ACF(I,L) * 2.99573) * SIGN(1.0, Q(I,L))
    QSTOT(I,L) = QSTOT(I,L) + QS(I,J,L)

100    CONTINUE
105    CONTINUE
C
999    RETURN
END
C

COMPUTE COEFF B1 FROM EQ. V.4 IIHR LIMITED
REPORT 131
C

B1=0.26*SQRT(RH(I,L)/D50P(I,L))
B1=AMIN1(B1,70.0)
IF(WKB1.NE.0.0) B1=WKB1
DEP=RH(I,L)
D50PP=D50P(I,L)
DO 100 J=1,N1
   QS(I,J,L)=0.0
C

COMPUTE SEDIMENT DISCHARGE QS FROM TLTM;
PARTICLE INCIPIENT MOTION IS DETERMINED BY
SHIELD'S CURVE
C

VAR1=SQRT(GSM1*DSG(J))
REYN=USTAR*DSG(J)/VIS
IF(ISHEAR.EQ.0) GO TO 161
REYSTA=SQRT(GSM1)*DSG(J)**1.5/VIS
CALL IWAGAK
SHIPAR=TAUC
GO TO 162
161
C

CALL SHIELD
162
C

USTARC=SQRT(SHIPAR)*VAR1
TEMP=USTARC-USTARC
C

IF(IT.GE.10.AND.IT.LE.15) WRITE(6,DTLTM)
C

**********IF(TEMP.LE.0.1*USTARC) GO TO 100
C
C
simulation
C

(Marko '89)
C
C

TEMP=AMAX1(TEMP,0.00001)
V6=TEMP/VAR1
V1=ABS(VEL(I,L)/VAR1)
V2=RH(I,L)/DSG(J)
ALOGV1=0.0
ALOGV6=0.0
IF(V1.LT.1.0.AND.V6.LT.1.0) GO TO 40
ALOGV1=ALOG10(V1)
ALOGV6=ALOG10(V6)
ALOGV7=TLTM1+TLTM2*ALOGV1+TLTM3*ALOGV1+ALOGV6+
   TLTM4*ALOG10(V2)*ALOGV6
C

IF(ALOGV7.LT.70) GO TO 60
CALL ERRWAR(1,11,IT,L,I,ALOGV7)
C

ALOV7=0.0
QSCAP(I,J,L)=10.*ALOGV7*VAR1*DSG(J)
QS(I,J,L)=QSCAP(I,J,L)*WIDTH(I,L)
C

C

COMPUTE WEIGHTING FACTOR WK FROM EQ. V.2
IIHR LIMITED REPORT 131
C

WK=(DSG(J)/D50P(I,L))**B1*WKB0
WK=AMIN1(WK,1.0)
C

SEDIMENT DISCHARGE CORRECTED BY WK AND
FLOW DIRECTION
Appendix I

Suspended-Sediment Dynamics in CHARIMA

Prepared by:

H.H. Shen

DRAFT
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I.A. Introduction

I.A.1. Need for Suspended-Load

The CHARIMA code, described in IIHR Report No. 343 (Holly et. al., 1990), simulates water and sediment movement in multiply connected networks of mobile-bed channels. This code can simulate not only unsteady water movement and non-uniform sediment transport, but also long-term bed evolution in a complex channel system. It has been verified through application to several natural river systems. However, application of CHARIMA has been limited to non-cohesive sediment, and to bedload sediment transport mechanisms.

In many engineering problems, fine sediment may be suspended in the water for some time and/or may move downstream at the water velocity until local downstream hydraulic conditions allow it to deposit on the bed. The exchange between suspended-load and bedload may also occur; that is, suspended-load may deposit on the bed, and bedload may be resuspended or redispersed into the water. It is often necessary therefore to simulate suspended-load transport, as well as bedload transport, in practical engineering problems. Holly and Rahuel (1991) presented a numerical model for the transport of both suspended-load and bedload in a single mobile-bed channel. In this study, new code for suspended-load transport in multiply connected networks of channels is incorporated into CHARIMA.

I.A.2. Need for Cohesive Dynamics

In a sediment mixture, different size particles may be present, with diameter ranging from less than 2μm to larger than 200mm, e.g., clay-sized, silt-sized, sand-sized and gravel-sized particles. The clay-sized particles will show characteristics of cohesion if clay minerals are involved because of physico-chemical forces. Basically, there are three groups of clay minerals: kaolinites, montmorillonites, and illites.

The cohesion of particles is mainly influenced by the following factors: 1) Concentration of typically prevalent cations and anions; 2) Total salt concentration; 3) pH
value; and 4) Fluid temperature. Usually, suspended clay particles will become cohesive when the salinity exceeds 2-3 ppm.

The behavior of cohesive sediment transport is essentially different from that of non-cohesive sediment. For non-cohesive sediment, gravitational force is the dominant one, whereas for cohesive sediment, gravitational force can be of little importance compared to physico-chemical forces. Therefore, procedures for simulation of erosion and deposition of non-cohesive sediment cannot be used for cohesive sediment; in other words, the transport of non-cohesive and cohesive sediments must be treated separately.

Although the mechanisms of cohesive-sediment transport are far from being sufficiently understood, many results obtained by various researchers can be used as a basis for solving engineering problems involving the transport of cohesive sediment. In this study, erosion and deposition models of cohesive sediment are introduced and described, and the suspended-load transport of cohesive sediment is incorporated into CHARIMA along with that of non-cohesive sediment.

I.B. Review of Literature and Proposed Methodology

I.B.1. Suspended-Load Transport

The basic one-dimensional equation for suspended-load mass conservation is:

\[
\frac{\partial}{\partial x}(C_j A) + \frac{\partial}{\partial x}(C_j Q) = \frac{\partial}{\partial x} \left( AK \frac{\partial C_j}{\partial x} \right) + S_j
\]

where:

- \( j = 1, 2, \ldots, J \)
- \( J \) = total number of size classes
- \( C_j \) = suspended load concentration for size class \( j \)
- \( A \) = cross sectional area of flow
- \( Q \) = flow discharge
- \( K \) = diffusion coefficient
- \( S_j \) = suspended sediment source term for size class \( j \)
  (volumetric flux per unit length)
By using the water continuity equation and dropping the size-class index j, Eq. (I-1) can be rewritten as:

\[ A \frac{\partial C}{\partial t} + Q \frac{\partial C}{\partial x} = \frac{\partial}{\partial x} \left( AK \frac{\partial C}{\partial x} \right) + S \]  (I-2)

or

\[ \frac{DC}{Dt} = \frac{1}{Adx} \left( AK \frac{\partial C}{\partial x} \right) + \frac{S}{A} \]  (I-3)

with

\[ \frac{D}{Dt} = \frac{\partial}{\partial t} + u \frac{\partial}{\partial x} \]

along

\[ \frac{dx}{dt} = \frac{Q}{A} \]  (I-4)

In solving this advection-diffusion equation of suspended-load transport, the Holly-Preissmann method (Holly and Preissman, 1977) assures computational accuracy by interpolating the concentration at the foot of the trajectory, not only using the concentrations at two computational points, but also by their gradients \( CX = \partial C / \partial x \). Thus another transport equation for \( CX \) is required. This equation can be obtained by differentiating Eq. (I-4) with respect to \( x \). First Eq. (I-4) is rewritten as:

\[ \frac{DC}{Dt} = \frac{1}{Adx} (AKCX) + \frac{S}{A} \]  (I-5)

and then differentiated:

\[ \frac{\partial CX}{\partial t} + Q \frac{\partial CX}{\partial x} + CX \frac{\partial}{\partial x} \left( \frac{Q}{A} \right) = - \frac{1}{A^2} \frac{\partial A}{\partial x} \frac{\partial}{\partial x} (AKCX) \]

\[ + \frac{1}{A dx^2} (AKCX) - \frac{S}{A^2} \frac{\partial A}{\partial x} + \frac{1}{Adx} \frac{\partial S}{\partial x} \]  (I-6)

Integration of Eq. (I-5) and Eq. (I-6) along the trajectory and approximation of all space derivatives implicitly as:

\[ \frac{\partial f}{\partial x} = \frac{f_i^{n+1} - f_{i-1}^{n+1}}{\Delta x} \]
irrespective of the advection Courant number, yields the following working equations:

\[
C_1^{n+1} - C_\xi = \Delta t \left( \frac{2}{A_1^{n+1} + A_{i-1}^{n+1}} \right) \\
\left( \frac{(AKCX)_i^{n+1} - (AKCX)_{i-1}^{n+1}}{\Delta x} + \frac{S_i^{n+1} + S_{i-1}^{n+1}}{2} \right)
\]

(I-7)

\[
CX_1^{n+1} - CX_\xi = -\Delta t \left( \frac{C_1^{n+1} + C_{i-1}^{n+1}}{2} \right) \left( \frac{Q_i^{n+1} - Q_{i-1}^{n+1}}{\Delta x} \right)
\]

\[
-\Delta t \left( \frac{2}{A_1^{n+1} + A_{i-1}^{n+1}} \right)^2 \left( \frac{A_i^{n+1} - A_{i-1}^{n+1}}{\Delta x} \right)
\]

\[
\left( \frac{(AKCX)_i^{n+1} - (AKCX)_{i-1}^{n+1}}{\Delta x} + \frac{S_i^{n+1} + S_{i-1}^{n+1}}{2} \right)
\]

(I-8)

\[
+ \Delta t \left( \frac{2}{A_1^{n+1} + A_{i-1}^{n+1}} \right) \left( \frac{S_i^{n+1} - S_{i-1}^{n+1}}{\Delta x} \right)
\]

In Eq. (I-8), the term involving \(\partial^2 (AKCX)/\partial x^2\) has been dropped because it does not lead to great errors in CX (see Toda and Holly, 1987).

Through the Holly-Preissmann Hermite cubic interpolation,

\[
C_\xi = f(C_1^n, C_{i-1}^n, CX_1^n, CX_{i-1}^n)
\]

\[
CX_\xi = g(C_1^n, C_{i-1}^n, CX_1^n, CX_{i-1}^n)
\]
the nonlinear system can be solved with the Newton-Raphson method by proceeding from upstream to downstream in a single branch if upstream boundary conditions for C and CX are given.

For a multiply connected network, an assumption of complete mixing at junctions (nodes) leads to:

\[ Q_{\text{ext}} C_{\text{ext}} + \sum_{\text{inflow}} Q C = C_{\text{out}} \sum_{\text{outflow}} Q \]  

(I-9)

where \( Q_{\text{ext}} C_{\text{ext}} \) is external mass inflow to the node, if any; and \( C_{\text{out}} \) is common to all outflow points associated with the junction. The condition for CX at nodes is a statement of pure advection,

\[ CX = \frac{\partial C}{\partial x} = -\frac{A \partial C}{Q \partial t} \]  

(I-10)

Equation (I-9) suggests that it may be possible to devise a solution scheme analogous to that used for hydrodynamic calculations in a looped network (see e.g. Cunge et al, 1980). If in the inflow summation all concentrations could be expressed in terms of known (previous-time-step) values through Eq. (I-7), then the only unknown in Eq. (I-9) would be the fully-mixed outflow concentration \( C_{\text{out}} \); indeed, the fully-mixed concentration for each node could be computed independently of the others. But in reality Eq. (I-7) includes other direct dependence on unknown concentrations at points not associated with the junction (e.g. \( C_{i-1}^{n+1} \)), and indirect dependence on these concentrations through source-terms such as \( S_{i-1}^{n+1} \) which depend strongly on the concentration. Moreover, the CX terms in Eq. (I-7) themselves arise from solution of Eq. (I-8), which depends again on unknown concentrations at points not associated with the junction.

In order to avoid this problem, the diffusion terms are uncoupled from the advection source in CHARIMA in a split-operator approach, so that the advection-source equations for C and CX are totally uncoupled:
\[ C_i^{n+1} - C_\xi = \frac{\Delta t}{2} \left( \frac{S_i^{n+1}}{A_i^{n+1}} + \frac{S_{i-1}^{n+1}}{A_{i-1}^{n+1}} \right) \] (I-11)

\[ CX_i^{n+1} - CX_\xi = \int_\xi^\eta \left( - C \frac{\partial}{\partial x} \left( \frac{Q}{A} \right) + \frac{\partial}{\partial x} \left( \frac{S}{A} \right) \right) \, dt \] (I-12)

where \( \eta \) represents the head of the trajectory point \((i, n+1)\).

Considering the fully-mixed nodal concentration \( C_N \) to be the primary nodal variable for Eq. (I-9), we have:

\[ Q_{\text{ext}} C_{\text{ext}} + \sum_{\text{inflow}} Q C = C_N \sum_{\text{outflow}} Q \] (I-13)

Now every \( C_{\text{in}} \) inflow concentration depends on either a known boundary inflow, known concentrations (and derivatives) at time level \( n \), or an unknown outflow \( C_N \) from another node (when linear time interpolation is used for the foot of a trajectory blocked by an upstream node). Therefore, Eq. (I-13) is a linear equation in \( C_N \) at connected nodes. For Eq. (I-12), \( CX \) is calculated along each link by simply deducing \( CX = -A/Q \, \partial C/\partial t \) at any boundary inflow or nodal outflow point. Thus only one nodal matrix inversion is needed for each size class and the nodal matrix inversion can follow the existing node-group procedure for hydrodynamics (see Section II.4.6).

It should be noted that nodes are coupled one with another through temporal interpolation when the foot of the trajectory leading to a node falls on another node, when the time step \( \Delta t \) is large or the link is short. In this case, the concentration at the downstream end of a link depends on the temporal interpolation at an upstream node.

Eq. (I-11) can also be modified as

\[ C_i^{n+1} - C_\xi = \Delta t \frac{S(C_i^{n+1})}{A_i^{n+1}} \] (I-14)
where a simple first-order end-of-trajectory approximation for the source term is used, and again $C_{\xi}$ may be a function of $C_n^{n+1}$ of another node.

Eq. (I-14) can be rewritten as

$$C_i^m + \Delta C_i = C_{\xi} + \frac{\Delta t}{A_{i}^{n+1}} \left( S_i(C_i^m) + \frac{\partial S_i}{\partial C_i} \Delta C_i \right)$$  \hspace{1cm} (I-15)

in which $C_{\xi} = C_{\xi O} + \eta(C_{NUS}^{n+1} - C_{\xi O})$, and $C_i^m$ is the value of the concentration at the end of the previous iteration. The relation for $C_{\xi}$ is a general one for the value of the concentration at the foot of the trajectory, accommodating both the "normal" case of Hermite-cubic spatial interpolation when the foot of the trajectory falls on the axis at the previous time, and the "abnormal" case in which the trajectory intersects the locus of an upstream node $N_{US}$. For the spatial-interpolation case, the switch $\eta$ is set to zero and $C_{\xi O}$ is simply the Hermit-cubic interpolant. For the temporal-interpolation case, the switch $\eta$ is set to the temporal interpolation factor and $C_{\xi O}$ is the upstream-node outflow concentration $C_{NUS}^{n}$ at the end of the previous time step.

Therefore we have

$$\Delta C_i \left( 1 - \frac{\Delta t}{A_{i}^{n+1}} \frac{\partial S_i}{\partial C_i} \right) = -C_i^m + C_{\xi O} + \eta(C_{NUS}^{n+1} - C_{\xi O})$$

$$+ \frac{\Delta t}{A_{i}^{n+1}} S_i(C_i^m)$$  \hspace{1cm} (I-16)

Substituting Eq. (I-16) into the nodal equation yields:

$$C_n^{n+1} \sum_{\text{out}} Q - \sum_{\text{in}} Q \left( C_i^m + \frac{-C_i^m + C_{\xi O} + \eta(C_{NUS}^{n+1} - C_{\xi O}) + \frac{\Delta t}{A_{i}^{n+1}} S_i(C_i^m)}{1 - \frac{\Delta t}{A_{i}^{n+1}} \frac{\partial S_i}{\partial C_i}} \right)$$

$$= Q_{ext} C_{ext}$$  \hspace{1cm} (I-17)
By comparing this equation with the matrix equation for node groups (Eq. (II.76) in IIHR Report No. 343), it is clear that \( C_N^{n+1} \) plays the role of \( \Delta Y \), and therefore the procedure for nodal matrix inversion for hydrodynamics can be used to solve Eq. (I-17).

