

KINSC USER'S MANUAL

KINEMATIC WAVE MODELS FOR FLOOD ROUTING
IN A STREAM CHANNEL

A. Molinas, G.W. Choi, P.Y. Julien

Center for Geosciences
Hydrologic Modeling Group

Colorado
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ACKNOWLEDGEMENTS

The LORD is my shepherd; I have everything I need. He lets me rest in fields of green grass and leads me to quiet pools of fresh water. He gives me new strength. He guides me in the right paths, as he has promised. Even if I go through the deepest darkness, I will not be afraid, LORD, for you are with me. Your shepherd's rod and staff protect me.(PSALMS 23: 1-4)

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The constructive comments and help from Jerry Richardson, Khalid Marcus, Glenn Moglen, Thomas Burke and Glen Sunada are greatly appreciated.

LIST OF SYMBOLS

Variables

A	Cross section area
$[A]$	Coefficient matrix
a	Component of coefficient matrix
$\{B\}$	Vector of intercept values
b	Top width
D_t	Dynamic contribution of lateral inflow
d_o	Steady uniform flow depth
g	Gravitational acceleration
h	Depth of flow from channel bed
L_o	Reference channel length
K	Conveyance
Q	Discharge
q	Lateral inflow
R	Hydraulic radius
r	Component of vector of intercept values
S_f	Friction slope
S_o	Slope of the channel bed
T	Wave period
t	Time
U_o	Steady uniform flow depth
V	Mean velocity
V_x	X-Component of velocity in lateral inflow
$\{x\}$	Vector of unknowns
x	Downstream distance
τ	Dimensionless wave period
y	Depth of flow from datum
Δt	Increment of time
Δx	Increment of distance
ρ	Fluid mass density
θ	Weighting factor

Superscripts

- n Current time step
- $n+1$ Next time step
- p Improved unknown value through iteration
- $p-1$ Unimproved unknown value

Subscripts

- i Current section number
- $i+1$ Next section number
- $i-1$ Previous section number

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I. INTRODUCTION

The study of water flow in steep mountain stream systems is of vital importance in the management of water resources systems and in the design of stream channel control works. In general, unsteady flood flows in stream channels can be simulated by simplified mathematical models which are derived from the governing one-dimensional nonlinear partial differential equations describing the laws of conservation of mass and momentum. These equations are simple models of extremely complex phenomena and they incorporate only the most important terms in simulating the real-life flow phenomena. Terms which are thought to be of secondary importance for modeling purposes are neglected. Theoretical analysis of even the simplified nonlinear partial differential equations is so complicated that analytic solutions can only be obtained by approximate methods.

A frequently employed approximation method for solving unsteady flow equations in natural channels is the finite difference method. In this method, the partial differential equations describing the channel flows are approximated by a set of difference equations. These equations are integrated in a step-by-step process through time. Depending on the integration scheme utilized, the finite difference methods are classified in two broad categories: explicit and implicit schemes. The explicit schemes utilize the known values of flow variables at a given time step to derive their values in the future time steps. In the implicit schemes, on the other hand, a set of simultaneous equations describing the relationship between values at a given time step and the previous time steps are solved to obtain the values of flow variables. Due to the nature of formulation, explicit schemes are easier to formulate and to implement in computer programming languages. However, in natural channels uncertain initial flow variables and stability restrictions cause modelers to choose implicit finite difference formulations rather than explicit finite difference formulations. Most implicit finite difference models can further be classified into two groups based on the type of equations solved. The first group solves the full nonlinear equations which are more rigorous in theory, but it has little advantage over the linear solutions (Barkau,1985). The second group solves the linear equations which have computational speed and stability advantage over the nonlinear equations.

In Sections II through VI of this manual, two mathematical models using kinematic wave theory are presented. The first model(KINSC1) is a nonlinear iterative model based on the Abbott-Ionescu implicit scheme. The second model(KINSC2) is a fully linear model based on the Four-Point(Preissmann) implicit scheme. In Section II, governing equations for one-dimensional unsteady water flow in channels are derived. Section III presents implicit formulations of governing equations used in the models and also gives the solution methods for the set of simultaneous equations resulting from implicit formulations. In the computer models presented in this manual, the user is allowed to enter several input parameters interactively. A step-by-step guide to the operation of the program is presented in Section IV and V of the manual. In Section VI, case studies demonstrating the application and capabilities of the model are given. Finally, Section VII presents the conclusions of the study.

II. FUNDAMENTALS OF CHANNEL FLOW

The equation describing the one-dimensional unsteady motion in a channel can be derived from Figure 2.1 that represents an instantaneous picture of the motion in an elementary reach. The instantaneous discharges through section I and II are Q and $Q + (\partial Q / \partial x) dx$, respectively.

During the time period dt , the volume accumulation within the reach is given by the expression $[Q - \{Q + (\partial Q / \partial x) dx\}] dt$. This volume must be equal to the increased storage within the element.

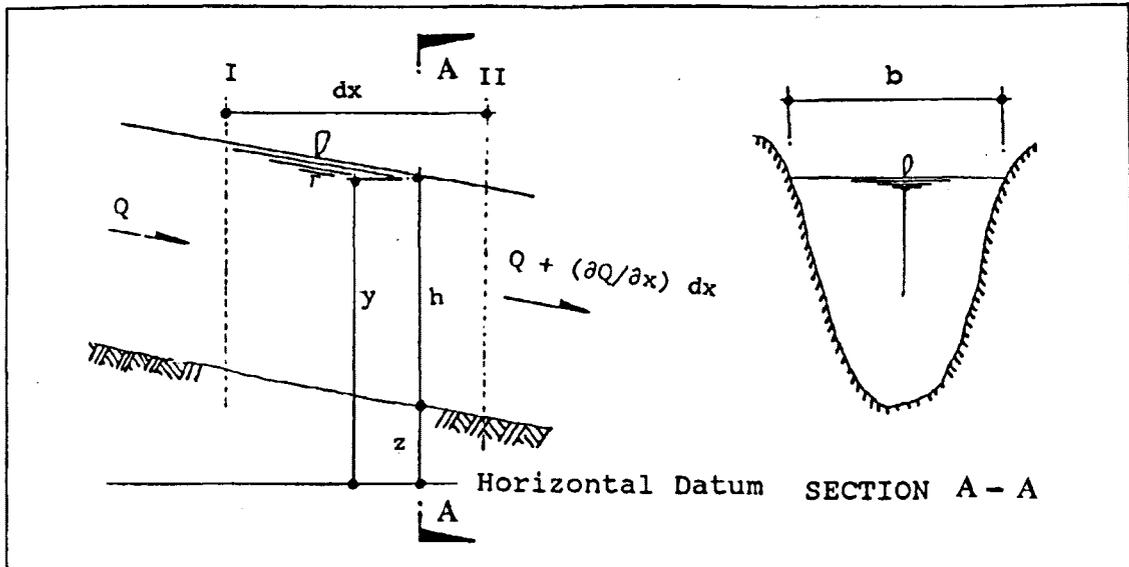


Figure 2.1 Elementary channel reach

Equating these two expressions:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q \quad [EQ. 2.1]$$

Equation [EQ. 2.1] can be reduced to the following equation when no lateral inflow is considered:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \quad [EQ. 2.2]$$

These equation [EQ. 2.1] and [EQ. 2.2] mathematically express the Law of Conservation of Mass applied to an incompressible fluid. The momentum equation can be obtained from Newton's Second Law. The only forces assumed to be acting upon the control volume of Figure 2.1 are gravitational and friction forces.

The gravitational force can be expressed as:

$$-(\rho A dx)g \frac{\partial y}{\partial x} \quad [EQ. 2.3]$$

And the friction force can be expressed as:

$$-(\rho A dx)g S_f \quad [EQ. 2.4]$$

The acceleration of the element with mass of $(\rho A dx)$ is given by $dV/dt = \partial V/\partial t + V(\partial V/\partial x)$.

From Newton's Second Law:

$$(\rho A dx) \left(\frac{\partial V}{\partial t} + V \frac{\partial V}{\partial x} \right) = -\rho A dx g \frac{\partial y}{\partial x} - \rho A dx g S_f \quad [EQ. 2.5]$$

$$\frac{\partial V}{\partial t} + V \frac{\partial V}{\partial x} + g \frac{\partial y}{\partial x} + g S_f = 0 \quad [EQ. 2.6]$$

From Figure 2.1, [EQ. 2.6] can be rewritten in terms of water depth, velocity, bed slope and friction slope using $y = z + h$ and $S_o = -\partial z/\partial x$.

$$\frac{\partial V}{\partial t} + V \frac{\partial V}{\partial x} + g \frac{\partial h}{\partial x} = g(S_o - S_f) \quad [EQ. 2.7]$$

Expressing [EQ. 2.7] in terms of Q and h (Cunge, 1980):

$$\frac{\partial Q}{\partial t} + \frac{\partial(Q^2/A)}{\partial x} + gA \frac{\partial h}{\partial x} = gA(S_o - S_f) \quad [EQ. 2.8]$$

The comparison of the order of magnitude of the internal, pressure, gravity and friction terms shows that the internal and pressure terms (the three terms on the left hand side in [EQ. 2.7] or [EQ. 2.8]) are insignificant compared with the gravity and friction terms. Their terms can be neglected in the mathematical modeling.

The resulting simplified form of the momentum equation is known as the kinematic wave equation, which is given as:

$$gA(S_o - S_f) = 0 \quad [EQ. 2.9]$$

or

$$S_f = S_o \quad [EQ. 2.10]$$

Ponce and Simons(1978) investigated the criteria for slow-rising flood waves based on a comparison of the attenuation of the analytical solution for the kinematic models.

The following definitions are used in the simplified criteria by Ponce and Simons: U_o =steady uniform flow mean velocity; d_o =steady uniform flow depth; S_o =bed slope; L_o =reference channel length; T =wave period of sinusoidal perturbation to steady equilibrium flow; τ =dimensionless wave period of the unsteady component of the motion, such that

$$L_o = \frac{d_o}{S_o} \quad [EQ. 2.11]$$

$$\tau = T \frac{U_o}{L_o} \quad [EQ. 2.12]$$

The suggested criteria by Ponce and Simons for the applicability of the kinematic wave models are $[\tau > 171]$ with 95% accuracy and $[\tau > 83]$ with 90% accuracy.

III. FINITE DIFFERENCE FORMULATIONS

The two basic differential equations (continuity and momentum equations) which are derived in the preceding section express the phenomena of the water flow in the channel. However, they furnish no direct answers as to the values of discharges and water depths which are solutions of the basic equations which are functions of time and space. That is, the theoretical analyses are so complicated that solutions can only be obtained by approximate methods. A frequently employed approximate method is the finite difference method.

In the finite difference methods, uncertain initial flow variables and stability restrictions cause modelers to choose implicit finite difference methods rather than explicit finite difference methods. The dependence of the coefficients upon the flow variables in the differential equations classifies the implicit models into two groups: the nonlinear models and the linear models. The nonlinear models are rigorous in theory but the iterations require a great deal of computational time. On the other hand, the linear models, which are developed by discretization of nonlinear coefficients, have computational speed and stability advantage over the nonlinear equations.

In this section, the finite difference formulations for a nonlinear model (KINSC1) and a linear model (KINSC2) are presented. KINSC1 is a nonlinear model based on the Abbott-Ionescu implicit scheme and uses Gauss-Seidel iterative method. On the other hand, KINSC2 is a fully linear model based on a four point implicit scheme and uses a double sweep method.

3.1 Finite Difference Formulation for KINSC1

3.1.1 Selection of the Scheme

An implicit scheme proposed by Abbott-Ionescu is selected for KINSC1. In the scheme two flow variables (Q and h) are computed at different grid points as shown in Figure 3.1. This scheme was first proposed by Abbott and Ionescu (1967) at the International Institute for Hydraulic and Environmental Engineering in Delft, the Netherlands. Because the flow variables are computed at different points, the difference approximations of the derivatives in [EQ 2.1] and [EQ 2.10] are not applied at the same cross section.

From this scheme, time derivative, space derivative and the coefficients are written as follows:

time derivative:
$$\frac{\partial h}{\partial t} = \frac{h_i^{n+1} - h_i^n}{\Delta t} \quad [EQ. 3.1]$$

space derivative:
$$\frac{\partial Q}{\partial x} = \frac{1}{2} \left(\frac{Q_{i+1}^{n+1} - Q_{i-1}^{n+1}}{2\Delta x} + \frac{Q_{i+1}^n - Q_{i-1}^n}{2\Delta x} \right) \quad [EQ. 3.2]$$

conveyance:
$$K_{i+1}^{n+1/2} = \frac{1}{4} (K_i^{n+1} + K_{i+2}^{n+1} + K_i^n + K_{i+2}^n) \quad [EQ. 3.3]$$

top width:
$$b_i^{n+1/2} = \frac{1}{2} (b_i^n + b_i^{n+1}) \quad [EQ. 3.4]$$

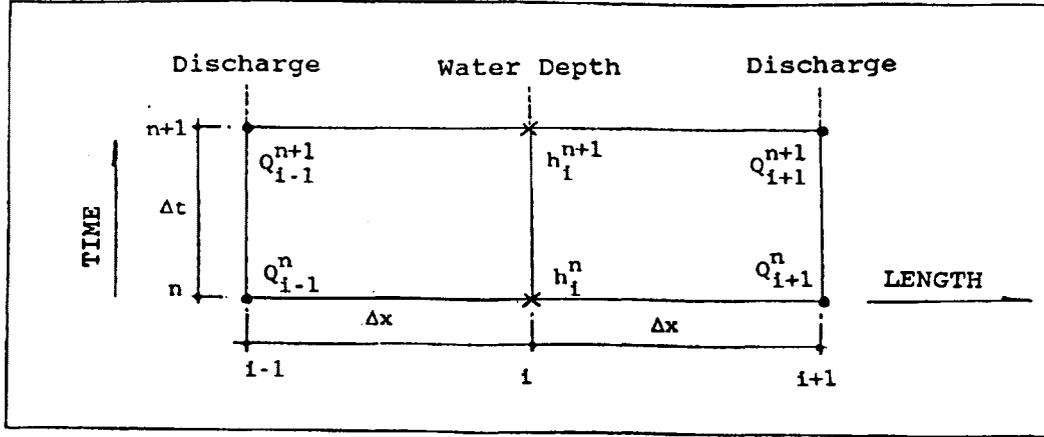


Figure 3.1 Formulation of Abbott-Ionescu Scheme

Using these derivatives and coefficients, the continuity equation [EQ. 2.1] and momentum equation [EQ. 2.10] are replaced by algebraic finite difference relationships. The continuity equation is replaced as follows:

$$b_i^{n+1/2} \frac{h_i^{n+1} - h_i^n}{\Delta t} + \frac{1}{2} \left(\frac{Q_{i+1}^{n+1} - Q_{i-1}^{n+1}}{2\Delta x} + \frac{Q_{i+1}^n - Q_{i-1}^n}{2\Delta x} \right) = \left(\frac{q_i^n + q_i^{i+1}}{2} \right) \quad [EQ. 3.5]$$

$$h_i^{n+1} = h_i^n + \frac{\Delta t}{2b_i^{n+1/2}} (q_i^n + q_i^{i+1}) - \frac{\Delta t}{4b_i^{n+1/2}\Delta x} (Q_{i+1}^{n+1} - Q_{i-1}^{n+1} + Q_{i+1}^n - Q_{i-1}^n) \quad [EQ. 3.6]$$