Therefore, the procedure for advection-source computation can be summarized as:

1. Loop on nodes;
2. Determine \( C_{in} = f(C_{Nus}) \) for each inflow link, Eq. (I-16);
3. Enter each inflow in the nodal Eq. (I-17);
4. Invert the nodal matrix to find \( C_N^{n+1} \) for all nodes;
5. Recover CX at outflow points from the now-known outflow concentration, using Eq. (I-10);
6. Complete the C, CX computation at interior points.

The uncoupled suspended-load diffusion can be integrated with the existing bedload-smoothing routine. For each size class, a space-time dependent diffusivity \( \Psi(x,t,j) \) is assumed:

\[
\frac{\partial C_i}{\partial t} = \frac{1}{A} \frac{\partial}{\partial x} \left( A^2 \Psi_j \frac{\partial C_i}{\partial x} \right) \tag{I-18}
\]

By using a fully implicit Crank-Nicholson scheme, we have:

\[
\frac{C_i^{n+1} - C_i^n}{\Delta t} = \frac{1}{A_i} \frac{2}{x_{i+1} - x_{i-1}} \left( \frac{(A_i + A_{i+1})(\Psi_{i+1}^1 + \Psi_{i+1}^2)}{4(x_{i+1} - x_i)} (C_{i+1}^{n+1} - C_i^{n+1}) \right) - \frac{1}{A_i} \frac{2}{x_{i} - x_{i-1}} \left( \frac{(A_i + A_{i-1})(\Psi_{i}^1 + \Psi_{i-1}^2)}{4(x_{i} - x_{i-1})} (C_i^{n+1} - C_{i-1}^{n+1}) \right) \tag{I-19}
\]

and then a general equation is obtained:

\[
PC_{i-1} + QC_i + RC_{i+1} + S = 0 \tag{I-20}
\]
\[ P = - \frac{(A_i + A_{i-1})(\Psi_i + \Psi_{i-1})}{4(x_i - x_{i-1})} \frac{2\Delta t}{A_i(x_{i+1} - x_{i-1})} \]

\[ R = - \frac{(A_i + A_{i+1})(\Psi_i + \Psi_{i+1})}{4(x_{i+1} - x_i)} \frac{2\Delta t}{A_i(x_{i+1} - x_{i-1})} \]

\[ Q = 1 - P - R \]

\[ S = - C_i^n \]

This equation is solved by the double-sweep method,

\[ C_{i-1} = E_{i-1}C_i + F_{i-1} \quad (I-21) \]

in which

\[ E_i = - \frac{R}{PE_{i-1} + Q} \]

\[ F_i = \frac{S + PF_{i-1}}{PE_{i-1} + Q} \]

At external boundaries or nodes, it is assumed that no diffusive exchange exists, that is, \( E_1 = 0 \) and \( F_1 = C_1^n \).

I.B.2. Cohesive Sediment Dynamics

The net source term \( S/A \) for cohesive sediment includes the effects of erosion and deposition and can be expressed as:

\[ \frac{S}{A} = \left( \frac{dC}{dt} \right)_d + \left( \frac{dC}{dt} \right)_e \quad (I-22) \]

where: \( (dC/dt)_d = \) bed exchange due to erosion;

\( (dC/dt)_e = \) bed exchange due to deposition;
(1) Erosion

Erosion is considered to occur only in accelerating flows when the bed shear stress exceeds the resistance of the bed (Hayter, 1983).

The rate of erosion $\varepsilon$ (volumetric flux per unit area) has the following general form (Mehta, 1983):

$$\varepsilon = \varepsilon(\tau_b - \tau_{ce}, \gamma_1, \gamma_2, \ldots)$$  \hspace{1cm} (I-23)

where: $\tau_{ce} =$ critical shear stress for erosion;
$\tau_b =$ actual bed shear stress;
$\gamma_1, \gamma_2, \ldots =$ parameters specifying erosion resistance.

The critical shear stress depends greatly on the properties of the bed. Erosion includes surface erosion and mass erosion; surface erosion must be treated differently for partially consolidated and settled beds.

Parchure and Mehta (1985) found that the rate of surface erosion for partially consolidated beds could be expressed as:

$$\varepsilon = \varepsilon_0 \exp \left( \frac{\tau_b - \tau_{ce}}{\tau_{ce}} \right)$$  \hspace{1cm} (I-24)

where $\varepsilon_0 =$ surface erosion rate constant;
$\alpha =$ empirical constant

In the case of settled beds, the critical shear stress varies little with the depth of the bed, so that

$$\frac{\tau_b}{\tau_{ce}} - 1 \equiv \Delta \tau_b$$  \hspace{1cm} (I-25)
is small. For small $\Delta \tau_b$, Eq. (I-24) can be developed in a Taylor-series expansion, and the expression for $\varepsilon$ then varies linearly with $\Delta \tau_b$. Therefore, the rate of erosion in a settled bed can be determined by:

$$
\varepsilon = M' \left( \frac{\tau_b - \tau_{ce}}{\tau_{ce}} \right)
$$

(I-26)

where $M' = \text{settled-bed erosion rate constant}.$

As the bed shear stress increases, the bed may fail at some plane below the surface, and clumps of material are mass eroded. The mass erosion may be expressed approximately by Eq. (I-26), but the erosion rate constant has a much larger value than that for surface erosion (Mehta, 1983).

Finally, the bed exchange due to erosion is determined by

$$
\left( \frac{dC}{dt} \right)_{\varepsilon} = \frac{\varepsilon}{d}
$$

(I-27)

where $d = \text{depth of flow}$

(2) Deposition

Deposition is considered to occur only in decelerating flows when the bed shear stress is not large enough to resuspend the sediment that settles onto and bonds with the bed surface. Many laboratory studies on deposition of cohesive sediment have been conducted.

Krone (1962) gave a general formula of deposition,

$$
\left( \frac{dC}{dt} \right)_{d} = - \frac{P_d w_s(C) C}{d}
$$

(I-28)

in which: $P_d = \text{probability of deposition};$
\( w_s(C) = \text{sediment settling velocity}; \)

and

\[
P_d = 1 - \frac{\tau_b}{\tau_{cd}}
\]  

(I-29)

where \( \tau_{cd} = \text{critical shear stress for deposition}. \)

The critical shear stress \( \tau_{cd} \) has a range of values instead of a unique value when the sediment particles are distributed in a wide size range. Mehta and Partheniades (1975) found \( \tau_{cd} \) ranging from 0.18 N/m² to 1.1 N/m² for kaolinite. Krone (1962) found \( \tau_{cd} = 0.06 \) N/m² when the initial suspension concentration \( C_0 \) was less than 0.3 g/l and \( \tau_{cd} = 0.078 \) N/m² when \( C_0 = 0.3-10 \) g/l for the San Francisco Bay sediment.

Krone (1962) found that when \( C < C_1(0.3-0.7 \text{g/l}) \), the sediment particles settle independently with little mutual interference, therefore the settling velocity was independent of \( C \). Integrating Eq. (I-28) yields,

\[
C = C_0 \exp \left( - \frac{P_d w_s}{d} t \right)
\]  

(I-30)

in which \( C_0 \) is the initial suspended sediment concentration and \( w_s \) is the free settling velocity. This formula is nearly the same as Eq. (2-66) in the HEC-6 report (1990).

When \( C > C_2(0.3-0.7 \text{g/l}) \), flocculation is considered to occur. The following logarithmic law was derived:

\[
\log \frac{C}{C_0} = -k \log t
\]  

(I-31)

or

\[
C = C_0 t^k
\]

where \( k \) is a function of \( d \) and \( P_d \).
Differentiation of above equation with respect to \( t \), enables one to obtain the rate of deposition:

\[
\left( \frac{dC}{dt} \right)_d = -k \frac{C}{t} = -k_1 C
\]  
(I-32)

where \( k_1 \) is related to the flocculation time, as well as to \( d \) and \( P_d \).

Since the settling velocity depends on flocculation time, \( k_1 \) can be also given as

\[
k_1 = \frac{w_s(C)P_d}{d}
\]  
(I-33)

where: \( w_s(C) \) = settling velocity as a function of \( C \).

Therefore, the rate of deposition is summarized as

\[
\left( \frac{dC}{dt} \right)_d = -\frac{w_sP_dC}{d} \quad \text{for } C < C_1
\]

\[
\left( \frac{dC}{dt} \right)_d = -\frac{w_s(C)P_dC}{d} \quad \text{for } C \geq C_1
\]  
(I-34)

For \( C_1 < C < C_2 \) (10-15 g/l), Krone (1962) and Owen (1971) gave

\[
w_s(C) = K'C^{4/3}
\]  
(I-35)

where \( K' \) is an empirical constant. This formula implies that, due to mutual interference, the settling velocity increases with the concentration.

For \( C \geq C_2 \), the settling velocity decreases with increasing concentration due to hindered settling (Hayter, 1983). Thus,

\[
w_s(C) = \frac{250gD^2 \rho_s}{\rho_w 18v} \left( \frac{C}{C_2} - 1 \right)^3
\]  
(I-36)
where: \( D \) = mean diameter of the particle in microns
\( \rho_s \) = density of suspended sediment
\( \rho_w \) = density of water
\( \nu \) = water viscosity
\( l \) = empirical constant (=0.6)

The parameters \( K' \), \( w_s \), and \( D \), depending on the type of sediment, must be determined by laboratory settling tests.

The bed shear stress is calculated by the following relation:

\[
\tau_b = \rho_e u_*^2
\]  \hspace{1cm} (I-37)

in which \( \rho_e \) is effective local water density, given by

\[
\rho_e = \rho_w + \frac{C}{\rho_s} (\rho_s - \rho_w)
\]  \hspace{1cm} (I-38)

\( u_* \) is calculated from the following equation:

\[
\frac{U}{u_*} = 2.5 \ln \left( \frac{3.32 u_* d}{\nu} - 17.56 \right)
\]  \hspace{1cm} (I-39)

The Newton-Raphson iteration method is used to obtain the value of \( u_* \) given \( U \), \( d \), and \( \nu \).

I.B.3. Non-cohesive Sediment Dynamics

For the computation of a non-cohesive sediment source, the source term \( S \) includes both deposition and entrainment (see Eq. (I-22)), which may or may not be in equilibrium (Holly & Rahuel, 1990).

The deposition component is expressed as
\[
\left( \frac{dC}{dt} \right)_d = \frac{w_s C_d}{d}
\]  \hspace{1cm} (I-40)

in which \( C_d \) is the near-bed concentration, presumed to depend primarily on the cross-sectional average suspended-load concentration \( C \).

The entrainment component is taken as

\[
\left( \frac{dC}{dt} \right)_e = \frac{w_s \beta C_e(d) \lambda}{d}
\]  \hspace{1cm} (I-41)

where \( C_e(d) \) is the near-bed equilibrium concentration evaluated for a bed having only grains of size \( d \) using the empirical expression of Van Rijn (1984b); \( \beta \) is the fractional representation of the size class in the bed layer; limiting their entrainment to their availability; and \( \lambda \) is an allocation coefficient \((0<\lambda<1)\). \( \lambda \) is used in Eq. (I-41) to calculate the equilibrium entrainment concentration although it was originally introduced to distinguish between bedload and suspended-load. \((1-\lambda)\) is used in the corresponding bedload equilibrium capacity equation to suppress bedload transport for size classes that should be transported not as bedload, but rather as suspended-load. The value of \( \lambda \) is calculated by the following equation (Holly and Rahuel, 1990):

\[
\lambda = \begin{cases} 
0.0 & \text{for } u_*/w_s < 0.4 \\
\frac{u_*}{\log w_s} + 0.92 & \text{for } 0.4 < u_*/w_s < 10 \\
1.0 & \text{for } u_*/w_s \geq 10.0
\end{cases}
\]  \hspace{1cm} (I-42)

It is important to note that the previously described source terms for both cohesive and non-cohesive sediment are calculated for each size class \( j \) in a mixture.
I.C. Implementation in CHARIMA

I.C.1. Suspended-load Procedure

(1) Load allocation

At inflow boundaries, the total load and its distribution need to be input by the user. Then the total load is attributed to bedload and suspended-load components, by size class, using the allocate coefficient $\lambda$, which is obtained from the linear semi-log approximations of Eq. (I-42).

At interior points, the theoretical bedload capacity, which is first computed without considering whether the sediment would be in motion as bedload or suspended-load, is reduced by the coefficient $(1-\lambda)$.

In CHARIMA, a new subroutine, MALLOC, is called from PILOT in each global iteration of each time step to limit the theoretical bedload to the non-suspended load component. Also, a new subroutine, BCSL, is called from PILOT in each global iteration of each time step to allocate boundary sediment inflow between bedload and suspended-load. The bedload allocation coefficient $\lambda$ is calculated in the new subroutine, ALLOC, which is called from MALLOC for interior points and from BCSL for boundary points.

(2) Suspended-load diffusion

In CHARIMA, a the subroutine DIFFUS, is called from PILOT to compute the suspended-load diffusion and to smooth the bedload in each global iteration of each time step. In DIFFUS, the coefficients in the equation $PC_{i-1} + QC_i + RC_{i+1} + S = 0$ are computed; the double-sweep coefficients are initialized by re-imposing the existing values at the end of the link; and then the recursive double-sweep coefficients E, F are computed. During the backward sweep, previous concentration and derivative values are loaded for subsequent use in the advection-source calculation. This is probably inconsistent with global iteration and it may be necessary to use other arrays for the suspended-load double-sweep coefficients. It should be noted that arrays VOLIN, DELT, CSLP, and CXSLP in this subroutine are used as temporary double-sweep coefficients for the diffusion operator.
(3) Advection-source computation

In CHARIMA, a new subroutine, SOURCE, is introduced to calculate the suspended-load source, in which the computation of the non-cohesive sediment source or the cohesive sediment source is driven by the options IENTR(J) and IDEP(J) for sediment type. SOURCE is called from PILOT in each global iteration of each time step.

For the advection-source computation, a new subroutine, SULOAD, is called from PILOT to manage the suspended-load advection-source computation for all size classes in each global iteration of each time step. In SULOAD, new subroutines SULINT, SUNODE and SULINK, are called sequentially. SULINT is called to prepare Holly-Preissmann interpolation coefficients that are independent of size class. SUNODE is called to manage the nodal matrix operation and determine CX at points associated with nodes for each size class. SULINK is called to complete the advection-source computation along links for each size class by using the nodal outflow concentration previously computed in SUNODE.

In SULINT, the local flow direction is determined first. For flow from I-1 toward I, temporal interpolation is performed if I=1 and spatial interpolation is performed for I between IREF and IREF+1 (IREF < I). For flow from I+1 toward I, temporal interpolation is performed if I=ILAST and spatial interpolation is performed for I between IREF and IREF-1 (IREF > I). In both cases, no action is taken at the nodal outflow points, as these are treated elsewhere in the fully-mixed nodal concentration. After the flow direction is determined, the Holly-Preissmann spatial interpolation coefficients are computed for use with all size classes.

In SUNODE, matrices are initialized to zero, and a new subroutine, SULODM, is called to load RMAT, SMAT, TMAT and VVECT for nodal mixing equations at all nodes in group NG. Then EMAT, and FVECT are regressively calculated after computing S(INV), EMAT(1), and FVECT(1). In the return matrix sweep, DYN vectors are computed and stored in FFVECT, and then DYN values are transferred from relative positions (as stored in FVECT) to absolute positions (as stored in DYN).
The purpose of SULODM is to load the nodal matrices for the advection-source computation. The relative position of node M in the group is determined by looping on nodes of the central group. External suspended-load inflow, if any, is loaded in the free vector. Through looping on links connected to node M, the point number associated with the node is identified and any outflow link is rejected. Then, the inflow concentration and/or its dependence on outflow concentration at the other end of the link are determined by calling a new subroutine, SULHP. If this inflow concentration does not depend on the outflow concentration of another link, only the diagonal matrix elements need to be loaded. Finally, the node group to which the opposite end of the link belongs is identified and free vector is loaded.

In SULINK, the concentration and its derivative at the upstream point of the link are loaded from the previous SUNODE computation. The concentration and its derivative are then calculated for each point of the link. Then the new subroutine SULHP, is called to obtain \( C_\xi \) and \( CX_\xi \) at the foot of the trajectory using previously computed Holly-Preissmann coefficients, or temporal interpolation coefficients. Finally, the concentration and its derivative at computational points are computed by direct application of the Holly-Preissmann equation.