The momentum equation [EQ. 2.10] for kinematic flood wave approximation can be rewritten in terms of discharge and conveyance, which is defined as $K = \frac{1.486}{n} R^{2/3} A$

$$\frac{Q^2}{K^2} = S_o \quad [EQ. 3.7]$$

[EQ. 3.7] is discretized as:

$$\frac{Q_{i+1}^n Q_{i+1}^{n+1}}{(K_{i+1}^{n+1/2})^2} = S_o \quad [EQ. 3.8]$$

or

$$Q_{i+1}^{n+1} = \frac{(K_{i+1}^{n+1/2})^2}{Q_{i+1}^n} S_o \quad [EQ. 3.9]$$

In order to solve the set of equations, [EQ. 3.6] and [EQ. 3.9], an iterative method is used. In this iterative method, the equations are solved starting with known initial values of flow variables at time step $n\Delta t$ as an approximate solution. These approximations are improved iteratively until convergence criteria is satisfied. In [EQ. 3.6] and [EQ. 3.9], the superscript $(n + \frac{1}{2})$ indicates that the coefficients are evaluated between two time levels $n\Delta t$ and $(n+1)\Delta t$. The coefficient $K_{i+1}^{n+1/2}$ is interpolated as $K_{i+1}^{n+1/2} = \frac{1}{4} (K_i^{n+1} + K_{i+2}^{n+1} + K_i^n + K_{i+2}^n)$ since it is evaluated at the discharge point.

3.1.2 Selection of the Algorithm

The gauss-Seidel iterative method is selected for solving [EQ. 3.6] and [EQ. 3.9]. This method is frequently used for solving engineering problems because of the advantages of less computing time and relatively rapid convergence. The governing equations can be expressed in the matrix form $[A] \{X\} = \{B\}$.

Where, $[A]$: coefficient matrix
 $\{X\}$: vector of unknown
 $\{B\}$: vector of intercept values

$$[A]\{x\} = \{B\} = \left\{ \begin{array}{l} a_{11}x_1^{(p)} + a_{12}x_2^{(p-1)} + a_{13}x_3^{(p-1)} + \dots + a_{1n}x_n^{(p-1)} = b_1 \\ a_{21}x_1^{(p)} + a_{22}x_2^{(p)} + a_{23}x_3^{(p-1)} + \dots + a_{2n}x_n^{(p-1)} = b_2 \\ \dots \\ \dots \\ a_{n1}x_1^{(p)} + a_{n2}x_2^{(p)} + a_{n3}x_3^{(p)} + \dots + a_{nn}x_n^{(p)} = b_n \end{array} \right.$$

[EQ. 3.10]

Superscript p means an improved unknown value through iteration, and $p-1$ means an unimproved unknown value. An improved unknown value at the first section can be expressed as:

$$x_1^{(p)} = \frac{1}{a_{11}} \left[- \sum_{j=2}^n a_{1j}x_j^{(p-1)} + b_1 \right] \quad [EQ. 3.11]$$

The general expression at i section is given as:

$$x_i^{(p)} = \frac{1}{a_{ii}} \left[- \sum_{j=2}^{i-1} a_{ij}x_j^{(p)} - \sum_{j=i+1}^n a_{ij}x_j^{(p-1)} + b_i \right] \quad [EQ. 3.12]$$

$$i = 2, 3, 4, \dots, n$$

Through [EQ. 3.11] and [EQ. 3.12], the unknown variables x_i are successively improved by substitution into the right hand side. As soon as a new value is computed, it is taken into account for subsequent computations. This is a method of successive relaxation. The iteration process is continued until the absolute value of the difference between two successive iterations is smaller than the accuracy criteria.

3.1.3 Organization of the Program

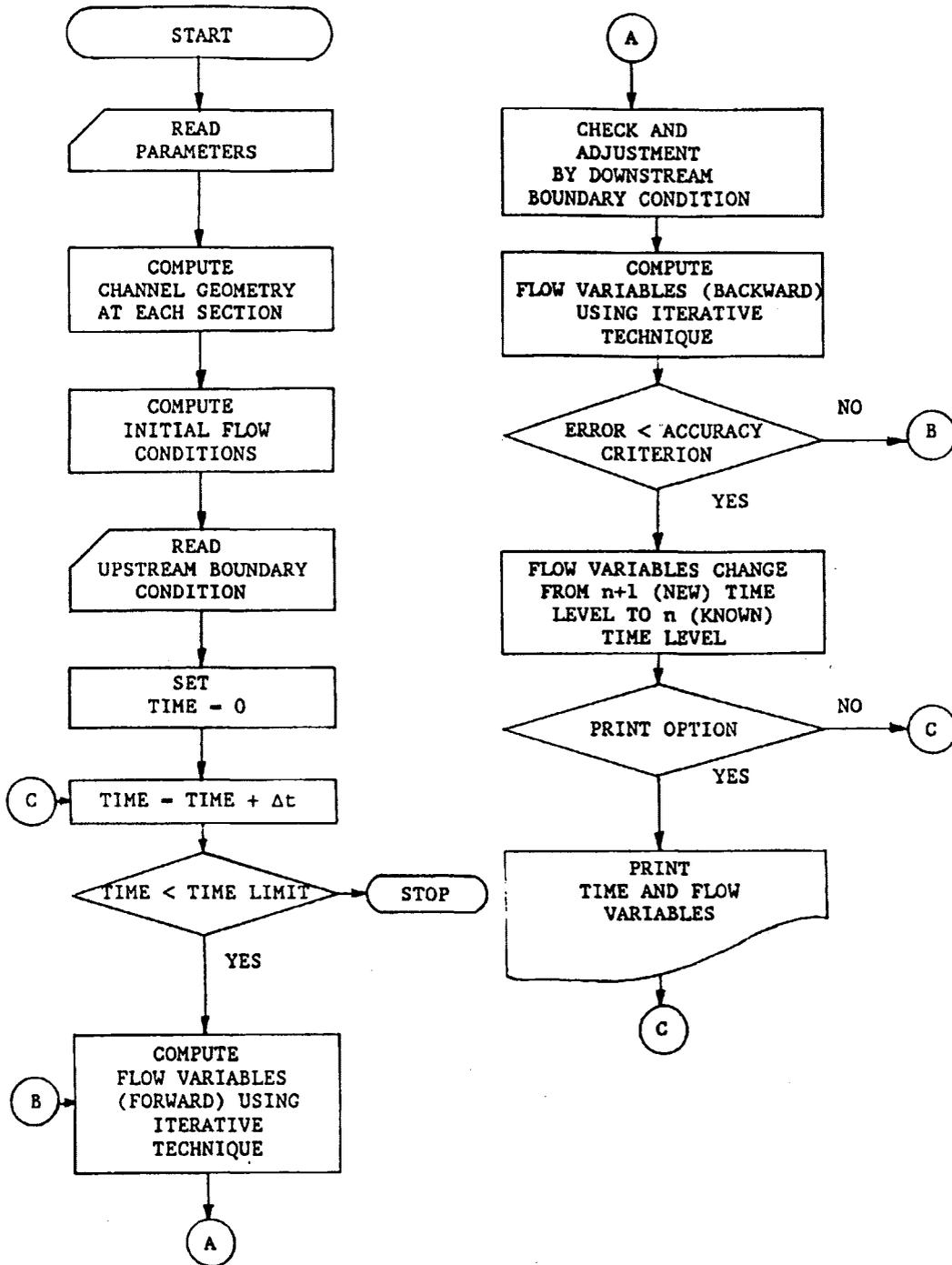
KINSC1 consists of a main program containing three major parts: determination of channel geometry and initial flow conditions, solution by the iterative method, and output of results.