The purpose of SULHP is to recover the concentration and its derivative at the foot of the trajectory from the Holly-Preissmann coefficients. It is called from SULINK for each interior point on a link and from SULODM for the downstream-most point on each link.

I.C.2. Cohesive Sediment Procedures

For a cohesive sediment source, a new subroutine, STRESS, is called from SOURCE to calculate the bed shear stress; a new subroutine, EROSION, is called to calculate the bedload exchange due to erosion; and a new subroutine, DEPOSI, is called to calculate the bedload exchange due to deposition. The erosion and deposition parameters used in EROSION and DEPOSI are read in PILOT for each size class.

In EROSION, the surface erosion of a settled bed is not taken into account because the sediment bed is not divided into unconsolidated (stationary suspension), partially con-
solidated and settled layers. The bed is considered simply to be a partially consolidated layer and its properties are assumed to be temporally and spatially unchangeable.

I.C.3. Catalogues of new subroutines and new variables

(1) New subroutines for Suspended-Load Transport
   1. Subroutine SOURCE
   2. Subroutine MALLOC
   3. Subroutine ALLOC
   4. Subroutine BCSL
   5. Subroutine DIFFUS
   6. Subroutine SULINT
   7. Subroutine SUNODE
   8. Subroutine SULODM
   9. Subroutine SULHP
  10. Subroutine SULINK
  11. Subroutine SULOAD

(2) New subroutines for cohesive sediment dynamics
   1. Subroutine EROSION
   2. Subroutine DEPOSI
   3. Subroutine STRESS

(3) New variables are listed as follows:

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Dimension</th>
</tr>
</thead>
<tbody>
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<td>H-P interpolation coefficient</td>
<td>IMAX</td>
</tr>
<tr>
<td>A2HP</td>
<td>H-P interpolation coefficient</td>
<td>IMAX</td>
</tr>
<tr>
<td>A4HP</td>
<td>H-P interpolation coefficient</td>
<td>IMAX</td>
</tr>
<tr>
<td>ABED</td>
<td>Reference level or equivalent roughness height of bed</td>
<td></td>
</tr>
<tr>
<td>ALAMB</td>
<td>Bedload allocation factor</td>
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<tr>
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<td>H-P interpolation coefficient</td>
<td>IMAX</td>
</tr>
<tr>
<td>B3HP</td>
<td>H-P interpolation coefficient</td>
<td>IMAX</td>
</tr>
<tr>
<td>Variable</td>
<td>Description</td>
<td>Value</td>
</tr>
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<td>-----------</td>
<td>------------------------------------------------------------------------------</td>
<td>--------</td>
</tr>
<tr>
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<td>H-P interpolation coefficient</td>
<td>IMAX</td>
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</tr>
<tr>
<td>CONSTJ</td>
<td>Working variable</td>
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<tr>
<td>CSL</td>
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<td>Suspended-load boundary inflow by size class</td>
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<td>Derivative of source with respect to concentration</td>
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<td>Temporal interpolation factor when foot of trajectory intersects timeline at upstream node</td>
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<td>Factor relating section-averaged concentration to near-bed value</td>
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</tr>
<tr>
<td>PDEP</td>
<td>Deposition parameters</td>
<td>6*N1</td>
</tr>
<tr>
<td>PENTR</td>
<td>Entrainment parameters</td>
<td>6*N1</td>
</tr>
<tr>
<td>PCONS</td>
<td>Consolidation parameters</td>
<td>4*N1</td>
</tr>
<tr>
<td>PORODJ</td>
<td>Consolidated porosity (Defaults to POROS)</td>
<td></td>
</tr>
<tr>
<td>POROSJ</td>
<td>Size-class porosity (Defaults to POROS)</td>
<td></td>
</tr>
<tr>
<td>REFCON</td>
<td>Reference suspended-load concentration</td>
<td></td>
</tr>
<tr>
<td>SGRAVJ</td>
<td>Size-class specific gravity (Defaults to SGRAV)</td>
<td></td>
</tr>
<tr>
<td>SHRNET</td>
<td>Excess shear stress</td>
<td></td>
</tr>
<tr>
<td>SLDIF</td>
<td>Longitudinal diffusion coefficient</td>
<td></td>
</tr>
</tbody>
</table>
SORCDJ  Bedload exchange due to deposition
SORCEJ  Bedload exchange due to entrainment
SSL     Net bedload exchange
         IMAX*LINKS*N1

I.D. **Modification to Input Data**

The following input data requirements are modifications of those described in the parent report, Appendix B.

I.D.1. Suspended-Load Requirements

(1) Record 4: New variable ISL after IDTTMX.
   ISL=0 to suppress suspended-load calculation
   ISL=1 to provoke suspended-load calculation

(2) Record 7: New variable SLDIF after QSDIF
   SLDIF= Longitudinal diffusion coefficient for suspended-load, ft²/sec.

I.D.2. Cohesive Sediment Requirements

New records 8a and 8b: Sediment parameters for each size class N1

(1) Record 8a; Format 7I5,9F5.0
   J= size-class number
   IENTR(J)= Entrainment option
      IENTR(J)=0 for non-cohesive entrainment
      IENTR(J)=1 for cohesive entrainment by the Mehta method
   IDEP(J)= Deposition option
      IDEP(J)=0 for non-cohesive deposition
      IDEP(J)=1 for cohesive deposition by the Mehta method
   ICONS(J)= Consolidation option
      ICONS(J)=0 for no consolidation
      ICONS(J)=1 for cohesive consolidation by the Mehta method
   IDUM,IDUM,IDUM= 3 unused fields
SGRAVJ= Specific gravity for this class (defaults to SGRAV)
POROSJ= Loose porosity for this class (defaults to POROS)
PORODJ= Consolidated porosity for this class (defaults to POROS)

(2) Record 8b: Format 6 F10.0
PENTR(1,J)= Surface erosion rate for partially consolidated bed, lb/ft²/sec
PENTR(2,J)= Surface erosion rate for settled bed (not used), lb/ft²/sec
PENTR(3,J)= Erosion rate for mass erosion, lb/ft²/sec
PENTR(4,J)= Critical bed shear stress increment for mass erosion (excess stress above critical stress for surface erosion), lb/ft²
PENTR(5,J)= Critical shear stress of bed for erosion, lb/ft²
PENTR(6,J)= (not used)

(3) Record 8c: Format 6 F10.0
PDEP(1,J)= Maximum shear stress above which no deposition can occur (critical shear stress for deposition), lb/ft²
PDEP(2,J)= Threshold concentration for flocculation, lb/ft³
PDEP(3,J)= Threshold concentration above which hindering effects may occur, lb/ft³
PDEP(4,J),PDEP(5,J),PDEP(6,J)= (not used)

(4) Record 8d: Format 4 F10.0
PCONS(1,J),PCONS(2,J),PCONS(3,J),PCONS(4,J)= (not used)

I.E. Example Applications

I.E.1. Test Case

A simple case is used to verify the coding of suspended-load and cohesive dynamics in CHARIMA.

(1) Test conditions

In this case, a simple network of channels with 3 links and 4 nodes, whose schematic topological diagram is shown in Fig. I-1, is assumed. The 3 links are divided
Figure I-1 Schematic topological diagram of test case
Table I-1 Geometric data of test case.

<table>
<thead>
<tr>
<th>Link name</th>
<th>Point No.</th>
<th>River mile (miles)</th>
<th>Thalweg elevation (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
<td>0.379</td>
<td>0.2</td>
</tr>
<tr>
<td>10</td>
<td>3</td>
<td>0.758</td>
<td>0.4</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>1.136</td>
<td>0.6</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td>1.515</td>
<td>0.8</td>
</tr>
<tr>
<td>10</td>
<td>6</td>
<td>1.894</td>
<td>1.0</td>
</tr>
<tr>
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<td>1</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>20</td>
<td>2</td>
<td>0.379</td>
<td>1.2</td>
</tr>
<tr>
<td>20</td>
<td>3</td>
<td>0.758</td>
<td>1.4</td>
</tr>
<tr>
<td>20</td>
<td>4</td>
<td>1.136</td>
<td>1.6</td>
</tr>
<tr>
<td>20</td>
<td>5</td>
<td>1.515</td>
<td>1.8</td>
</tr>
<tr>
<td>20</td>
<td>6</td>
<td>1.894</td>
<td>2.0</td>
</tr>
<tr>
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<td>1</td>
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<td>1.0</td>
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<td>2</td>
<td>0.379</td>
<td>1.2</td>
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<tr>
<td>30</td>
<td>3</td>
<td>0.758</td>
<td>1.4</td>
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<tr>
<td>30</td>
<td>4</td>
<td>1.136</td>
<td>1.6</td>
</tr>
<tr>
<td>30</td>
<td>5</td>
<td>1.515</td>
<td>1.8</td>
</tr>
<tr>
<td>30</td>
<td>6</td>
<td>1.894</td>
<td>2.0</td>
</tr>
</tbody>
</table>
into 6 computational points. The channel sections are assumed to be rectangular. A summary of the geometric data is given in Table I-1.

The number of size classes is given as N1=5. The standard sediment sizes and the cumulative size distributions for the bed material and tributary inflow to the nodes are summarized in Table I-2. Two size classes are assumed to be cohesive, and the rest are assumed to be non-cohesive.

Two upstream boundary conditions and one downstream condition are given. The upstream boundary conditions include the water discharge and sediment inflow. The downstream boundary condition is the water surface elevation. Steady boundary conditions of water discharge and sediment inflow are given at nodes 3 and 4. A steady boundary condition of water surface elevation is given at node 1. The initial conditions and boundary conditions are summarized in Table I-3.

The primary sediment parameters used in the test case are listed in Table I-4. The computational time step is \( \Delta t = 1 \) minute.

(2) Analysis of results

Fig. I-2 shows the time history of water discharge at points 3 and 2 of link 20. It can be seen from this figure that the water discharges of these two points remain almost unchanged until about 20 minutes, then decrease with time until about 40 minutes, and again increase with time. This is because the water will start to move due to the initial water-surface profiles, but there is a time lag at the two points for wave propagation, which means that the water at the two points will not move until the wave reaches the m. The water discharge at point 3 shows a larger decrease than that of point 2, possibly due to the initial water-surface profiles. It is also seen from the figure that the water discharges of the two points finally tend to equalize. This implies that the flow is becoming steady because of the steady inflow boundary condition.

Fig. I-3 shows the time history of suspended-load concentration of classes 1 and 2 at point 3 of link 20. It can be seen from this figure that the suspended-load concentrations
Table I-2. Cumulative size distributions of bed material and tributary inflows.

<table>
<thead>
<tr>
<th>D(mm)</th>
<th>0.030</th>
<th>0.062</th>
<th>0.149</th>
<th>0.320</th>
<th>0.430</th>
<th>0.650</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDF</td>
<td>0.0</td>
<td>0.46</td>
<td>0.62</td>
<td>0.86</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

(Bed material)

<table>
<thead>
<tr>
<th>Node</th>
<th>D$_{50}$(mm)</th>
<th>0.030</th>
<th>0.062</th>
<th>0.149</th>
<th>0.320</th>
<th>0.430</th>
<th>0.650</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>CDF</td>
<td>0.0</td>
<td>0.46</td>
<td>0.62</td>
<td>0.86</td>
<td>0.94</td>
<td>1.00</td>
</tr>
<tr>
<td>4</td>
<td>CDF</td>
<td>0.0</td>
<td>0.46</td>
<td>0.62</td>
<td>0.86</td>
<td>0.94</td>
<td>1.00</td>
</tr>
</tbody>
</table>

(Tributary inflow)
<table>
<thead>
<tr>
<th>Link name</th>
<th>Point No.</th>
<th>Initial discharge ($\text{ft}^3/\text{s}$)</th>
<th>Initial water stage (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1</td>
<td>3054.0</td>
<td>10.0</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
<td>3054.0</td>
<td>10.2</td>
</tr>
<tr>
<td>10</td>
<td>3</td>
<td>3054.0</td>
<td>10.4</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>3054.0</td>
<td>10.6</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td>3054.0</td>
<td>10.8</td>
</tr>
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<td>10</td>
<td>6</td>
<td>3054.0</td>
<td>11.0</td>
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<td>1</td>
<td>1527.0</td>
<td>11.0</td>
</tr>
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<td>11.05</td>
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<td>11.103</td>
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<td>11.158</td>
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<td>11.276</td>
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<td>1</td>
<td>1527.0</td>
<td>11.0</td>
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<tr>
<td>30</td>
<td>2</td>
<td>1527.0</td>
<td>11.05</td>
</tr>
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<td>3</td>
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<td>11.103</td>
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<td>4</td>
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<td>11.158</td>
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<td>11.215</td>
</tr>
<tr>
<td>30</td>
<td>6</td>
<td>1527.0</td>
<td>11.276</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time (Min.)</th>
<th>Inflow node</th>
<th>Discharge ($\text{ft}^3/\text{s}$)</th>
<th>Total load (lb/ft$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-300</td>
<td>3</td>
<td>1527.0</td>
<td>1.0</td>
</tr>
<tr>
<td>0-300</td>
<td>4</td>
<td>1527.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>
Table I-4 Parameters of cohesive sediment by size class.

<table>
<thead>
<tr>
<th>J</th>
<th>PENTR(1,J)</th>
<th>PENTR(2,J)</th>
<th>PENTR(3,J)</th>
<th>PENTR(4,J)</th>
<th>PENTR(5,J)</th>
<th>PENTR(6,J)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(lb/ft²/s)</td>
<td>(lb/ft²/s)</td>
<td>(lb/ft²/s)</td>
<td>(lb/ft²)</td>
<td>(lb/ft²)</td>
<td>(lb/ft²)</td>
</tr>
<tr>
<td>1</td>
<td>0.00006</td>
<td>0.0002</td>
<td>0.00016</td>
<td>0.100</td>
<td>0.050</td>
<td>0.000</td>
</tr>
<tr>
<td>2</td>
<td>0.00005</td>
<td>0.0001</td>
<td>0.00014</td>
<td>0.100</td>
<td>0.060</td>
<td>0.000</td>
</tr>
<tr>
<td>3</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>4</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>5</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>J</th>
<th>PDEP(1,J)</th>
<th>PDEP(2,J)</th>
<th>PDEP(3,J)</th>
<th>PDEP(4,J)</th>
<th>PDEP(5,J)</th>
<th>PDEP(6,J)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(lb/ft²)</td>
<td>(lb/ft³)</td>
<td>(lb/ft³)</td>
<td>(lb/ft³)</td>
<td>(lb/ft³)</td>
<td>(lb/ft³)</td>
</tr>
<tr>
<td>1</td>
<td>0.072</td>
<td>0.020</td>
<td>0.630</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>2</td>
<td>0.071</td>
<td>0.016</td>
<td>0.560</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>3</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>4</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
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<tr>
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<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>
Figure I-2 Time history of water discharge at points 3 and 2 of link 20
Figure I-3  Time history of suspended-load concentration of classes 1 and 2 at point 3 of link 20
of class 1 and class 2, both of which are cohesive sediment, are increasing gradually with time, and the concentration of class 1 is larger than that of class 2. This is because the inflow sediment from the upstream boundary moves with the water, and the pdf value of class 1 was given as larger than that of class 2 in the boundary inflow data.

Fig. I-4 shows the water discharge distribution along link 20 at different times. It can be seen from the figure that the initial discharge is uniform along the link, and the discharge distributions at other times are declining from upstream to downstream along the link. This tendency is consistent with that in Fig. I-2. Because the water at downstream points starts to move earlier than at upstream points, the discharges of downstream points decrease more than those of upstream points during the decreasing period of discharge.

Fig. I-5 shows the distributions of suspended-load concentration of class 1 along link 20 at different times. It can be seen in this figure that the initial suspended-load concentration along the link is zero, and the concentrations at other times show declining distribution from upstream to downstream along the link. This means that the sediments are moving gradually with the water from upstream to downstream. The front of the propagating wave is flattening with time, implying that the concentration distribution tends to become uniform along the link with time because of the steady supply of sediments at the upstream boundary.

I.E.2. Watts Bar Reservoir System

(1) Data set and test conditions

The schematic topological diagram of the Watts Bar Reservoir System is shown in Fig. I-6. It has 28 links and 27 nodes, and is divided into 5 node groups. In accordance with the topological structure established in CHARIMA, the geometric descriptions of computational points in each link are given as input data and listed in Table I-5. The cross-sectional data at each computational point is given in the input data set CARDIN.DAT included at the end of this appendix.
Figure I-4 Water discharge distributions along link 20 at different times
Figure I-5  Distributions of suspended-load concentration of class 1 along link 20 at different times
Table I-5 Geometric data of Watts Bar Reservoir System.

<table>
<thead>
<tr>
<th>Link name</th>
<th>Point No.</th>
<th>River mile (miles)</th>
<th>Thalweg elevation (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>1</td>
<td>529.9</td>
<td>670.0</td>
</tr>
<tr>
<td>100</td>
<td>2</td>
<td>532.2</td>
<td>665.7</td>
</tr>
<tr>
<td>200</td>
<td>1</td>
<td>532.2</td>
<td>665.7</td>
</tr>
<tr>
<td>200</td>
<td>2</td>
<td>534.7</td>
<td>644.0</td>
</tr>
<tr>
<td>200</td>
<td>3</td>
<td>537.7</td>
<td>636.4</td>
</tr>
<tr>
<td>200</td>
<td>4</td>
<td>538.8</td>
<td>657.6</td>
</tr>
<tr>
<td>200</td>
<td>5</td>
<td>543.7</td>
<td>673.8</td>
</tr>
<tr>
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<td>0.0</td>
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<td>0.9</td>
<td>720.0</td>
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</tr>
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<td>2</td>
<td>557.0</td>
<td>689.1</td>
</tr>
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<td>3</td>
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<td>695.52</td>
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<td>700</td>
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<td>567.7</td>
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The total number of size classes is given as N1=10. The standard sediment sizes and the initial cumulative size distributions for the bed material and tributary inflows to the nodes are given in Table I-6.

As boundary conditions, one downstream (Watts Bar Dam) condition and 11 upstream conditions are specified. Unsteady water discharges and sediment inflows are imposed at the upstream boundaries, and a water stage hydrograph is given at the downstream boundary. The detail of the boundary conditions can be seen in the input data set CARDIN.DAT shown at the end of this appendix. As initial conditions, initial water discharges and water stages at each computational points are given (see CARDIN.DAT).

For test conditions, all sediment sizes are declared to be non-cohesive, and the primary numerical parameters are given as follows:

Δt = 1 hour
iteration number = 1
characteristic length associated with nodes = 100 feet

(2) Some modifications to CHARIMA code

Because of the complicated geometric structure of the Watts Bar Reservoir and the unsteady boundary conditions, reverse flows may possibly occur in some links and inflow discharges may be zero at some upstream boundary nodes. Therefore, it was necessary to make some modifications to the CHARIMA code when applying it to Watts Bar Reservoir.

BLOCK.FOR: The dimensions of T-arrays TSIZE, T1SIZE, T2SIZE, T3SIZE and NTSIZE are enlarged to be identical to those in NEWMAIN.FOR.

BCSL.FOR: In the case of zero inflow discharge at an upstream boundary node, control should be sent to the statement 200, that is, the following statement is added: IF(QTR(NINQ(MNODE)).EQ.0.0) GO TO 200.

CRITER.FOR: If the FB value is too small, the QB value could possibly become very large, and thus result in overflow error. Therefore it is necessary to add the following statement: IF(FN.LT.0.03) THEN FN=0.03.
### Table I-6 Cumulative size distributions of bed material and tributary inflows

**Bed material**

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<th>0.0625</th>
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DIFFUS.FOR: In order to avoid confusion due to the use of CSLP and CXSLP as working arrays for double-sweep coefficients, new arrays EQS, FQS, ESL and FSL are introduced to store the double-sweep coefficients. Thus the values of CSLP and CXSLP do not need to be set in this subroutine, instead they are set every time step in ENDSTP.FOR.

ENDSTP.FOR: 1). The output formats for CSL and DEG are changed from F type to PG type to present very small values. 2). The previous values of CSL(CSLP) and CXSL(CXSLP) in every time step are assigned in this subroutine, instead of in DIFFUS.FOR. The previous values of AREA, Y, RK and PRK are also assigned in this subroutine, instead of in FLOCA.FOR.

EXNER.FOR: In the Entry EXNER1, the degradation SLDD due to suspended-load should be divided by the density of sediment, which is equal to 62.42*SGRAV(62.42 is the density of water in units of \( \text{lb/ft}^3 \)).

FLOCA.FOR: Since the previous values of the variables AREA, Y, RK and PRK are assigned immediately after the hydrodynamics solution is obtained in this subroutine, the sediment calculations have no access to the values of these variables at the previous time step. Therefore, these statements are removed from this subroutine and added to ENDSTP.FOR.

MALLOC.FOR: Control should be sent to the statement 190 when the friction velocity USTAR is zero (or the discharge is zero) to avoid a "floating-point exception" error. Therefore, the following statement should be added: IF(USTAR,EQ,0,0) GO TO 190.

NEWMAIN.FOR: 1). The dimensions of T-arrays TSIZE, T1SIZE, T2SIZE, T3SIZE and NTSIZE are enlarged to 20000, 50000, 50000, 63000 and 5000 respectively. 2). Some additional changes are made because the subroutines have been modified.

NODSD.FOR: In Entry NODSD1, there were some operations which could result in a floating-point exception error when the sorting option is switched on (ISORT \geq 1). That is, arrays QSJNOD(J), CDF(J) and variable QSINF were not calculated correctly, and their calculations are corrected in this study.
SEXION.FOR: 1). The statement "FIRCAH=.TRUE." is removed from the subroutine SECPRO, and added at the beginning of the subroutine SEXION. 2). Some statements are added to automatically adjust the conveyances to ensure that they are monotonically increasing with water stage.

SOURCE.FOR: 1). Suspended-load concentration is largely dependent on the value of ABED, which represents the reference level or equivalent roughness height of the bed. Although it is difficult to determine the ABED value, its minimum value is 0.01*depth. The ABED value is given as 4 feet in the computation for the Watts Bar Reservoir. 2). Control should be sent to the statement 20 when the discharge at a computational point is zero. 3). CALL RAZ should be put at the place before entering the DO loop 10, otherwise the arrays DSDC and SSL are always set to zero.

SULINK.FOR: 1). When loading the concentration CSL and its derivative CXSL at the upstream point of a link, if the discharge at this point is zero, the values of CSL and CXSL are given as zero. 2). CXSL at computational points are calculated from the following modified formula:

\[ CX_{i}^{n+1} - CX_{i}^{n} = \left( -0.5*(CX_{i}^{n+1} + CX_{i}^{n}) \frac{\Delta(Q/A)}{\Delta x} + \frac{\Delta(S/A)}{\Delta x} \right) \Delta t \]

and IASS is defined as IASS=IREF(I,L), instead of IASS=I + ISIGN(1,IREF(I,L) - I).

(3) Because CX values (CXSL) at nodes were approximately calculated by the equation \( CX = - \frac{1}{u} \frac{\partial C}{\partial t} \), when the velocities at nodes are very small, the CX values could be very large, and thus result in an anomalous interpolation. Therefore, the values of CX(CXSL) at nodes are modified as follows: CX at nodes are still calculated by the above equation, if the absolute value of CX at a node is larger than some limiting value, then CX of this node is set to be equal to the weighted average of the CX value at the upstream point of the link attached to this node and the CX value of this node at previous time step.

SULODM.FOR: If a node, whose inflow discharge is zero or very small, exists, a floating-point exception error can occur due to the singular matrix. In this case, since the inflow
sediment at this node does not exist, its free vector VVECT is also zero. Therefore a non-zero value can be given to the coefficient matrix to avoid the problem of a singular matrix.

In addition, the variable DETER should be declared as a REAL*8 in SUNODE.FOR, NEWMAIN.FOR, GAUJOR.FOR, DONODE.FOR, FLOCA.FOR and SULOAD.FOR, and SNGL(DETER), instead of simple DETER, to be sent to ERRWAR.FOR for avoiding overflow problems.

(3) Analysis of results

Since the Watts Bar Reservoir is a very complicated multiply connected system, it is not feasible here to illustrate all the results obtained by CHARIMA. In the following, only the results of one representative link (link 601) are illustrated and analyzed.

Fig. I-7 shows the inflow discharge and sediment hydrographs at the boundary node 6001, which is the upstream node of link 601. In this figure, the inflow discharge and sediment are very small and almost remain the same until about 80 hours, after that, they vary rapidly with time and especially have very large values at about 200 hours. Fig. I-8 shows the discharge distributions along link 601 at different times. It can be seen from this figure that the discharge distributions along this link are almost uniform and their values correspond to the values of inflow discharge at node 6001. Fig. I-9 shows the bedload distributions along the link at different times. In this figure, the bedload discharges of the entire link at 30 hours and 50 hours are very small because of the small sediment inflow at the boundary node 6001, while the bedload discharges in the upstream portions of the link at 100 hours and 200 hours have much larger values, and these large bedloads gradually move downstream with time. Fig. I-10 shows the distributions of suspended-load concentration of all size classes lumped together along the link at different times. In this figure, the suspended-load concentrations of the whole link at 30 hours and 50 hours are very small because the inflow discharge and sediments from the upstream boundary are very small. After about 100 hours, the suspended-load concentrations of the link have larger values due to larger inflow sediments from the upstream boundary. Moreover, since the bed of this link is very irregular, the sediments eroded from the bed vary greatly along it thus making the distribution of suspended-load concentrations along the link very complicated when the discharges of the link are large. Fig. I-11 shows the distributions of
Figure I-7  Inflow discharge and sediment hydrographs at the boundary node 6001
Figure I-8 Discharge distributions along link 601 at different times
Figure I-9 Bedload distributions along link 601 at different times
Figure I-10  Distributions of suspended-load concentration of all size classes along link 601 at different times
Figure I-11 Distributions of the bed level in link 601 at different times
the bed level at different times. In this figure, the changes of the bed level are seen to be very small; only a slight deposition about 3-4.5 miles from the downstream boundary can be seen.

In summary, the results obtained by CHARIMA for the test case and Watts Bar Reservoir are reasonable, and the CHARIMA code can be used to simulate both cohesive and non-cohesive suspended sediment transport in a multiply connected system of channels.

I.F. Conclusions and Future Needs

In this study, treatments of suspended-sediment transport and cohesive dynamics were implemented in CHARIMA on the basis of the earlier version described in IIHR Report No. 343. The resulting version of CHARIMA can deal with transport of both non-cohesive and cohesive suspended-load, as well as that of bedload, in multiply connected networks of mobile-bed channels.

The new version of CHARIMA was applied to a test case and to the Watts Bar Reservoir. The principal conclusions obtained are summarized as follows:

(1) The modified Holly-Preissmann algorithm (Hybrid H-P/Crank-Nicholson solver) used in the study is satisfactory for simulating the transport of suspended sediment in multiply connected networks of channels for which it is difficult to apply the old H-P method. This new algorithm also has simpler difference equations than those of the old H-P method.

(2) Traditional cohesive sediment models implemented by the Corps of Engineers (in HEC-6, STUDH etc.) were investigated, and more recent models presented by Mehta and others were adopted in this study. For example, the deposition model of cohesive sediment used in HEC-6 etc. only accounted for the case of slow aggregation and suspended-load concentration less than 0.3g/l; in other words, the flocculation of sediment and the effect of hindered settling were not taken into account. In this study, the deposition model presented by Mehta and others was used to consider both sediment flocculation and the effect of hindered settling under high suspended-load concentration.
The following recommendations are given for future research:

(1) Many more physical parameters must be determined for the transport of cohesive sediment than for non-cohesive sediment, and it is almost impossible to give them general values. Rather, they must be determined specifically by experiment. Unfortunately, however, few such experiments have been performed. The values of these parameters used in this study were chosen from limited references. It is recommended that more experiments concerning the characteristics of cohesive sediment be conducted to determine these physical parameters under various conditions.

(2) As described earlier, the rate of surface erosion for cohesive sediment depends on the properties of the bed; in other words, it should be treated differently for partially consolidated and settled beds. In this study, however, the surface erosion for a settled bed was not incorporated into CHARIMA. For future study, the temporal and spatial changes of properties of beds should be taken into account by dividing the bed into several layers. In each layer the density and shear strength can be approximately assumed to be uniform or to vary linearly with depth.

(3) In this study, bed consolidation was not taken into account. Because bed consolidation determines the shear strength and density profile of the bed, and thus influences greatly the transport of sediment, it should be incorporated into the numerical model. It is recommended that the mechanism of consolidation be studied experimentally in more detail.

I.G. Additional References


I.H. Acknowledgements

This study was performed with the support of the Tennessee Valley Authority as part of the Watts Barr reservoir project. The participation and support of William Waldrop and Jerry Schohl are particularly appreciated.

Dr. H. H. Shen, Postdoctoral Research Associate at the Iowa Institute of Hydraulic Research, performed most of the analyses, programming, and tests under the supervision of Dr. Forrest M. Holly Jr. Dr. Shen prepared this appendix.
## I.I. Listing of CARDIN.DAT file for Watts Bar Reservoir

Tests of Watts-Bar Reservoir Model --- 4/1/92

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Appendix J

Treatment of Sediment Transport over Weirs and Bed-Layers Model in CHARIMA

Prepared by:

H.H. Shen

DRAFT
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<td>Bed degradation of link 30 at 100 and 500 minutes</td>
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(3) Exner equation

In contrast to the SEDICOUPT code, the concept of bed equilibrium capacity is not introduced in CHARIMA. For a weir link, it is simply assumed that there is no exchange between bedload and suspended-load at a weir, and \( Q_{sj,d} = Q_{sj,w} \) thus the Exner equation is simplified to

\[
(1 - p) B \frac{\partial z}{\partial t} = 0 \tag{J-4}
\]

where

\begin{align*}
  p & = \text{sediment porosity} \\
  B & = \text{active sedimentation width} \\
  z & = \text{bed elevation of weir link}
\end{align*}

Eq. (J-4) indicates that the bed elevation of a weir link does not vary with time. But since the bed-level change at computational points is taken as the weighted-average change in the adjacent reaches (in subroutine PILOT), the weir-link end points can have changing bed elevations even though the weir link itself does not generate any change.

J.B.2. Bed-Layer Model and Consolidation

Several models concerning bed layers and consolidation have been proposed. Hayter and Mehta (1982) presented a thorough bed-profile and consolidation model. In this model, the bed is considered to be composed of an original, settled bed section and a new-deposit bed section. The new-deposit bed section is subdivided into unconsolidated new-deposit layers and partially consolidated new-deposit layers. The unconsolidated new-deposit bed will resume transport and the partially consolidated new-deposit bed and settled bed will undergo resuspension when subjected to an excess shear stress. Although this model gives a good description of the bed-profile physics, it is complicated and many parameters need to be determined; therefore it is not necessarily easy to apply this model to an engineering problem. Delo (1988) proposed a simple and practical model, which in this study is incorporated into CHARIMA.
In Delo’s model, the bed is discretized into a series of layers with variable thickness. Each layer has a specified sediment density \( \rho_b \), critical shear stress \( \tau_{cr} \) for erosion and residence duration \( T_r \). The critical shear stress is dependent on the density of the deposits, and the residence duration \( T_r \) is used to account for consolidation. Consolidation of the deposited sediment bed is caused by the self-weight of the sediment particles and is accounted for by increasing the bed density and critical shear stress with time.

When deposition occurs, the deposits always fill up the first layer so that the thickness of the first layer increases consequently. The residence time \( t_{re} \) of deposits in the first layer is considered to begin from the first time step during which no deposition is predicted to occur. If further deposition occurs for \( t_{re} < 2 \) hours (the value of \( T_r \) for the first layer), the value of \( t_{re} \) is reset to zero. When \( t_{re} \geq 2 \) hours and if no erosion occurs, the content of the first layer enters into the underlying more consolidated layer and is added to its existing contents. When the bed shear stress exceeds the critical shear stress of the top layer, then erosion occurs, and if the top layer is totally eroded, the underlying layer is exposed for subsequent erosion.

This kind of procedure is repeated for other layers. Therefore, the residence times of deposits \( t_{re} \) are compared to the residence durations \( T_r \) every 2 hours for each layer, and if consolidation occurs, the content of the layer goes into the underlying more consolidated layer and the total thickness of each layer is adjusted accordingly.