The input data for determination of channel geometry and initial flow conditions are explained in the Section V (How to Use the Program).

Solution by iterative method is initiated from upstream to downstream. For the fast convergence, the values of the calculated flow variables at the downstream end are adjusted by downstream boundary condition (Manning's equation) and iteration is continued until the difference between the successive iterations is within the accuracy criteria.

The numerical values of water depths, water surface elevations, discharges, etc. are printed in the output file.

3.1.4 Flow Chart for the Program KINSC1



3.2 Finite Difference Formulation for KINSC2

3.2.1 Selection of the Scheme

A four point implicit scheme proposed by Preissmann is selected for KINSC2. This scheme was introduced by Preissmann (1961) and has been described in a number of papers (Cunge and Wegner, 1964; Amein and Fang, 1970; Liggett and Cunge, 1975; Barkau, 1985 and so on).

In this scheme two flow variables (Q and h) are computed at the same computational grid points as shown in Figure 3.2.

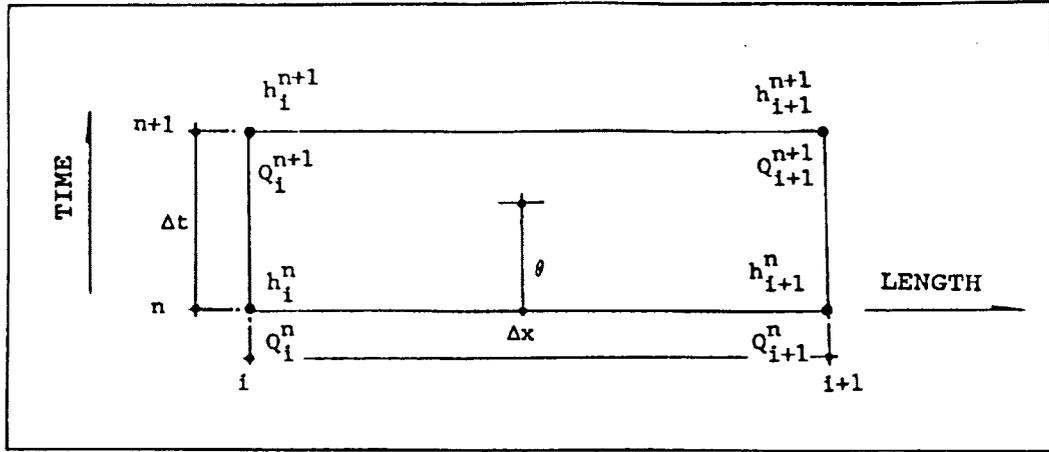


Figure 3.2 Formulation of a four point scheme

From this scheme time derivative, space derivative and the coefficient are written as follows:

$$\text{time derivative: } \frac{\partial h}{\partial t} = \frac{1}{2} \left(\frac{h_{i+1}^{n+1} - h_{i+1}^n}{\Delta t} + \frac{h_i^{n+1} - h_i^n}{\Delta t} \right) \quad [EQ. 3.13]$$

$$\text{space derivative: } \frac{\partial Q}{\partial x} = \theta \left(\frac{Q_{i+1}^{n+1} - Q_i^{n+1}}{\Delta x} \right) + (1 - \theta) \left(\frac{Q_{i+1}^n - Q_i^n}{\Delta x} \right) \quad [EQ. 3.14]$$

$$\text{top width: } b_{i+1/2}^n = b_i^n + b_{i+1}^n \quad [EQ. 3.15]$$

If $\theta = 1$ (fully implicit scheme), then the space derivative is rewritten as follows:

space derivative:
$$\frac{\partial Q}{\partial x} = \frac{Q_{i+1}^{n+1} - Q_i^{n+1}}{\Delta x} \quad [EQ. 3.16]$$

Using these derivatives and coefficient, the continuity equation [EQ. 2.1] and momentum equation [EQ. 2.10] are replaced by algebraic finite difference relationships as follows:

For the continuity equation:

$$\frac{b_{i+1/2}^n}{2\Delta t} (h_i^{n+1} - h_i^n + h_{i+1}^{n+1} - h_{i+1}^n) + \frac{1}{\Delta x} (Q_{i+1}^{n+1} - Q_i^{n+1}) = \frac{1}{2} (q_{i+1/2}^n + q_{i+1/2}^{n+1}) \quad [EQ. 3.17]$$

Multiplying [EQ. 3.17] by $(4\Delta t)$,

$$2b_{i+1/2}^n (h_i^{n+1} - h_i^n + h_{i+1}^{n+1} - h_{i+1}^n) + 4 \frac{\Delta t}{\Delta x} (Q_{i+1}^{n+1} - Q_i^{n+1}) = 2\Delta t (q_{i+1/2}^n + q_{i+1/2}^{n+1}) \quad [EQ. 3.18]$$

[EQ. 3.18] can be rewritten as a simple finite difference form by substituting Θ for $\frac{\Delta t}{\Delta x}$.

$AQ_i^{n+1} + Bh_i^{n+1} + CQ_{i+1}^{n+1} + Dh_{i+1}^{n+1} = R \quad [EQ. 3.19]$
--

The expressions of the coefficients of [EQ. 3.19] can be written as follows:

$$A = -4\Theta$$

$$B = 2b_{i+1/2}^n$$

$$C = 4\Theta$$

$$D = 2b_{i+1/2}^n$$

$$R = 2b_{i+1/2}^n h_i^n + 2b_{i+1/2}^n h_{i+1}^n + 2\Delta t (q_{i+1/2}^n + q_{i+1/2}^{n+1})$$

The friction slope, S_f , is expressed as a function of the discharge (Q) and the conveyance (K), which is defined as a function of water depth (h) using Manning's equation. This friction slope, which is accordingly a function of two flow variables, renders the momentum equation a nonlinear equation which requires iterations for the solution. To derive the linear equation from this nonlinear equation, the friction slope can be discretized using Taylor's series as follows:

$$S_{f_i}^{n+1} = S_{f_i}^n + \frac{2S_{f_i}^n}{Q_i^n} (Q_i^{n+1} - Q_i^n) + \frac{2S_{f_i}^n K_i^n}{K_i^n A_i^n} \left(\frac{5b_i^n}{3} - \frac{4R_i^n}{3} \right) (h_i^{n+1} - h_i^n) \quad [EQ. 3.20]$$

$$S_{f_{i+1}}^{n+1} = S_{f_{i+1}}^n + \frac{2S_{f_{i+1}}^n}{Q_{i+1}^n} (Q_{i+1}^{n+1} - Q_{i+1}^n) - \frac{2S_{f_{i+1}}^n K_{i+1}^n}{K_{i+1}^n A_{i+1}^n} \left(\frac{5b_{i+1}^n}{3} - \frac{4R_{i+1}^n}{3} \right) (h_{i+1}^{n+1} - h_{i+1}^n) \quad [EQ. 3.21]$$