Because this kind of bed-layer model is introduced in this study, the model of bed erosion must also be modified. The source term erosion component for non-cohesive sediments can be represented by the following equation (Van Rijn, 1988):

\[
S_{ej} = 0.015Bw_j \beta_j D_j \left( \frac{u^*}{u*_{cr}} \right)^{1.5} \left( \frac{u*_{cr}^2}{\frac{(s-1)g}{v^2}} \right)^{1/3} \left( \frac{1.5}{0.3} \right)
\]

\( (J-5) \)

where \( S_{ej} \) = component of source term due to erosion  
\( w_j \) = settling velocity  
\( \beta_j \) = fractional representation of size class \( j \) in the bed
a = effective roughness height
s = specific density of sediment
\( \nu \) = viscosity coefficient
\( D_j \) = diameter of particle size j
\( u_* \) = bed shear velocity
\( u_{*cr} \) = critical bed shear velocity according to Shields

Assuming that dimensionless critical shear stresses are constant for each size class and are given by

\[
\frac{\tau_{cr}}{\gamma(s-1)D_j} = 0.06 \quad u_{*cr}^2 = \frac{\tau_{cr}}{\rho} \quad (J-6)
\]

and

\[
u^2 = gRS_f \quad \gamma = \rho g \quad (J-7)
\]

where \( \gamma \) is the specific weight of water, the following equation is obtained:

\[
S_{ej} = 1.0206Bw_j \beta_j \frac{D_j}{a} \left( \frac{gRS_f - \tau_{cr}/\rho}{\tau_{cr}/\rho} \right)^{0.2} \left( \frac{D_j}{s-1})^{1.6} \right) \left( \frac{(s-1)(s-1)g^{0.2}}{\nu^2} \right) \left( \frac{RS_f - 0.06(s-1)D_j}{1.5} \right)^{1.5} \quad (J-8)
\]

This was the equation used in the CHARIMA code for the erosion component of non-cohesive sediments. In this study, the critical bed shear stresses are assumed to vary temporally and spatially, depending on the characteristics of deposits on the bed. Therefore, Eq. (J-5) with a local critical shear stress \( \tau_{cr} \) is used in CHARIMA if the bed-layer model is active:

\[
S_{ej} = 0.015Bw_j \beta_j \frac{D_j}{a} \left( \frac{gRS_f - \tau_{cr}/\rho}{\tau_{cr}/\rho} \right)^{0.5} \left( \frac{D_j}{s-1})^{1/3} \right)^{0.3} \left( \frac{(s-1)}{\nu^2} \right)^{0.3} \left( \frac{\nu RS_f - \tau_{cr}}{\tau_{cr}} \right)^{0.5} \quad (J-9)
\]
J.C. *Implementation in CHARIMA*

J.C.1. Weir-Type Link Procedure

The treatment of sediment transport over a weir link is incorporated into subroutine DIFFUS. For a weir link, its LTYPE value is not zero, thus control is sent to statement 70 to calculate the recursive double-sweep coefficients for the weir link. First, it is necessary to find the bed elevation ZUS of the weir upstream point, then ZUS is compared to the weir sill elevation YW. For bedload, the recursive double-sweep coefficients EQS and FQS are given as 1 and zero respectively, to enforce Eq. (J-2). If ZUS < YW, no bedload is allowed to cross the weir and thus the bedload discharge QS at the upstream point of the weir is set to zero. If ZUS ≥ YW, bedload can move downstream over the weir and thus QS at the upstream point of the weir is calculated by the sediment discharge equations as for fluvial links. For both cases, the QS at the downstream point of the weir is calculated by the backward sweep of double-sweep method. For suspended-load, the recursive double-sweep coefficients ESL and FSL are given as 1 and zero respectively, enforcing Eq. (J-3), and the backward sweep is carried out as for fluvial links.

In subroutine SOURCE, control is sent to statement 10 for a weir link to set the source term to zero.

Some modifications for weir links are made in subroutine SULODM. Control is sent to statement 150 for weir links. Here, the interpolation coefficient ETA is set to 1, and variables SSL and DSDC related to the source term are set to zero.

The treatment of weir links also must be reflected in the subroutine SULINK. For a weir link, control is sent to statement 110 or 120, depending on the flow direction, to set the suspended-load concentration at the downstream point of the weir to be equal to that of the upstream point.
J.C.2. Bed-Layer Model and Consolidation Procedure

A new subroutine RDBED is introduced and called from NEWMAIN to read the bed characteristics, such as total number of layers the bed, density of deposits, residence duration and critical shear stresses (by size class) of each layer.

The initial bed conditions are specified in a new subroutine INITBED, which is also called from NEWMAIN. In INITBED, the thickness of each layer at the beginning of the computation is read.

Subroutine SOURCE is modified according to the description of Section J.B.2. If LBED=0 (bed-layer model is not active), Eq. (J-8) is used, and if LBED=1 (bed-layer model is active), Eq. (J-9) is used.

Bed consolidation is incorporated into the entry EXNER2 of subroutine EXNER. If LBED=0, this part is inactive. When LBED=1, the treatment is divided into three cases by the value of VOLOUT, which is the depth of degradation in one time step. 1). If VOLOUT > 0, deposition occurs, and the bed is aggrading. Deposits enter into the first layer and the thickness of the first layer increase consequently. The shear stress of the bed TAUCRI is set to equal to shear strength CRISTR of the first layer. The residence time IRETI of deposits in the first layer is set to zero, and the residence times of deposits in other layers increases by IDELT; 2). If VOLOUT = 0, no deposition or erosion occurs. The residence times of deposits in every layer increase by IDELT; 3). If VOLOUT < 0, erosion occurs, and the bed is degrading. If VOLOUT is larger than the thickness of the top layer, the top layer is totally eroded and the underlying layer becomes the top layer, then the critical shear stress TAUCRI of the bed is set to equal to shear strength of this new top layer. If VOLOUT is smaller than the thickness of the top layer, the top layer is partially eroded, thus the thickness of the top layer decreases by VOLOUT, and the TAUCRI value of the bed remains unchanged. In these two cases, the residence times IRETI of the underlying layers increase by IDELT.

A new subroutine CONSOL is called from NEWMAIN to calculate the consolidation of deposited sediment layers if both LBED and LCONS are equal to 1. In this subroutine, IRHOUR is a temporal variable which represents the residence time (IRETI) of
deposits in hours. The IRHOUR value of each layer is compared to the residence duration RESDUR of the layer every 2 hours; if IRHOUR ≥ RESDUR, consolidation occurs in this layer, then the content of this layer is added to the underlying layer, and the thickness and residence time of this layer are set to zero. If this layer is the top one, the critical bed shear stress TAUCRI is given as the shear strength CRISTR of its underlying layer.

J.C.3. Catalogues of New Subroutines and New Variables

(1) New subroutines for bed-layer model and consolidation
   1. Subroutine INITBED
   2. Subroutine RDBED
   3. Subroutine CONSOL

(2) New variables are listed as follows:

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<td>Density of deposit in each layer</td>
<td>LAYERS</td>
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<tr>
<td>IRETI</td>
<td>Residence time of deposits</td>
<td>IMAX<em>LINKS</em>LAYERS</td>
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<td>Total number of bed layers</td>
<td>IMAX<em>LINKS</em>LAYERS</td>
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<td>RESDUR</td>
<td>Residence duration of each layer</td>
<td>LAYERS</td>
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<td>TAUCRI</td>
<td>Critical stress of bed by size class</td>
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<tr>
<td>THICK</td>
<td>Thickness of each layer</td>
<td>IMAX<em>LINKS</em>LAYERS</td>
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J.D. Modification to Input Data

J.D.1. Weir Link Requirements

The link-type variable LTYPE has already been included in the input data of CHARIMA; no further modification to input data for a weir link is needed.
J.D.2. Bed-Layer Model and Consolidation Requirements

(1) Record 2: New variable LAYERS (Format I5) after IYALIN
   \text{LAYERS} = \text{Total number of bed layers}

(2) Record 4: New variables LBED and LCONS (Format 2I5) after ISL
   \text{LBED} = 0 \text{ Bed-layer model not active}
   \text{LBED} = 1 \text{ Bed-layer model active}

   \text{LCONS} = 0 \text{ Bed consolidation not calculated}
   \text{LCONS} = 1 \text{ Bed consolidation calculated}

(3) Record 8c: Format I5, 3F8.3
   \text{M} = \text{Layer number}
   \text{DENBED(M)} = \text{Deposit density of each layer (not used)}
   \text{RESDUR(M)} = \text{Residence duration of each layer, hours}
   \text{CRISTR(M,N1)} = \text{Shear strength of each layer by size class, lb/ft}^2

\textbf{J.E. Tests and Demonstration}

J.E.1. Test Conditions

(1) Weir link

   A simple network of channels which includes a weir link is used to verify the code
   added to CHARIMA for weir links. It can be obtained simply by breaking link 20 of the
   network of channels used in Appendix I into 3 links (link 21, link 22 and link 23), one of
   which (link 22) is specified as weir link. The elevation and width of the weir are given as
   1.5 feet and 10 feet respectively. The schematic diagram of the new network of channels is
   shown in Fig. J-1 and a summary of the geometric data is illustrated in Table J-1. The dis-
   tribution of bed material, boundary and initial conditions and other parameters are the same
   as in the test case of Appendix I.
Figure J-1  Schematic topological diagram of test case (including weir link)
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<tr>
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<td>1.515</td>
<td>1.80</td>
</tr>
<tr>
<td>30</td>
<td>6</td>
<td>1.894</td>
<td>2.00</td>
</tr>
</tbody>
</table>
(2) Bed-layer model and consolidation

The network of channels used in Appendix I is also used in this study. The bed is divided into 10 layers and the characteristics of each layer are given in Table J-2. In this table, the residence duration of the 10th layer can be considered as infinitely large, which means that consolidation of deposits in this layer will never occur. The distribution of bed material, boundary and initial conditions and other parameters are the same as in Appendix I.

J.E.2. Analysis of Results

(1) Weir link

Fig. J-2 shows the distributions of water stage along links 21, 22 and 23 (link 22 is weir link) at different time steps. It can be seen from this figure that the difference between the water stages at the upstream and downstream points of the weir increases with time and finally reaches a steady state. Fig. J-3 shows the distributions of discharge along links 21, 22 and 23 at different time steps. In this figure, the discharges upstream of the weir are nearly linearly distributed, the closer to the weir, the smaller the discharge is, while the discharges at downstream side of the weir have a uniform distribution. The discharge distribution along these links has a tendency to become uniform with time and finally reaches a steady and uniform state. Fig. J-4 shows the distributions of bedload discharge along links 21, 22 and 23 at different time steps. From this figure, it can be obviously seen that the bedload discharges at all points except for the points near the upstream boundary are always very small, and little bedload sediments from the upstream boundary reach the downstream side. This is because the sediments from the bed (calculated by the sediment-discharge capacity equation) are much smaller than the bedload sediments imposed at the upstream boundary, and the bedload sediments from the upstream boundary are not likely to move downstream along with the water so that they accumulate in the area near the upstream boundary. Since the bed elevation of the point upstream immediately of the weir is higher than the elevation of the weir crest, the bedload can cross the weir and the bedload discharge at either side of the weir always remain the same (it can hardly be seen in this figure, their values being too small). Fig. J-5 shows the bed level in links 21, 22 and 23 at different time steps. In this figure, the bed upstream of the weir is aggrading with time because the bedload from the upstream boundary accumulate in the area near the upstream boundary. Fig. J-6 shows the distributions of suspended-load concentration of all size
<table>
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<tr>
<th>Layer</th>
<th>Density (lb/ft$^3$)</th>
<th>Residence Duration (hours)</th>
<th>Shear Strength by Size Class (lb/ft$^2$) (j=1, N1)</th>
</tr>
</thead>
<tbody>
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</tr>
<tr>
<td>10</td>
<td>18.66</td>
<td>9999</td>
<td>0.158 0.159 0.160 0.161 0.162</td>
</tr>
</tbody>
</table>
Figure J-2  Distributions of water stage along links 21, 22 and 23 at different times
Figure J-3  Distributions of discharge along links 21, 22 and 23 at different times
Figure J-4  Distributions of bedload discharge along links 21, 22 and 23 at different times
Figure J-5 Bed level in links 21, 22 and 23 at different times
Figure J-6  Distributions of suspended-load concentration of all size classes along links 21, 22 and 23 at different times
classes along links 21, 22 and 23 at different time steps. It can be seen from this figure that the suspended-load sediments are crossing the weir and moving downstream with time, while the suspended-load concentrations at the two points associated with the weir always remain the same.

(2) Bed-layer model and consolidation

In order to investigate the effects of the bed-layer model on sediment transport and bed evolution, the CHARIMA code was run for two cases, with the bed-layer model switched off and on, and the results of these two cases compared. The former case is called Run 1 and the latter one is called Run 2. The other computational conditions are the same for Run 1 and Run 2.

Figure J-7 show the distributions of suspended-load concentration of all size classes along link 30 at 100 minutes and 500 minutes. In this figure, Run 2 has the similar distributions to Run 1, but the values of Run 2 are a little smaller than those of Run 1. This is because the critical bed shear stresses are set to larger values and become even larger due to consolidation when the bed-layer model is switched on, so that the bed is less eroded. Fig. J-8 shows the degradation of the bed at 100 minutes and 500 minutes. Because the degradation of the bed is very small, no obvious difference can be seen in this figure.

**J.F. Conclusions and Future Needs**

In this study, a new version of CHARIMA was developed from the earlier version in IIHR Report No. 343 and Appendix I. This new version can deal with sediment transport over a weir-type link, and can account for nonuniform and unsteady bed shear strength and bed consolidation.

The new version of CHARIMA was applied to two test cases. The main conclusions obtained are summarized as follows:

(1). A weir-type link was introduced to represent hydraulic structures in natural rivers, and the basic equations for such weir-type links were derived. The earlier version of CHARIMA was updated by incorporating the treatment of sediment (including bedload and suspended-load) transport over a weir link into it.
Figure J-7  Distributions of suspended-load concentration of all size classes along link 30 at 100 and 500 minutes
J.H. Acknowledgements

This study was performed with the support of the Tennessee Valley Authority as part of the Watts Barr reservoir project. The participation and support of William Waldrop and Jerry Schohl is particularly appreciated.

Dr. H. H. Shen, Postdoctoral Research Associate at the Iowa Institute of Hydraulic Research, performed most of the analyses, programming, and tests under the supervision of Dr. Forrest M. Holly Jr. He also prepared this appendix.
Appendix K

COMPOUND CROSS-SECTIONS

By Lj. Savic and F.M. Holly, Jr.

January 1994

I. INTRODUCTION AND PURPOSE

The objective of this work is to implement the capability to handle compound cross-sections, with the roughness coefficient varying across the section, in CHARIMA. Prior to this development, CHARMA necessarily assumed a constant roughness across the cross section, a very common feature of natural watercourses is the lateral variability of roughness as bed material changes across the channel, especially in streams with highly mobile beds.

A constant longitudinal energy slope across the section is assumed (see Cunge at al., 1980) to compute the equivalent section conveyance and the coefficient of non-uniform velocity distribution in the momentum flux term of the momentum equation (momentum-flux coefficient).

The momentum flux-coefficient was previously treated as a constant for the cross-section (i.e. independent of the flow depth), which is a valid assumption for compact sections; for a compound section, due to the prominent differences in the velocity across the section, the momentum-flux coefficient can significantly vary with the flow-depth.

II. PROPOSED METHODOLOGY FOR COMPOUND SECTION

The procedure outlined by Cunge et al., 1980 (sections 2.1 and 4.5) is adopted herein. A compound cross-section is divided into the appropriate number of segments (N segments in Fig.1), each of them treated as having a distinct discharge $Q_i$, area $A_i$, and value of the roughness coefficient. The total cross-sectional discharge/area equals the sum of the segment discharges/areas:

$$Q = \sum_{i=1}^{N} Q_i \quad \text{and} \quad A = \sum_{i=1}^{N} A_i.$$  \hspace{1cm} (1)

A constant elevation of the energy grade line across the section is assumed, which implies a constant longitudinal friction slope $S_f$ for the entire section, and therefore for all of its segments. Since the discharge can be expressed as the product of the conveyance and the square-root of the friction slope (i.e. $Q = K \sqrt{S_f}$), one can obtain the equivalent conveyance of the compound section as the sum of its segment conveyances:
(2): \[ K = \sum_{i=1}^{N} K_i = \sum_{i=1}^{N} k_{str} A_i R_i^{2/3} \] if the resistance is defined by the Strickler coefficient, or:

(3): \[ K = \sum_{i=1}^{N} K_i = \sum_{i=1}^{N} \sqrt{\frac{8 g}{f_i}} A_i R_i^{2/3} \] if the resistance is defined by the Darcy-Weisbach friction factor, where:

K = equivalent (total) cross-sectional conveyance,
A = total cross-section flow area,
N = number of segments across the section,
K_i = conveyance for the i-th segment of the cross section,
A_i = flow area of the i-th segment,
R_i = hydraulic radius of the i-th segment, where \( R_i = \frac{A_i}{P_i} \), and:
P_i = wetted perimeter of the i-th segment,
g = gravitational acceleration,
k_{str} = Strickler coefficient for the i-th segment,
f_i = Darcy-Weisbach friction factor for the i-th segment.