The momentum equation can be rewritten into a simple linear equation by substituting [EQ. 3.20] and [EQ. 3.21] into [EQ. 2.9].

$$EQ_i^{n+1} + Fh_{i+1}^{n+1} + GQ_{i+1}^{n+1} + Hh_{i+1}^{n+1} = Q \quad [EQ. 3.22]$$

The expression of the coefficients of [EQ. 3.19] can be written as follows:

$$E = \frac{gA_i^n S_{f_i}^n}{Q_i^n}$$

$$F = -\frac{gA_i^n S_{f_i}^n K_i^n}{K_i^n A_i^n} \left(\frac{5b_i^n}{3} - \frac{4R_i^n}{3} \right)$$

$$G = \frac{gA_{i+1}^n S_{f_{i+1}}^n}{Q_{i+1}^n}$$

$$H = -\frac{gA_{i+1}^n S_{f_{i+1}}^n K_{i+1}^n}{K_{i+1}^n A_{i+1}^n} \left(\frac{5b_{i+1}^n}{3} - \frac{4R_{i+1}^n}{3} \right)$$

$$Q = gA_{i+1/2}^n S_o + \frac{1}{2}gA_i^n S_{f_i}^n + \frac{1}{2}gA_{i+1}^n S_{f_{i+1}}^n - \frac{gA_i^n S_{f_i}^n K_i^n}{K_i^n A_i^n} \left(\frac{5b_i^n}{3} - \frac{4R_i^n}{3} \right) h_i^n$$

$$- \frac{gA_{i+1}^n S_{f_{i+1}}^n K_{i+1}^n}{K_{i+1}^n A_{i+1}^n} \left(\frac{5b_{i+1}^n}{3} - \frac{4R_{i+1}^n}{3} \right) h_{i+1}^n$$

The procedure for the decision of the coefficients of the momentum equation is indicated in the flow chart for the subroutine KINEM.

3.2.2 Selection of the Algorithm

The double sweep method, which takes advantage of the banded matrix structure of equations to compute the solution, is selected for solving [EQ. 3.19] and [EQ. 3.22]. The major advantage of this method is the reduction of the storage required for the coefficient matrix. That is, the computer storage required for the coefficient matrix is reduced significantly from the $2N \times 2N$ matrix to the $2N \times 4$ matrix. Here, N is the number of sections required for computing flow variables.

Two equations can be written in matrix notation as $[A] \{X\} = \{B\}$,

where $[A]$: coefficient matrix
 $\{X\}$: vector of unknown
 $\{B\}$: vector of intercept values

The coefficient matrix $[A]$ can be expressed in the following form:

$$[A] = \begin{pmatrix} a_{11} & a_{12} & - & - & - & - & - & - \\ a_{21} & a_{22} & a_{23} & a_{24} & - & - & - & - \\ a_{31} & a_{32} & a_{33} & a_{34} & - & - & - & - \\ - & - & a_{41} & a_{42} & a_{43} & a_{44} & - & - \\ - & - & a_{51} & a_{52} & a_{53} & a_{54} & - & - \\ - & - & - & - & - & - & - & - \\ - & - & - & - & - & - & - & - \\ - & - & - & - & - & - & a_{2n,1} & a_{2n,2} \end{pmatrix} \quad [EQ. 3.23]$$

If the components of $[A]$ are shifted horizontally such that the relative positions of the components in any one row remain the same, $[A]$ takes the form $[A']$. Also, two equations can be written in matrix notation such as $[A'] \{X\} = \{B\}$. The coefficient matrix $[A']$ can be expressed by [EQ. 3.24].

$$[A'] = \begin{pmatrix} - & - & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \\ - & - & - & - \\ - & - & - & - \\ - & - & - & - \\ a_{2n-1,1} & a_{2n-1,2} & a_{2n-1,3} & a_{2n-1,4} \\ a_{2n,1} & a_{2n,2} & - & - \end{pmatrix} \quad [EQ. 3.24]$$

This matrix can be solved by the decision of the value of matrix coefficients and then the unknown values. The recurrent formulas for the coefficient calculation, applicable to even-numbered rows ($i = 2,4,6,\dots,2n$) are:

$$M_{i,2} = -\alpha_{i,1} \frac{M_{i-1,4}}{M_{i-1,3}} + \alpha_{i,2} \quad [EQ. 3.25a]$$

and

$$Z_i = -\alpha_{i,1} \frac{Z_{i-1}}{M_{i-1,3}} + r_i \quad [EQ. 3.25b]$$

in which $M_{1,3} = \alpha_{1,3}$, $M_{1,4} = \alpha_{1,4}$ and $Z_1 = r_1$

The recurrent formulas, applicable to the odd-numbered rows ($i = 3, 5, 7, \dots, 2n-1$) are:

$$M_{i,2} = -\alpha_{i,1} \frac{M_{i-2,4}}{M_{i-2,3}} + \alpha_{i,2} \quad [EQ. 3.26a]$$

$$M_{i,3} = -\alpha_{i-1,3} \frac{M_{i,2}}{M_{i-1,2}} + \alpha_{i,3} \quad [EQ. 3.26b]$$

$$M_{i,4} = -\alpha_{i-1,4} \frac{M_{i,2}}{M_{i-1,2}} + \alpha_{i,4} \quad [EQ. 3.26c]$$

and

$$Z_i = -M_{i,2} \frac{Z_{i-1}}{M_{i-1,2}} - \alpha_{i-1} \frac{Z_{i-2}}{M_{i-2,3}} + r_i \quad [EQ. 3.26d]$$

The computations of the coefficients proceed sequentially from $i = 2$ to $i = 2n$. The components of the unknown values, X_i , are obtained by back-substitution commencing at $i = 2n$ and proceeding sequentially to $i = 1$.

The unknown at $i = 2n$ is:

$$X_{2n} = \frac{Z_{2n}}{M_{2n,2}} \quad [EQ. 3.27]$$

and the recurrent formula for odd-numbered row is:

$$X_i = \frac{Z_i - M_{i,4} X_{i+1}}{M_{i,3}} \quad [EQ. 3.28]$$

while the formula for even-numbered row is:

$$X_i = \frac{Z_i - a'_{i,4} X_{i+2} - a'_{i,3} - a'_{i,3} X_{i+1}}{M_{i,2}} \quad [EQ. 3.29]$$

The double sweep method converges faster than iterative matrix methods and thus saves computational time. The solution procedure by this double sweep method is shown in the flow chart for the subroutine MATRIX.

3.2.3 Organization of the Program

KINSC2 consists of a main program and two subroutine programs. The main program has the same three major parts as KINSC1: determination of channel geometry and initial flow conditions, solution by the double sweep method, and output of results.

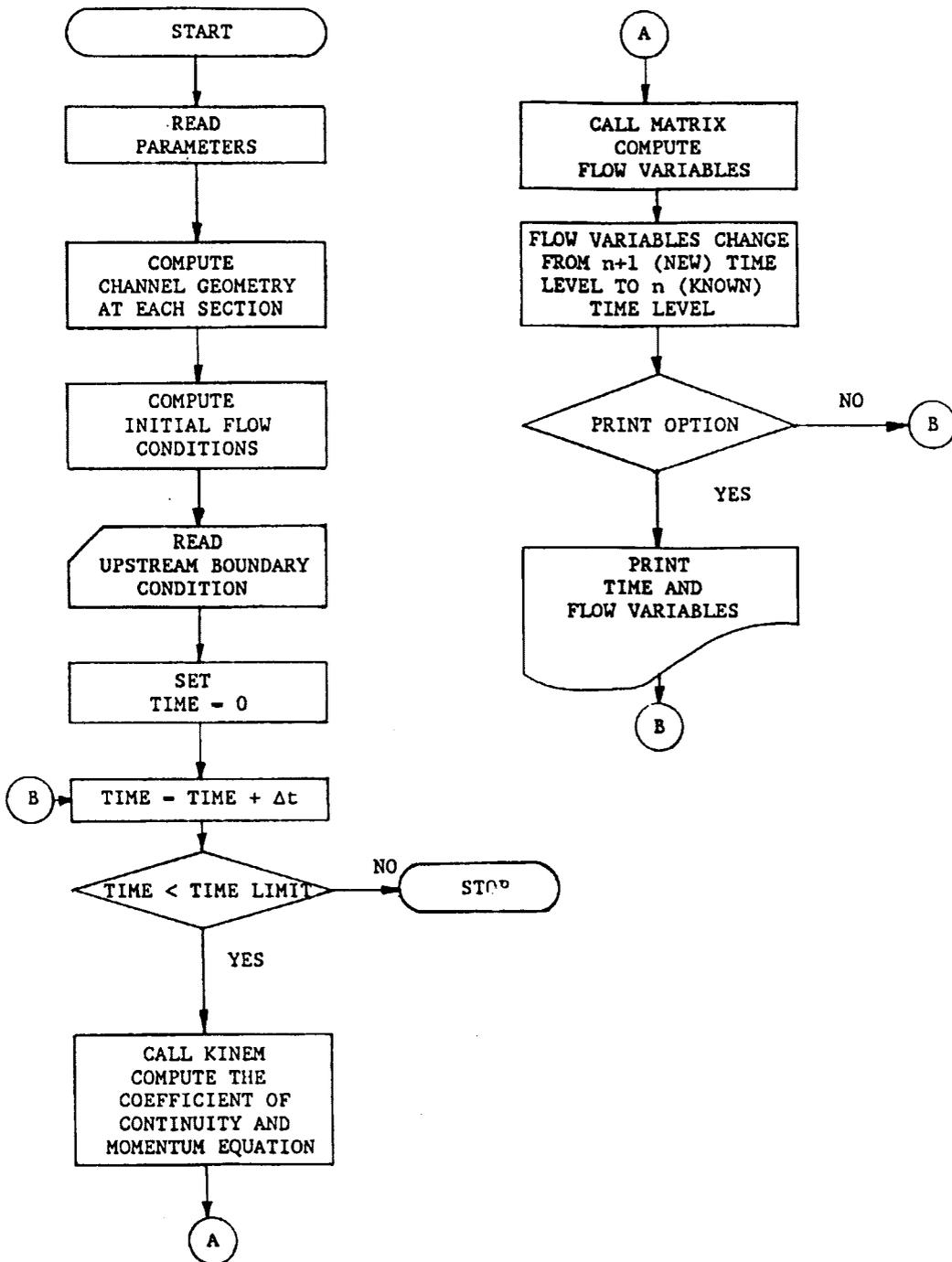
The determination of channel geometry and initial flow conditions, and output of results are identical to KINSC1.

The double sweep method consists of two sweeps: forward and backward. The forward sweep is carried on to compute the value of coefficient matrix by applying [EQ. 3.25] and [EQ. 3.26]. The first component of unknown value is obtained by using the value of the coefficient calculated by the downstream boundary condition. The rest of the components of the unknown are obtained in the backward sweep. That is, the decision of the components of the unknown proceeds from the last section to the first section.

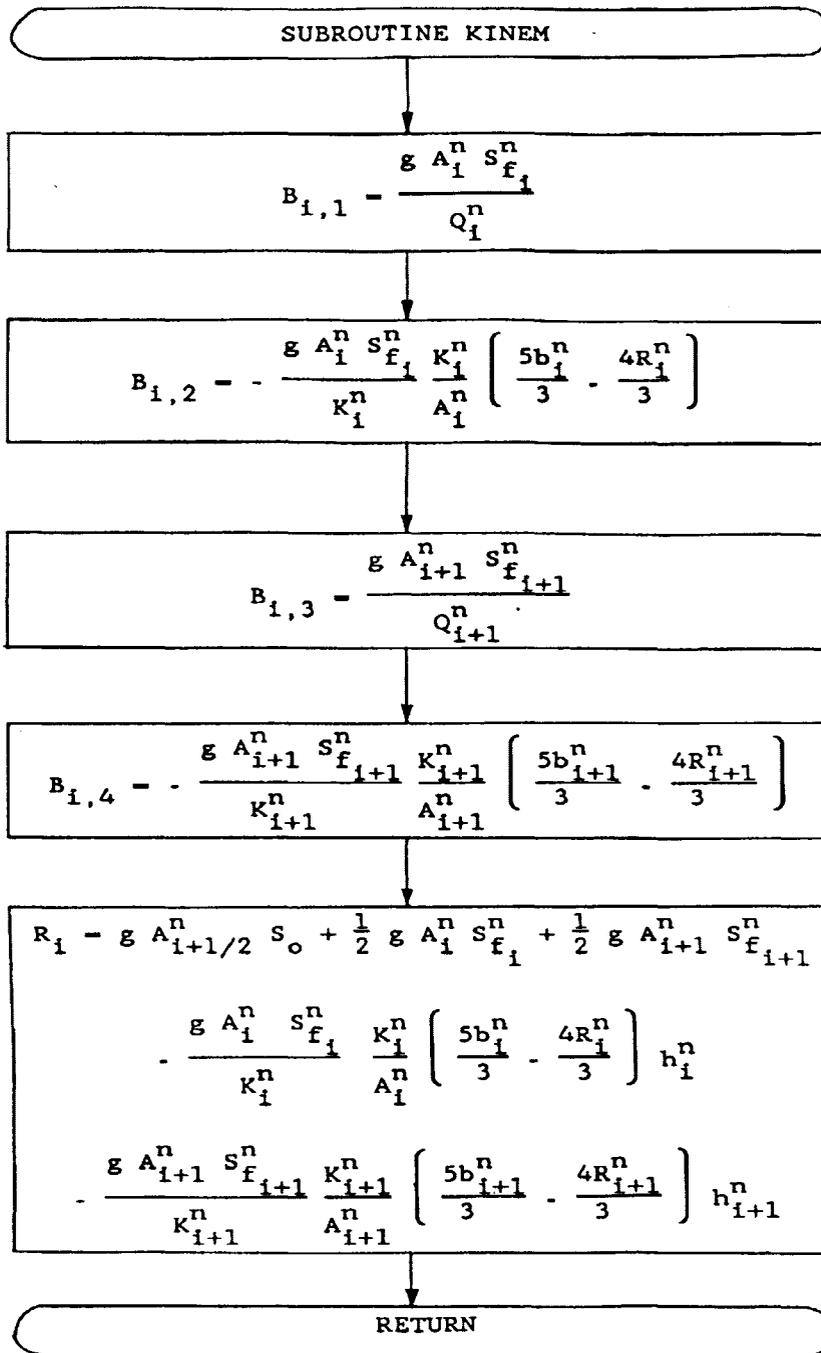
The subroutine KINEM is used to compute the values of the coefficient matrix in the forward scheme and the subroutine MATRIX is used to compute the values of the unknown in the backward scheme.