!!!!! THE FIGURE IS INCLUDED IN THE PRINTED DRAFT ATTACHED TO THE "NOTES ON THE REPORT"

Figure 1. Compound cross section divided into N segments

In CHARIMA the conveyance is stored as a so-called "geometric" conveyance, which is a property of the geometry of the section only, independent of the roughness coefficient (or friction factor). This enables use of the same geometric type of cross section for more than one actual computational point in the model. If the Strickler coefficient is used, one can rewrite Eq. (2) as:

(2'): \[ K = \bar{k}_{str} \sum_{i=1}^{N} k_{str} A_i R_i^{2/3} = \bar{k}_{str} \sum_{i=1}^{N} k_{r_i} A_i R_i^{2/3} \]

and for the Darcy-Weisbach form:

(3'): \[ \bar{K} = \sqrt{\frac{1}{f} \sum_{i=1}^{N} \sqrt{\frac{8 g}{f_i}} A_i R_i^{2/3}} = \sqrt{\frac{1}{f} \sum_{i=1}^{N} \sqrt{\frac{8 g}{f_{r_i}}} A_i R_i^{2/3}} \]

where:
\( \bar{k}_{str} \) = representative value of the Strickler coefficient for the entire cross-section,
\( k_{r_i} \) = relative Strickler coefficient for the i-th segment,
\( \bar{f} \) = representative value of the Darcy-Weisbach friction factor for the entire cross-section,
\( f_r_i \) = relative Darcy-Weisbach friction factor for the i-th segment.

Now, the geometric conveyance is defined as:

(4): 
\[ K_{\text{GEOM}} = \frac{K}{K_{\text{str}}} = \sum_{i=1}^{N} k_r A_i R_i^2 \] for the Strickler form, and:

(5): 
\[ K_{\text{GEOM}} = \sqrt{\bar{f}} K = \sum_{i=1}^{N} \frac{8 g A_i R_i^2}{f_{r_i}} \] for the Darcy-Weisbach form.

The momentum-flux correction coefficient \( \alpha \) compensates for the highly non-uniform velocity distribution across the compound cross-section (since one of the de St. Venant hypothesis implies a uniform velocity across the section):

(6): 
\[ \alpha \frac{Q^2}{A} = \sum_{i=1}^{N} \frac{Q^2}{A_i} \]

By again invoking the assumption of a constant energy level across the section, one obtains:

(7): 
\[ \alpha = \frac{A}{K^2} \sum_{i=1}^{N} \frac{K_i^2}{A_i} = \frac{A}{K_{\text{GEOM}}^2} \sum_{i=1}^{N} \frac{K_{\text{GEOM}}^2}{A_i} \]

III. COMPOUND-SECTION IMPLEMENTATION IN CHARIMA

Since the momentum-flux correction coefficient \( \alpha \) is now treated as a function of both flow depth and time, new array storage must be added to CHARIMA, as follows:

ALPHAS(I,L) = array where the values of \( \alpha \) for the current time step \((n+1)\) are stored;

ALPHAP(I,L) = array where the values of \( \alpha \) for the previous time step \((n)\) are stored.

ALPHPR(I,L) = array where the values of \( \partial \alpha / \partial y \) for the current time step \((n+1)\) are stored.

Space for the array ALPHAS(IMAX,LINKS) is created in NEWMAIN.FOR in the T1(i174) array; array ALHPAP(IMAX,LINKS) follows it with initial index i175; and array ALPHPR(IMAX,LINKS) follows with initial index176. To accommodate the \( \alpha (y) \) values for the cross-sections, the dimension of array SEGEO (i.e., array T(i12) in NEWMAIN.FOR) is increased from NSECS*(3+3*NLEVMX) to NSECS*(3+4*NLEVMX).

Major modifications are made in subroutines SEXITN.FOR, COEFF.FOR and SECPRO.FOR. Minor modifications, concerning the argument lists and local dimensions, affected all subroutines that call one or more of the above subroutines, either directly, or through other subroutines:

NEWMAIN.FOR, FLOCA.FOR, USENHA.FOR, USACK.FOR, USTLTM.FOR, USPOW.FOR, SEDQUS.FOR, POINTS.FOR, DOLINK.FOR, CHECKS.FOR, and ENDSTP.FOR.
The last two subroutines (CHECKS.FOR and ENDSTP.FOR) also include statements for updating the current value of $\alpha$.

**III.1 Subroutine SEXION.FOR**

For a compound cross-section type the index ISEC (read in SEXION.FOR, in record 16) must be assigned a value of 2. If ISEC=2 (i.e. if the section is compound) the designated number (NBSEC) of distance-level-relative roughness data triplets is read. The distances and levels are defined as for the option ISEC=1, at the limiting points of each segment (see Fig.1), and the relative roughness is designated for each segment of the section, i.e. between the limiting points. Thus for the last triplet, the relative roughness has no significance.

Computation of geometric properties of the compound cross-section proceeds according to the methodology given in section II above. Geometric properties of the cross-section (area A, geometric conveyance $K_{GEOM}$, hydraulic radius $R$, and momentum-flux correction coefficient $\alpha$) are computed for the designated number of water levels (NLEVEL) using the depth increment step (DH). For each segment of the section the area $A_i$, wetted perimeter $P_i$, and hydraulic radius $R_i$ are computed, then the summations for the total area, geometric conveyance $K_{GEOM}$ and momentum-flux correction coefficient $\alpha$ are updated (see Eqs. 4, 5, and 7) until all the segments of the section have been processed.

Values of geometric properties are then stored in the SEGEO(i) array in the same order as for the previous compact sections, the only difference being the inclusion of the momentum correction $\alpha$ as the last segment of the array (SEGEO(ISECA+1+3*NLEVEL)). To assure consistency in the array structure, $\alpha$ values of unity are stored in this last segment of SEGEO(i) in case of a "normal" section (i.e. if ISEC=1 or 0).

**III.2 Subroutine COEFF.FOR**

The major modification in this subroutine arises from the variable $\alpha$, which is now a function of time and flow depth; hence it has to be appropriately discretized and the derivatives $\frac{\partial \alpha}{\partial y}$ must appear in the Newton-Raphson procedure, and accordingly in the de St. Venant coefficients ($A'$, $B'$, $C'$, $D'$ and $G'$) for the momentum equation. Using the same methodology as in section II.4.3 of the parent report, one can discretize the $\alpha$ coefficient as:

\begin{equation}
\alpha = \frac{\theta}{2} (\alpha_{i+1}^{n+1} + \alpha_i^{n+1}) + \frac{1-\theta}{2} (\alpha_{i+1}^{n} + \alpha_i^{n}),
\end{equation}

while the coefficients of the momentum equation are modified as:
\[ A' = A'_{\text{old}} \]
\[
\frac{1}{2} \left( \frac{\partial \alpha}{\partial y} \right) + \left( \frac{Q_{i+1}^n + Q_i^n}{A_{i+1}^n + A_i^n} \right) + (1 - \theta) \left( \frac{Q_{i+1}^n}{A_{i+1}^n} + \frac{Q_i^n}{A_i^n} \right) \\
\left[ \frac{\theta}{\Delta X} (Q_{i+1}^n - Q_i^n) + \frac{1 - \theta}{\Delta X} (Q_{i+1}^n - Q_i^n) \right] \\
\frac{\theta}{2} \left( \frac{\partial \alpha}{\partial y} \right) + \left( \frac{Q_{i+1}^n + Q_i^n}{A_{i+1}^n + A_i^n} \right)^2 + \frac{(1 - \theta)}{4} \left( \frac{Q_{i+1}^n}{A_{i+1}^n} + \frac{Q_i^n}{A_i^n} \right)^2 \\
\left[ \frac{\theta}{\Delta X} (A_{i+1}^{n+1} - A_i^n) + \frac{1 - \theta}{\Delta X} (A_{i+1}^{n+1} - A_i^n) \right] \\
\frac{\theta}{2} \left( \frac{Q_{i+1}^n}{A_{i+1}^{n+1}} \right)^2 B_{i+1}^{n+1} \left[ \frac{\theta}{\Delta X} (\alpha_{i+1}^{n+1} - \alpha_i^n) + \frac{1 - \theta}{\Delta X} (\alpha_{i+1}^{n+1} - \alpha_i^n) \right] \\
+ \frac{\theta}{\Delta X} \left( \frac{\partial \alpha}{\partial y} \right) \left[ \frac{\theta}{2} \left( \frac{Q_{i+1}^n}{A_{i+1}^{n+1}} + \frac{Q_i^n}{A_i^{n+1}} \right)^2 + \frac{(1 - \theta)}{2} \left( \frac{Q_{i+1}^n}{A_{i+1}^{n+1}} + \frac{Q_i^n}{A_i^n} \right)^2 \right] \\
(9):
\]
\[ B' = B'_{\text{old}} + \theta \frac{Q_{i+1}^n}{A_{i+1}^{n+1}} \left[ \frac{\theta}{\Delta X} (\alpha_{i+1}^{n+1} - \alpha_i^n) + \frac{1 - \theta}{\Delta X} (\alpha_{i+1}^{n+1} - \alpha_i^n) \right] \]

\[ C' = C'_{\text{old}} \]
\[
- \frac{1}{2} \left( \frac{\partial \alpha}{\partial y} \right) + \left( \frac{Q_{i+1}^n + Q_i^n}{A_{i+1}^n + A_i^n} \right) + (1 - \theta) \left( \frac{Q_{i+1}^n}{A_{i+1}^n} + \frac{Q_i^n}{A_i^n} \right) \\
\left[ \frac{\theta}{\Delta X} (Q_{i+1}^n - Q_i^n) + \frac{1 - \theta}{\Delta X} (Q_{i+1}^n - Q_i^n) \right] \\
\frac{\theta}{4} \left( \frac{Q_{i+1}^n + Q_i^n}{A_{i+1}^n + A_i^n} \right)^2 + \frac{(1 - \theta)}{4} \left( \frac{Q_{i+1}^n}{A_{i+1}^n} + \frac{Q_i^n}{A_i^n} \right)^2 \\
\left[ \frac{\theta}{\Delta X} (A_{i+1}^{n+1} - A_i^n) + \frac{1 - \theta}{\Delta X} (A_{i+1}^{n+1} - A_i^n) \right] \\
\frac{\theta}{2} \left( \frac{Q_{i+1}^n}{A_{i+1}^{n+1}} \right)^2 B_{i+1}^{n+1} \left[ \frac{\theta}{\Delta X} (\alpha_{i+1}^{n+1} - \alpha_i^n) + \frac{1 - \theta}{\Delta X} (\alpha_{i+1}^{n+1} - \alpha_i^n) \right] \\
+ \frac{\theta}{\Delta X} \left( \frac{\partial \alpha}{\partial y} \right) \left[ \frac{\theta}{2} \left( \frac{Q_{i+1}^n}{A_{i+1}^{n+1}} + \frac{Q_i^n}{A_i^{n+1}} \right)^2 + \frac{(1 - \theta)}{2} \left( \frac{Q_{i+1}^n}{A_{i+1}^{n+1}} + \frac{Q_i^n}{A_i^n} \right)^2 \right] \\
(11):
\]
\[ (12): \quad D' = D'_{\text{old}} - \theta \frac{Q_i^{n+1}}{A_i^{n+1}} \left[ \frac{\theta}{\Delta X} (\alpha_{i+1}^{n+1} - \alpha_i^{n+1}) + \frac{1-\theta}{\Delta X} (\alpha_{i+1}^n - \alpha_i^n) \right] \]

\[ G' = G'_{\text{old}} - \left[ \frac{\theta}{\Delta X} (\alpha_{i+1}^{n+1} - \alpha_i^{n+1}) + \frac{1-\theta}{\Delta X} (\alpha_{i+1}^n - \alpha_i^n) \right] \]

\[ (13): \quad \frac{\theta}{2} \left( \frac{(Q_i^{n+1})^2}{A_i^{n+1}} + \frac{(Q_i^n)^2}{A_i^n} \right) + \frac{1-\theta}{2} \left( \frac{(Q_i^{n+1})^2}{A_i^{n+1}} + \frac{(Q_i^n)^2}{A_i^n} \right) \]

**III.3 Subroutine SECPRO.FOR**

Subroutine SECPRO.FOR was modified consistently with the changes in subroutines SEXION.FOR and COEFF.FOR. The major change is computation of the \( \alpha \) coefficient. Recall that CHARIMA has always included the possibility of specifying a constant, non-standard value of \( \alpha \) for any cross section (in POINTS.FOR, record 11), primarily to allow suppression of the kinetic-energy term in or near supercritical flow conditions.

If the value of coefficient \( \alpha \) read in POINTS.FOR (ALPHA(I,L) in record 11), is the same as the standard imposed value ALIMP (record 6), this is taken as a "signal" that the user does not intend to manually modify the global value of \( \alpha \) for the section, and therefore that the new automatic compound-section procedure should be used. As a consequence, ALPHAS(I,L) (the current value of \( \alpha \) at the section I,L) is read from the SEGEOM(I) "table" of geometric properties of cross-sections. (Note, that if a value of zero, or a blank space, is assigned to ALPHA in record 11, it is automatically loaded with the standard value of ALIMP). If ALPHA(I,L) differs from ALIMP then ALPHAS(I,L)=ALPHA(I,L) (i.e. the current value of \( \alpha \) is set to the user-assigned value for the section). Note here that for a non-compound section, a constant value of unity was assigned to the \( \alpha \) array, so that all sections are treated alike in this subroutine.

**III.4 INPUT-DATA MODIFICATIONS**

In case of a compound cross-section (which is signalled by ISEC=2 in record 16 read in SEXION.FOR) the raw cross-sectional geometric data for the record 17 are arranged differently than for the compact sections (ISEC=0 or ISEC=1) of the previous version of the code. Two pairs of three values (distance and bed level for each data point, and relative roughness for the segment following the first of the two adjacent points) are read for each record, except, possibly, for the last record when only one pair can be read (no segment follows the last point). If the value of the relative roughness (Strickler roughness coefficient, or Darcy-Weisbach friction factor) is omitted or set to zero (or less than zero), it is automatically changed to unity. Therefore, when frictionless flow is desired, a very small non-negative and non-zero value of the roughness coefficient should be specified.
Appendix L

RADIONUCLIDE FATE AND TRANSPORT

By Lj. Savic, I. Park, and F.M. Holly, Jr.

January 1994

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I. INTRODUCTION AND PURPOSE

The implementation of suspended-sediment capability in CHARIMA (described in Appendix J) of this report) made it possible to envisage simulation of the advective-diffusive transport of any water-quality constituent with little additional modification to the code. The first such modification was for the transport of heat, for which a new "sediment class" more properly called a "constituent" was defined and signaled using a special "sediment entrainment" code of 11 on type 8 records. The appropriate surface-heat-exchange source-term relations were coded for use with this constituent.

The next constituent envisaged was a radioactive contaminant, in response to the modelling needs of the Tennessee Valley Authority's Watts Bar reservoir project. Treatment of a radioactive constituent, referred to subsequently as a "radionuclide" in this report, is considerably more complicated than the treatment of heat or other non-reactive constituent. This is primarily because a radionuclide is transported in multiple modes in the water-sediment system. The dissolved fraction in the water column is transported as any other dissolved constituent, with radioactive decay. But it also adsorbs on, and desorbs from, sediment particles, both those in suspension and those on the bed, and selectively by size class of sediment. Therefore a single radionuclide constituent must be represented as a multitude of constituents according to the transport mode, whether it is associated with sediment particles in suspension, on the bed or in subsurface, layers, etc.