3.2.4 Flow Charts for the Program KINSC2

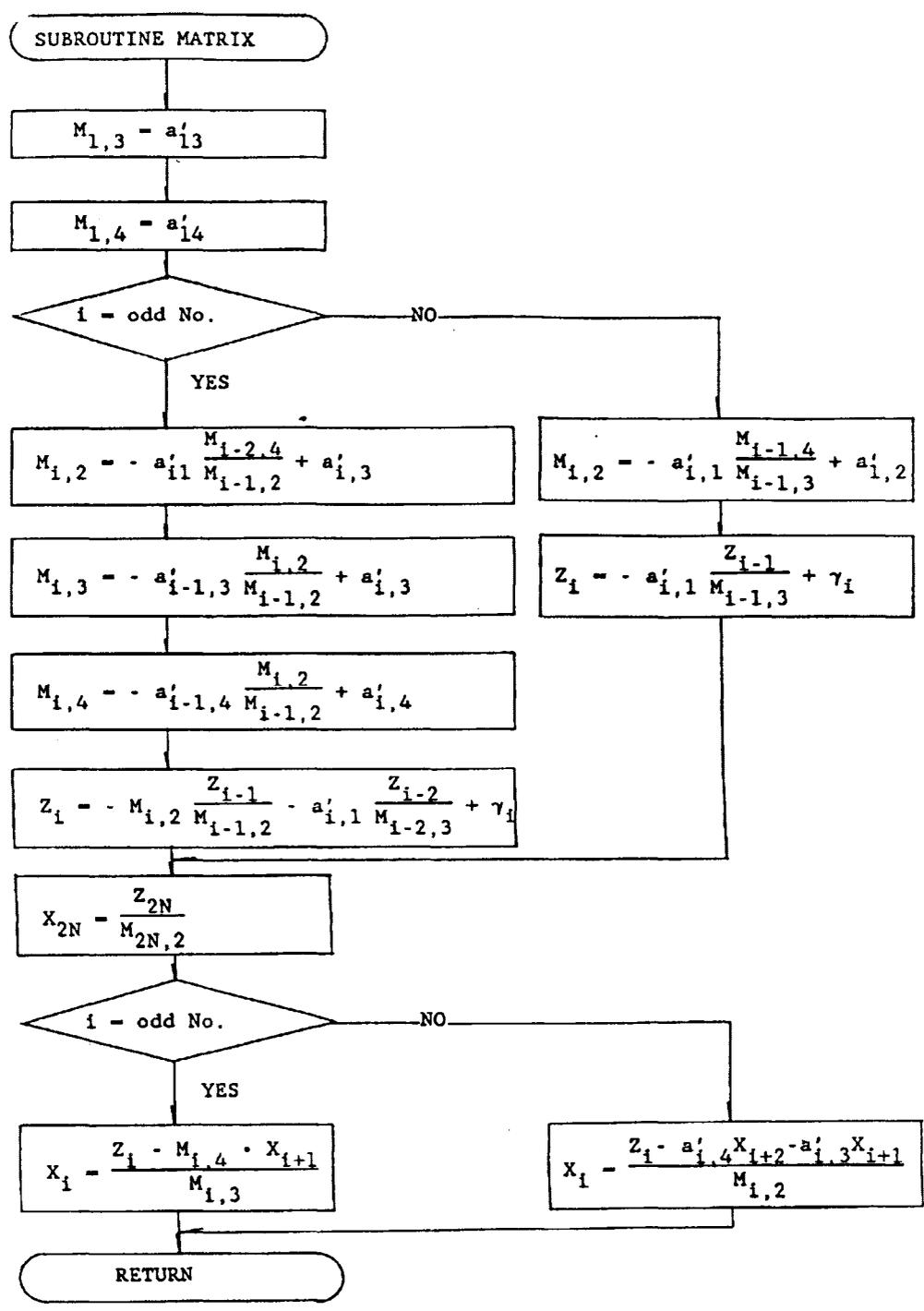
3.2.4.1 Main Flow Chart



3.2.4.2 Flow Chart for the Subroutine KINEM



3.2.4.3 Flow Chart for the Subroutine MATRIX



IV. BEFORE USING THE PROGRAM

Two kinematic wave models, KINSC1 and KINSC2, using finite difference formulations developed in the previous section were programed in Fortran language.

KINSC1 is a nonlinear model based on the Abbott-Ionescu implicit scheme and uses Gauss-Seidel iterative method. On the other hand, KINSC2 is a fully linear model based on a four point implicit scheme and uses the double sweep method.

KINSC1 consists of a main program, whereas KINSC2 consists of a main program and two subroutines which are KINEM for decision of the matrix coefficients of the momentum equation and MATRIX for the decision of the unknown variables.

To avoid unnecessarily large storage required of the PC, the dimensions of the variables are fixed on 10 segments and 100 cross sections. If the number of segments is greater than 10, then the dimensions of LENG, SLOP, TOP, B and TLEN must be increased to the number of the segments. If the number of cross sections is greater than 100, then the dimensions of Q, H, K, REACH, Z, SO, A, R, Y, QQ, and T in KINSC1 and Q, H, K, REACH, Z, SO, A, R, Y, QQ, T, SS, SF, TT, MM, and AA in KINSC2 must be increased to the number of the cross sections. Also, the dimension of ZZ, RR, and XV in KINSC2 must be increased as much as twice the number of cross sections.

To run the models, an IBM PC, PC-XT, PC-AT or compatible is needed. An Epson compatible Dot-Matrix printer, Hewlett-Packard Laser-Jet+ printer or Hewlett-Packard Laser-Jet Series II printer is also needed to print out the results.

To excute and increase the dimensions in the program, IBM PC/MS DOS(Version 2.0 or greater) is needed. To make an execution file after increasing the dimensions or debugging, a Microsoft Fortran Compiler(Version 4.0 or greater) is needed. Data input in the program is explained in the next section.

V. HOW TO USE THE PROGRAM

This section describes how to use the main program and to input the parameters in appropriate format.

The first step is to execute "KINSC1" or "KINSC2". This is accomplished by typing on your PC:

KINSC1

or

KINSC2

Now you are ready to enter the output file name and input data. Please be make sure that KINSC1 is a nonlinear model using an iterative technique and KINSC2 is a linear model using a double sweep technique.

5.1 Setting The Output File

This is done by typing the output file name at the following instruction on your PC:

Instruction : ENTER THE OUTPUT FILE NAME (DEV:FNAME.EXT)

Example : **A:KINSC1.OUT** for the case of "A" drive, file name of "KINSC1" and extension of "OUT".

5.2 Setting Number of Segments and Time Limit

This is done by typing segment numbers having different bed slope in a channel and calculation time limit at the following instruction on your PC:

Instruction : ENTER NO. OF SEGMENTS HAVING DIFF. BED SLOPE & TIME LIMIT

Example : **1,1000.** for the case of a single segment with a constant slope and time limit of 1000 seconds.