The basic advection-diffusion process for dissolved and adsorbed radionuclides is essentially the same as that invoked for heat or suspended sediment. It is the source/sink, or exchange, of radionuclide among the various modes of transport that attracts most of the attention in this generalization of CHARIMA.

Radionuclide (RC) transport in rivers is a complex phenomenon encompassing different transport media (RC dissolved in water, RC adsorbed to suspended and/or bed sediment - so-called particulate RC, RC absorbed by biota), and different exchange processes between the RC and the transport media, and within the RC itself (adsorption/desorption, decay). To these complexities is added the complexity of the sediment transport itself.

To study such a complex phenomenon one must use a reliable tool for the hydrodynamic and sediment transport predictions, since water and sediment are the vehicles by which the RC contaminant is distributed and transported. The goal of this study is to incorporate radionuclide transport capability in CHARIMA. The requirements of the model are:

1. To be able to predict the time-evolution of radionuclides (i.e. the concentration of RC) in a river reach; and

2. To be able to determine the origin of the RC contaminant in a reach (i.e. the source of the particular RC).

In section 2 some basic characteristics of RC transport in natural watercourses are discussed, then in section 3 the general conservation principles are formalized in the form of transport equations for dissolved and particulate RC contaminant. There follows a brief outline of the numerical procedures for incorporating these equations into CHARIMA (in section 4). In section 5 the performance of the model is tested for a simple channel and
the complex system of the Watts-Bar reservoir. Finally in section 6 conclusions and suggestions for the further development are given.

In this section the basic characteristics of radionuclide (RC) transport in watercourses are presented.

Radionuclides are transported and accumulated in a river reach by several media, the most important being:

1. RC dissolved in water,
2. RC adsorbed to suspended sediment,
3. RC adsorbed to bed sediment (consisting of the deposition of previously suspended sediment particles to which RC had been adsorbed),
4. RC absorbed by biota.

RC transport is usually associated with a constant change of transport media. Dissolved RC can be adsorbed to the surface of suspended-sediment and bed-sediment particles exposed to the water, thus becoming so-called particulate RC or be desorbed back into dilution, depending on the physical and chemical properties of the water, sediment, and radionuclide. Depending on the flow conditions, suspended sediment grains may settle and become bed sediment or become re-suspended, taking adsorbed particulates with them. Biota will absorb dissolved RC-s from the water and even from the bed. Therefore, the study of the radionuclide transport in natural watercourses involves transport processes (sediment transport and transport of the dissolved contaminant), adsorption/desorption processes, and even ecological processes.

Though still far from being completely understood (and mathematically described), the sediment transport problem seems to be the best studied and modeled of all the above-mentioned processes (for numerical modeling of transport processes in water see Cunge et al., 1980, and for applications in CHARMA see the main body of this report). Many mechanisms influence water-sediment adsorption/desorption problems, and the radionuclide exchange with biota is very complicated as well.

Adsorption between sediment and RC can be physical and chemical (ion-exchange is considered herein as a chemical adsorption). Physical adsorption usually occurs with coarser sediment, while chemical adsorption occurs with fine sediments (clays and fine silts). Three main groups of factors influence the adsorption/desorption processes:

1. Chemical characteristics of water, the most important being the pH factor and the concentration of the ions competing with the RC ions in the adsorption/desorption processes;

2. Physical and chemical characteristics of sediment, with particle size being important for both coarse and fine sediment, and chemical and mineralogical characteristics particularly important for clays;

3. Chemical, nuclear (and physical) characteristics of radionuclides.

The presence of more than one species of RC can significantly influence the adsorption/desorption of another RC. Also, flocculation processes introduce additional complications, as well as precipitation and re-dissolution of RC.
Radioactive decay may produce a new radioactive material (parent-daughter relation) which constitutes a separate RC contaminant; the fate and transport of this daughter constituent may or may not be taken into account, depending on its decay rate.

Some of the above mechanisms are less important than others, and can be omitted in same cases.

II. MODELING OF RADIOACTIVE CONTAMINANT TRANSPORT

The abundance of transport media, together with the variety, complexity and ambiguity of the mechanisms by which RC is transferred from one media to another, make radionuclide transport significantly more complicated to model than conservative-contaminant transport. In addition, further complications arise if more than one species of RC is present in the system (which is a fairly common case); also, the so-called parent-daughter relations (when the product of the decay of one RC is another RC of significantly long half-life), if present, can contribute significantly to the modeling complexity.

Transport equations for the different "phases" of a radionuclide are proposed here. The equations are based on the assumption of one-dimensional flow (see the main body of this report and Cunge et al. 1980 for the details); additional assumptions, regarding the transport of RC, are discussed where appropriate. The relationships describing the adsorption/desorption between the sediment and water, and absorption of RC by biota, are left in functional form in this section, in anticipation of becoming more specific subsequently. Some currently used expressions (Onishi et al., 1984) are suggested, but are not necessarily definitive or exclusive. All equations are based on the conservation principles for a stationary control volume.

The total RC transport is divided into six "phases":

1. Dissolved RC (radionuclide),
2. Particulate RC transported by suspended sediment,
3. Particulate RC transported in the bed active layer (mixed layer),
4. Particulate RC in the active stratum,
5. Particulate RC accumulated in other strata (layers),
6. RC exchanged with and accumulated in biota.

The basic assumptions and limitations, common to all six phases, are:

1. No Parent-Daughter relationships are included;
2. No Exchange (adsorption/desorption) between bed-layers is accounted for, except for the mixed layer (active layer);
3. Volatilization processes are considered to be insignificant herein, and hence not included;
4. Contaminant sources are represented as internal and external boundary conditions;

5. Continuous efflux/influx along a reach is not included.

II.1. Dissolved RC (radionuclide)

The rate of change of the dissolved radionuclide concentration \( R_D \) in the reach (see Fig.2) equals the net influx of the dissolved RC (advection flux), plus the diffusion of the RC, plus exchange of the RC with: a) suspended sediment, b) mixed-layer bed sediment, and c) biota (aquatic life), minus radioactive decay:

\[
\frac{\partial R_D}{\partial t} + u \frac{\partial R_D}{\partial x} = \frac{1}{A} \frac{\partial}{\partial x} \left( KA \frac{\partial R_D}{\partial x} \right) - \sum_{k=1}^{K_{\text{max}}} E_{DC} \left( R_D, R_{c,k}, \varphi_{j,k} \right) - (1-p) \frac{B_B}{A} \sum_{k=1}^{K_{\text{max}}} \beta_k E_{Db} \left( R_D, r_{b,k}, \psi_{j,k} \right) - \sum_{m=1}^{M_{\text{max}}} \frac{V_{F,m}}{A} E_{DF} \left( R_D, r_{F,m}, \eta_{j,m} \right) - \lambda R_D
\]

where:

- \( R_D \) = dissolved radionuclide concentration (volume of RC or radioactivity per unit volume of water),
- \( u \) = averaged cross-section flow velocity,
- \( A \) = cross-section flow area,
- \( K \) = longitudinal diffusion coefficient,
- \( E_{DC} \left( R_D, R_{c,k}, \varphi_{j,k} \right) \) = exchange function between water and suspended sediment,
- \( R_{c,k} \) = radionuclide concentration of particulates adsorbed on suspended sediment (volume of RC or radioactivity per unit volume of water),
- \( \varphi_{j,k} \) = parameters of suspended sediment exchange (adsorption/desorption) function, indexed by j,
- \( k \) = index of sediment size classes (k=1,...,K_{\text{max}})
- \( K_{\text{max}} \) = number of sediment size classes,
- \( p \) = porosity of the (bed) sediment,
- \( D_B \) = sediment-particle diameter (in active layer (mixed layer)),
- \( B_B \) = bottom width of the cross section,
- \( \beta_k \) = active-layer size fraction of class k,
- \( E_{Db} \) = exchange function between water and active-layer bed sediment,
- \( r_{b,k} \) = radionuclide concentration of particulates adsorbed on bed sediment (volume of RC or radioactivity per weight of sediment),
- \( \psi_{j,k} \) = parameters of bed sediment exchange (adsorption/desorption) function,
Figure 2. Control volume for radionuclide transport and accumulation.
\[ \forall_{F,m} = \text{volume of a particular biota-species per unit length of reach, indexed by } j, \]
\[ E_{DE} \left( R_D, r_{F,m}, \eta_{j,m} \right) = \text{exchange function between water and biota,} \]
\[ r_{F,m} = \text{radionuclide concentration of particulates absorbed by biota} \]
\[ \text{(volume of RC or radioactivity per weight of sediment), indexed by } j, \]
\[ \eta_{j,k} = \text{parameters of absorption function,} \]
\[ m = \text{index of biota species (m=1,...,Mmax),} \]
\[ M_{\text{max}} = \text{number of biota species considered,} \]
\[ \lambda = \text{radionuclide decay constant.} \]

For the exchange functions one can use the forms developed by Onishi et al., (1984), or some other expressions. Onishi’s relation is a linear function, based on the equilibrium of dissolved and particulate RC for a particular sediment and RC. For the exchange function between dissolved RC and RC adsorbed to suspended sediment Onishi proposes:

\[ (2): E_{DC} \left( R_D, c_{,k}, \Phi_{j,k} \right) = K_k \left( K_{D,k} \cdot c_{,k} - R_D \right) \]

where:
\[ K_k = \text{transfer rate of adsorption/desorption with } k\text{-th class sediment particle in motion,} \]
\[ K_{D,k} = \text{distribution coefficient between dissolved RC and particulate RC associated with } k\text{-th sediment in motion,} \]
\[ C_k = \text{concentration of the } k\text{-th class of suspended sediment (weight of sediment per volume of water),} \]

and for the exchange function between the dissolved and bed-sediment RC:

\[ (3): E_{Db} \left( R_D, r_{b,k}, \Psi_{j,k} \right) = K_{b,k} \left( K_{D,k} \cdot R_D - r_{b,k} \right) \]

where:
\[ K_{b,k} = \text{transfer rate of adsorption/desorption with } k\text{-th class bed-sediment particle.} \]

Transfer rate coefficients \( K_k \) and \( K_{b,k} \), and distribution coefficients \( K_{D,k} \) are obtained through calibration.

**II.2. Particulate RC transported by Suspended sediment**

The rate of change of the concentration of the particulate radionuclides adsorbed to the suspended sediment \( (R_{c,k}) \) in the reach equals the net influx of the suspended-
sediment RC, plus the diffusion of the RC, minus the exchange of suspended-sediment RC with water, plus the source from/to the bed sediment, minus radioactive decay:

\[
\frac{\partial R_{c,k}}{\partial t} + u \frac{\partial R_{c,k}}{\partial x} = \frac{1}{A} \frac{\partial}{\partial x} \left( KA \frac{\partial R_{c,k}}{\partial x} + \sum_{k=1}^{K_{\text{max}}} \phi_{j,k} \frac{R_{c,k}}{C_k} \right) + E_{DC} \left( R_{D,c,k} \cdot \phi_{j,k} \right) +
\]

where:

\[S_{\text{Er},k}\] = erosion sediment source,
\[S_{\text{Dep},k}\] = deposition sediment source.

Note that the radionuclide concentration adsorbed to suspended sediment \( R_{c,k} \) is defined in units of volume/mass of radionuclide per volume of water, while the concentration of the radionuclide adsorbed to bed sediment is expressed in units of volume/mass of radionuclide per volume/mass of the one class of bed sediment.

**II.3. Particulate RC transported in the bed-active layer**

The active layer (mixed layer) is defined herein as a layer of bed sediment in which the sediment particles move.

The rate of change of the particulate radionuclide concentration adsorbed to the bed sediment in the active layer (\( r_{b,k} \)) equals the net influx of the bed-sediment RC, minus exchange of RC with water, minus source-exchange with suspended sediment, plus the floor source from the active stratum (i.e., exchange with the first layer below the active layer), minus radioactive decay:

\[
(1-p) \frac{\partial}{\partial t} \left( T_m B_b \beta_k r_{b,k} \right) = - \frac{\partial}{\partial x} \left( Q_{s,k} r_{b,k} \right) +
\]

\[
(5): \quad + (1-p) 2 D_k B_b \beta_k E_{Db} \left( R_{D,c,k} \cdot r_{b,k} \cdot \psi_{j,k} \right) -
\]

\[
- \left( S_{\text{Er},k} r_{b,k} - S_{\text{Dep},k} \frac{R_{c,k}}{C_k} \right) + S_{f,k} \left( r_{b,k} \cdot r_{11,k} \right) -
\]

\[
- \lambda (1-p) T_m B_b \beta_k r_{b,k}
\]

\( k=1, K_{\text{max}} \)

where:

\[Q_{s,k}\] = bedload sediment discharge,
\[S_{f,k} (r_{b,k}, r_{11,k})\] = floor source between the active layer and active stratum,
\[r_{11,k}\] = radionuclide concentration of particulates adsorbed in the active stratum sediment (volume of RC or radioactivity per weight of sediment),
\[T_m\] = thickness of the bed active layer (mixed layer),
II.4. Particulate RC in the active stratum

The active stratum is defined herein as the bed layer immediately below the active layer, with which it exchanges sediment (and radioactive) material.

The rate of change of the particulate radionuclide concentration adsorbed to the active-stratum sediment $r_{i_{1,k}}$ in the reach equals the influx/efflux of the RC through the floor-source exchange with active layer, minus radioactive decay:

$$\frac{d}{dt} T_{i_{11,k}} B_{b} \beta_{i_{11,k}} r_{i_{11,k}} = -S_{f,k} (r_{b,k} \cdot r_{i_{11,k}}) - \lambda (1-p) T_{i_{11,k}} B_{b} \beta_{i_{11,k}} r_{i_{11,k}}$$

where:

$\beta_{i_{11,k}} = \text{active-stratum size fraction of class } k.$

II.5. Particulate RC accumulated in other strata (layers)

The rate of change of the particulate radionuclide concentration of the n-th layer of bed sediment $r_{i_{n,k}}$ is proportional to radioactive decay only:

$$\frac{d}{dt} T_{i_{n,k}} B_{b} \beta_{i_{n,k}} r_{i_{n,k}} = -\lambda (1-p) T_{i_{n,k}} B_{b} \beta_{i_{n,k}} r_{i_{n,k}}$$

$n=2, L_{\text{max}}$

where:

$\beta_{i_{n,k}} = \text{bed-layer size fraction of class "} k\text{"},$

$r_{i_{n,k}} = \text{radionuclide concentration of particulates adsorbed in the n-th layer of bed sediment} \ (\text{volume of RC or radioactivity per weight of sediment}),$

$L_{\text{max}} = \text{number of layers}.$

Once buried below a new active stratum (as a result of the deposition of suspended material), the old active stratum becomes a second bed layer, and exchanges no sediment with other layers thereafter; since its sediment content (and volume) become constant, Eq.7 can be solved analytically for the unknown concentration $r_{i_{n,k}}$ as:

$$r_{i_{n,k}} = r_{i_{n,k}} (t_{n0}) \exp \left\{ -\lambda (t-t_{n0}) \right\}$$

$k=1, L_{\text{max}}, \ n=2, L_{\text{max}}$

where:

$t_{n0} = \text{time when the n-th layer became "inactive" layer (at that time the second layer),}$

i.e. when its sediment properties became frozen.
II.6. RC exchanged with and accumulated in biota

The rate of change of the biota radionuclide concentration \( r_{F,m} \) in the reach results from the exchange of RC with water (dissolved RC), and from radioactive decay:

\[
\frac{\partial}{\partial t} \left( \nu_{F,m} r_{F,m} \right) = -\nu_{F,m} E_{DF} \left( R_D, r_{F,m}, \eta_{j,m} \right) - \lambda \nu_{F,m} r_{F,m} \quad m=1,M_{\max}.
\]

Biota exchange is not considered further herein.

III. IMPLEMENTATION IN CHARIMA

In this section a numerical implementation of the mathematical model (presented in section II) to CHARIMA is discussed. Also, a means of tracing the origin of radionuclide contamination is suggested.

Equations (1) and (4) for dissolved and suspended RC, being of advection-diffusion type with a source term, are solved applying the same split-operator approach as in CHARIMA. The advection-source step is solved by the Holly-Preissmann method, updating the source terms at the end of each global iteration (for details see Appendix I).

A new type of source term (in addition to those used for a conservative contaminant) required modifications of the existing routines \text{SOURCE.FOR, SULOAD.FOR, SULINK.FOR, and SULODM.FOR,} and development of new routines \text{SRNEXC.FOR, DISSBED and DISSUS} for RN-constituent advection-source equations. The diffusion step subroutine (\text{DIFFUS.FOR}) is also slightly modified.

Equations (5-7) for particulate RC adsorbed to bed sediments (active layer, active stratum, and inactive bed layers) are discretized in finite difference form, and solved within the global iteration loop in subroutines \text{RNMLAY.FOR and NODRN.FOR, just as the sediment equations are solved in CHARIMA (EXNER.FOR, NODSD.FOR and HYSOR2.FOR), taking into account the additional source terms due to exchange (adsorption/desorption) and radioactive decay.}

Boundary conditions for radionuclides must be prescribed at each nodal point where the contaminant is introduced into the river. Both dissolved concentrations and particulate concentrations adsorbed to suspended and active-layer bed sediment must be prescribed. The initial conditions must provide the initial radionuclide concentration at each point and for each transport/accumulation media (i.e. dissolved in water, and adsorbed to moving and bed sediment). Subroutines \text{RDSED.FOR and TOPLOL.FOR} are modified to facilitate efficient specification and manipulation of boundary conditions.

The main program \text{NEWMAIN.FOR} and \text{ENDSTP.FOR} are modified for manipulation with new memory allocation and subroutine calls.

From a dependent-variable point of view, treatment of RC's has rather important (and onerous) implications for the code. The new dependent variables are:

\[ R_D \quad = \text{dissolved concentration in the water-column;} \]
\[ R_C \quad = \text{adsorbed concentration on suspended-sediment particles;} \]
\( r_b \) = adsorbed concentration on bed-layer (bedload) particles;  
\( r_l \) = adsorbed concentration on bed-strata particles.

All of these variables (arrays) are associated with computational points/reaches, i.e. they are doubly dimensioned with the link number and point (or reach) number. In addition, they are all specific to a species (i.e. to a type of RC), and sediment-attached RNs are associated with sediment size-classes, and bed layers.

However, in the notation of CHARIMA, these arrays would have only three dimensions.

CSL \((i, l, j)\); \( i=\text{point}, l=\text{link}, j=\text{constituent (species)}\);

This notation reflects that in its present form, CHARIMA includes any number of constituents. By convention, the constituents that are sediment size classes \((k=1,N1)\) appear first in the list of constituents; the remaining constituents \((j)\) are taken to be non-sediment, i.e. they do not participate in the sediment-transport operations of the program.

RN-type constituents (which are by definition non-sediment constituents) are designated using the existing variable specifying the "entrainment option" for a sediment class; for RN constituents \(\text{ENTR}(J)=21\) (record 8a).

Additional record 8a indices \(\text{IDEP}(J)\) and \(\text{ICONS}(J)\) are used to designate the RN constituent's "state" (dissolved, suspended-sediment attached, etc.). For dissolved RN constituents, \(\text{IDEP}(J)=0\), and for the sediment-carried RNs \(\text{IDEP}(J)=ks\), where \(ks\) is the size class number associated with the sediment size-class carrying the constituent \(J\).

Similarly \(\text{ICONS}(J)\) is associated with the layers in which the RN-carrying sediment is buried. If \(\text{ICONS}(J)=0\) then RN class \(J\) is either dissolved, or suspended-sediment-attached. If \(\text{ICONS}(J)=1\) then the RN class \(J\) is in the mixing layer; \(\text{ICONS}(J)=2\) designates that RN is in the first layer (active stratum), and so forth up to the \(\text{ICONS}(J)=\text{LAYERs}+1\) which represents the last layer.

For example, in a model with \(N1=3\) sediment size classes, \(\text{LAYERs}=3\) bed layers, the following constituent list might be generated:
### Constituent Description

| k=1 | Sediment size class 1 - created in data set |
| k=2 | Sediment size class 2 - created in data set |
| k=3 | Sediment size class 3 - created in data set |
| j=4 | Heat (csl=temperature) - created in data set |
| j=5 | Cesium 135 (csl=RD) - created in data set |
| (6) | Cesium 135 (csl=RC, for size class 1) |
|     | IENTR =21 IDEP=0 ICONS=0 |
| (7) | Cesium 135 (csl=RC, for size class 2) |
|     | IENTR =21 IDEP=2 ICONS=0 |
| (8) | Cesium 135 (csl=RC, for size class 3) |
|     | IENTR =21 IDEP=3 ICONS=0 |
| (9) | Cesium 135 (csl=rb, for size class 1) |
| (10) | Cesium 135 (csl=rb, for size class 2) |
| (11) | Cesium 135 (csl=rb, for size class 3) |
| (12) | Cesium 135 (csl=r1, for size class 1, layer 1) |
| (13) | Cesium 135 (csl=r1, for size class 1, layer 2) |
| (14) | Cesium 135 (csl=r1, for size class 1, layer 3) |
| (15) | Cesium 135 (csl=r1, for size class 2, layer 1) |
| (16) | Cesium 135 (csl=r1, for size class 2, layer 2) |
| (17) | Cesium 135 (csl=r1, for size class 2, layer 3) |
| (18) | Cesium 135 (csl=r1, for size class 3, layer 1) |
| (19) | Cesium 135 (csl=r1, for size class 3, layer 2) |
| (20) | Cesium 135 (csl=r1, for size class 3, layer 3) |
| j=21 | Mercury (csl=RD) - created in data set |
| (22) | etc etc etc. |

**Table 1**

Here the parenthesized constituent numbers denote constituents "slaved" to the parent species (the parent species is the dissolved RN component, and the "slaved" species are sediment-sorbed components). The sorbed RN classes are created automatically or manually in the subroutine RDSED.FOR, with the rigid structure specified above.

Once this massive constituent list has been created, the existing transport mechanisms in CHARIMA are processed in the same general fashion as for the conservative constituent case. Just as a sediment constituent (i.e. a sediment size class) triggers the bedload, suspended-load, sorting, armorning, etc. operations, and just as a heat constituent (IENTR(J)=11) triggers the advection-diffusion and surface-heat exchange processes, now a new RN constituent (IENTR(J)=21, with additional designators IDEP(J) and ICONS(J)) associated with both the parent and slaved species, dictate the operations to be processed during the loop on constituents.

The dissolved and suspended-load-sorbed RN concentrations are considered as point variables since they are treated the same way as other conventional constituents (which are designated as point variables). The bed-sediment concentrations are, on the other hand, reach variables, since the radionuclide "Exner" equation, discretized along the computational reach, describes changes in a reach. It would be possible to introduce a new variable for the bed-layer-sediment point concentrations (by interpolation), however, this

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would appear to be a waste of (already substantial) memory, without any concomitant significant gain of information, since one is interested in the accumulation of RN in a reach, not at points.

The following new arrays have been created to support the RN computations:

- \( \text{SSLD}(\text{IMAX}, \text{LINKS}, \text{N1}) \) = deposition (sediment) source term in the current time step.
- \( \text{SSLDp}(\text{IMAX}, \text{LINKS}, \text{N1}) \) = deposition source term in the previous time step.
- \( \text{TMLAY}(\text{IMAX}, \text{LINKS}) \) = mixed-layer thickness in the current time step.
- \( \text{TMLAYp}(\text{IMAX}, \text{LINKS}) \) = mixed-layer thickness in the current time step.
- \( \text{RNML}(\text{NODES,NC}) \) = RN concentrations at nodes.
- \( \text{NINRNN}(\text{N2}) \) = working array to facilitate assigning RN-data in TOPOLO.

Array SS LD is stored in the space T3(i177) in NEWMAIN.FOR, array SS LDLp in T3(i178), array TMLAY in T3(i179), array TMLAYp in T3(i180), array RNML in T3(i181), and array NINRN in NT(i182).

Though treatment of radionuclides does not imply any fundamental structural change to CHARIMA, it does imply a significant increase in array storage and computational effort, depending very strongly, and nonlinearly, on the number of species and number of sediment size classes and bed layers. The additional memory requirements generated by one RC species (compared to a simple constituent) can be estimated as:

\[
4 \times N1 \times (2 + \text{LAYERS}) \times \text{IMAX} \times \text{LINKS} \quad \text{(the number 4 represents 4 arrays: CSL, CSLP, SSL and SSLP, all being of dimension IMAX*LINKS*NC). Thus for the Watts Bar model, for example, with 10 size classes, 28 links, 18 points (max) per link, and 5 subsurface layers, the supplemental memory is at least 120 kbytes per species.}
\]

Boundary-condition management is accommodated in the present structure, whereby each constituent is assigned a sequence number NINCO(NODES,NC) in the list of time-dependent data. Initial-condition loading also is accommodated by the present structure, in which each computational point/reach is assigned an initial concentration for each constituent.

**IV. DESCRIPTION OF NEW AND MODIFIED SUBROUTINES**

Subroutines newly developed for radionuclide constituents are as follows:

1. SRNEXC
2. DISSUS
3. DISBED
4. RNMLAY
5. NODRN
6. RNOUt
IV.1. SRNEXC, DISSUS and DISSBED

The subroutine SRNEXC is used for computation of the radionuclide (RN) source term and its derivative for dissolved and suspended-sediment-attached constituents (and can be easily adapted for the bed-sediment radionuclide source). It is first called from NEWMAIN.FOR to transfer dummy array addresses.

During each time step it is called as an entry SRNEXC1 from SOURCE.FOR. The execution of SRNEXC1 is conditioned in SOURCE by the type of the constituent. Only dissolved and suspended-sediment-attached RN's are treated by advection processes; hence SRNEXC1 is performed only if IENTR(J)=21 and ICONS(J)=0.

The source term of a dissolved constituent comprises of decay term, and the sum of adsorption/desorption interactions with all suspended and mixing-layer RN constituents (see sections I and II and Eq.1-4). For a suspended-sediment-carried RN constituent the source term consists of the decay term, adsorption/desorption exchange with the dissolved component, and mechanical exchange with mixing-layer material through the sediment source (erosion and deposition) terms. All these processes are modeled according to the equations of section II. The Onishi-type adsorption/desorption exchange functions between the dissolved and suspended, and dissolved and bed sediments are called via subroutines DISSUS.FOR and DISBED.FOR respectively (Onishi 1984). These subroutines can be modified if needed to accommodate a different type of exchange function.

Since the dissolved RN component (parent-class constituent) interacts with all the suspended and mixing layer RN components ("slaved" classes), it is necessary to sum the values of adsorption/desorption functions for each of the slaved classes in the parent-class source term; hence when the parent class (dissolved RN component) is encountered, its index J is remembered as JDIS, and its source term SSL(JDIS,I,L) and its derivative DSDC(JDIS,I,L) are initialized with the decay operator. For each of the subsequent suspended-sediment "slaved" RN classes, the adsorption/desorption contribution to the parent components is added to the SSL(JDIS,I,L) and DSDC(JDIS,I,L) arrays; also, the mixing layer adsorption/desorption contributions to the parent class are computed (subroutine DISBED.FOR) and added.

In order to avoid division by small values resulting in artificially high RN fluxes, the value of suspended sediment concentration for which interactions with suspended sediment RN and dissolved RN are allowed is limited to 0.00005 lb/ft3. (This value can be changed if needed.)

It is useful to recall the units adopted for the RN constituents:

| Dissolved RN                  | Radioactivity per volume of water |
| Suspended-sediment-attached RN | Radioactivity per volume of water |
| Bed-sediment-attached RN      | Radioactivity per weight of sediment |
| Suspended-sediment concentration | weight of sediment per volume of water |

IV.2. RNMLAY

Subroutine RNMLAY computes the evolution of radionuclide contaminant in the mixing layer. It is called from NEWMAIN when the sediment computation is performed (ISED1=1), when at least one RN constituent is assigned (IRNUC=1), and when RN computations are desired (IRADI=1). Temporarily the auxiliary index ISTRK is used to
condition RNMLAY performance: if ISTRK=0, perform the computation; it is used for testing purposes to detach the influence of bed computations on the dissolved constituent and sediment constituents. This ISTRK "device" should be eliminated after the testing is completed.

The procedures in RNMLAY are based on the mixing-layer RN equation Eq.5 (the Exner-type equation) and use discretization procedures similar to those employed in the EXNER1 and HYSOR2 subroutines.

All the fluxes of Eq.5 are modeled using current and previous time-step values of RN concentrations with the time-weighting coefficient THATAT. The only exception is the bed-sediment RN flux term (first right-hand-side term of Eq.5) where only previous-time-step RNs are used, to avoid the "implicit scheme" which would result if the current-time-step values were used.

The deposition flux between suspended and mixing-layer components (and for the sake of consistency, the erosion flux also) is suppressed for values of suspended sediment lower than 0.00005 lb/ft3 to avoid the possibility of excessive RN concentrations that would artificially result from the division by a small number. Similar "devices" are used in DISSUS for the adsorption/desorption functions.

Adsorption/desorption terms are treated by the same equations as in SRNEXC (for dissolved and suspended sediment components); only the discretization is different herein, since both current and previous step values are used for the RN concentrations (as in EXNER1 and HYSOR2). Detailed description of variables is given in the source code itself.

IV.3. NODRN

Subroutine NODRN computes the mixing-layer RN concentrations at nodes (array RNML(NODES,NC). This provides the mixing-layer RN fluxes (first term on the right-hand side of Eq.5) for the end reaches of the links. It is called from NEWMAIN under the same conditions as RNMLAY.

The structure of NODRN is very similar to that of the NODSD subroutine. Mixing-layer RN concentration at a nodal point is computed as a weighted average of the concentrations of the end-points of all sediment-carrying inflow links to the node (i.e. the links discharging into the node) including external inflow (boundary conditions). The weighting factor is the bed-sediment discharge (at the end of the inflow links, plus any external inflow).

The following subroutines have been modified for radionuclide constituents:

1. NEWMAIN
2. RDSED
3. TOPOLO
4. SOURCE
5. SULOAD
6. SULODM
the current organization of the code requires the sequence numbers (NINCO) to be assigned for all non-sediment constituents (even as zeros/blanks).

In order to avoid the large number of null entries ("0" entries) for NINCO, which would be required for all the bed-layer RNs, parent and slaves, the NINCO values need be furnished in records 10a only for the dissolved, suspended and mixing-layer RNs. They are then stored temporarily in an auxiliary array NINRN(J), and finally re-stored in the designated array NINCO(NODES,NC) with appropriate null entries for the layer constituents entered automatically.

IV.7. SOURCE

The order of computation of sediment-source and constituents sources is reversed from that in the previous version of the code, since the sediment (deposition/erosion) source is needed for the RN-source computations.

A call to the new RN subroutine SRNEXC.FOR (entry SRNEXC1) for computing the RN-constituent sources is added.

IV.8. LOAD

Index ICONS(J) is introduced to identify the dissolved and suspended-sediment-attached radionuclide constituents, since only they are subjected to the advection-diffusion operator.

IV.9. LDM

The test for avoiding negative concentrations is modified to accommodate RN constituents.

IV.10. UNLINK

The test for avoiding negative concentrations is modified to accommodate RN constituents.

IV.11. DIFFUS

Index ICONS(J) is introduced to identify the dissolved and suspended-sediment-attached radionuclide constituents, since only they are subjected to the advection-diffusion operator.

IV.12. SORT

Arrays TMLAY(IMAX,LINKS) and TMLAYP(IMAX,LINKS) are introduced to provide the mixed-layer thickness for the RN mixed-layer computation.

IV.13. HYSOR2

Arrays TMLAY(IMAX,LINKS) and TMLAYP(IMAX,LINKS) are introduced to provide the mixed-layer thickness for the RN mixed-layer computation.
The new previous-time-step deposition source term SSLDP is updated.

In many cases the origin of the radionuclide accumulated in a particular reach can be of considerable interest. Since most of the processes solved by CHARIMA are based on an Eulerian treatment, it would be impossible to provide a basically Lagrangian type of tracking of the contaminant without substantial alterations of the code. However, one can circumvent the problem by assigning a nominally different RC species (constituent) for each source of RC-s, i.e. to each boundary, or each bed-layer initial condition, where the RC is introduced into the system. Even if these constituents have identical properties, they can be uniquely traced back to their origin using their unique constituent numbers.
ADDITIONAL REFERENCES