5.3 Setting The Upstream Elevation and Channel Roughness

This is done by typing the upstream channel bed elevation and channel roughness (Manning's N) at the following instruction on your PC:

Instruction : ENTER TOP ELEVATION AND ROUGHNESS OF THE CHANNEL

Example : **100.,0.03.** for the case of the upstream channel bed elevation of 100ft and channel roughness of 0.03.

5.4 Setting The Geometry of Each Segment

This is done by typing segment numbers, lengths, slopes and widths for each segment at the following instruction on your PC:

Instruction : ENTER SEGMENT NO.,LENGTH,SLOPE & WIDTH IN EACH SEGMENT

Example : **1,1000.,0.01,100.** for the case of a segment channel having a constant slope of 0.01, 1000 ft length and 100 ft width.

5.5 Setting The Magnitude of Space and Time Increment

This is done by typing the intervals of space increment and time increment at the following instruction on your PC:

Instruction : ENTER THE INTERVAL OF LENGTH AND TIME FOR CALCULATION.

Example : **100.,10.** for the case of length interval of 100 ft and time interval of 10 seconds.

5.6 Setting The Magnitude of Base Flow

5.6.1 Selection of The Base Flow Condition

This is done by selecting "1" for the base water depth or "2" for the base discharge at the following instruction on your PC: If you select "1" as the base flow condition, the computer automatically requires the base water depth(Ref. 4.6.2) and if you select "2" as the base flow condition, the computer requires the base discharge(Ref. 4.6.3).

Instruction : SELECT THE BASE FLOW OPTION (WATER DEPTH:1, DISCHARGE:2)

Example :**2** for the case that the base flow condition is discharge.

5.6.2 Input of The Base Water Depth

This is done by typing the base water depth at the following instruction on your PC:

Instruction : ENTER THE BASE WATER DEPTH OF THE CHANNEL

Example : **3.** for the case of the base water depth of 3 ft.

5.6.3 Input of The Base Discharge

This is done by typing the base discharge at the following instruction on your PC:

Instruction : ENTER THE BASE DISCHARGE OF THE CHANNEL

Example : **1000.** for the case of the base discharge of 1000 cfs.

5.7 Setting The Magnitude and Duration of The Lateral Inflow

This is done by typing the unit discharge(cfs/ft) and duration (seconds) of the lateral inflow at the following instruction on your PC:

Instruction : ENTER THE DISCHARGE FOR LATERAL INFLOW & DURATION

Example : **0.5,100.** for the case of a unit discharge of 0.5 cfs/ft and duration of 100 seconds.

5.8 Setting Upstream Boundary Condition

5.8.1 Selection of The Upstream Boundary Condition

This is done by selecting "1" for a constant discharge, "2" for a sinusoidal type discharge and "3" for a linear type discharge as an upstream boundary condition. If you select "1","2" or "3" as the upstream boundary condition, the computer automatically requires the constant discharge(Ref.4.8.2), sinusoidal type discharge(Ref.4.8.3) or linear type discharge(Ref.4.8.4), respectively.

Instruction : SELECT UPSTREAM BOUNDARY OPTION (CONS.:1,SINU.:2,LIN.:3)

Example : 1 for the case of upstream boundary condition of constant discharge.

5.8.2 Input of The Constant Discharge

This is done by typing the constant discharge at the following instruction on your PC:

Instruction : ENTER THE DISCHARGE IN UPSTREAM BOUNDARY CONDITION

Example : **1500.** for the case of the constant discharge of 1500 cfs at upstream boundary.

5.8.3 Input of The Sinusoidal Type Discharge

This is done by typing the parameters(D1, D2, D3 & TL) for the sinusoidal type discharge at the following instruction on your PC:

Instruction : ENTER PARAMETERS FOR THE SINUSOIDAL UPSTREAM BOUNDARY

Example : **0.5,1.0,20.,360000.** for the case of the base flow of 0.5 cfs/ft (D1), amplitude of 1.0 cfs/ft (D2), period of 20 hours (D3) and duration of 360000 seconds (TL).

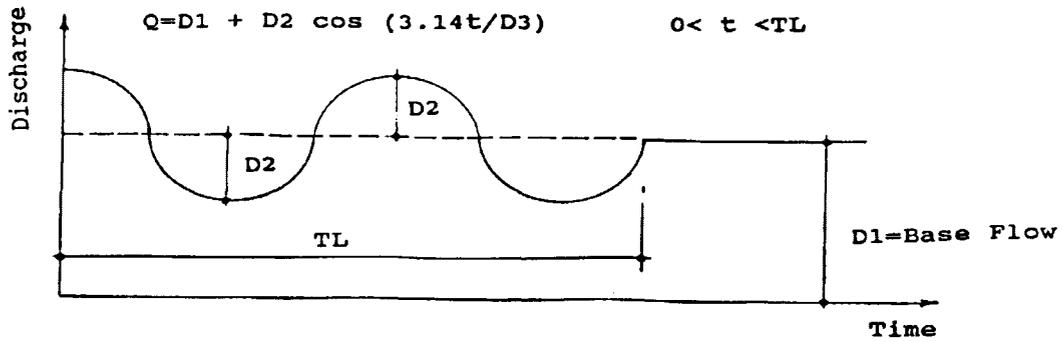


Figure 5.1 Sinusoidal type discharge

5.8.4 Input of The Linear Type Discharge

This is done by typing the parameters (T1, T2 & QM) for linear type discharge at the following instruction on your PC:

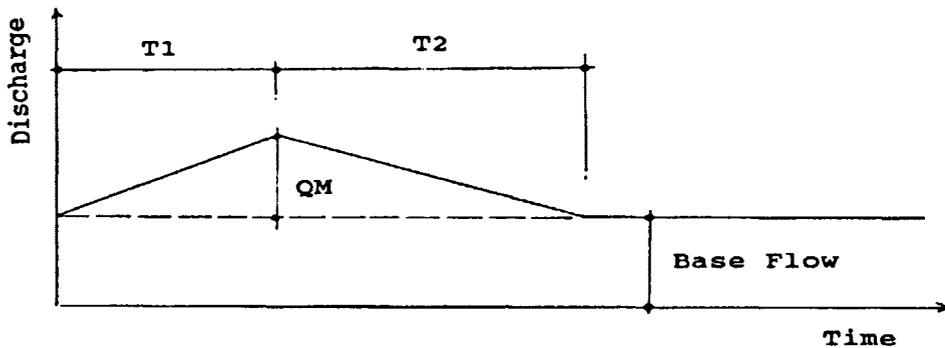


Figure 5.2 Linear type discharge

Instruction : ENTER THE PARAMETERS FOR LINEAR UPSTREAM BOUNDARY

Example : **600.,1800.,500.** for the case that the duration of increment, the duration of decrement and peak discharge are 600 seconds (T1), 1800 seconds (T2) and 500 cfs (QM), respectively.

5.9 Summary of Instructions

- (1) ENTER THE THE OUTPUT FILE NAME (DEV: FNAME.EXT)

- (2) ENTER NO. OF SEGMENT HAVING DIFF. BED SLOPE & TIME LIMIT
- (3) ENTER TOP ELEVATION AND ROUGHNESS OF THE CHANNEL
- (4) ENTER SEGMENT NO., LENGTH, SLOPE & WIDTH IN EACH SEGMENT
- (5) ENTER THE INTERVAL OF LENGTH AND TIME FOR CALCULATION
- (6) SELECT THE BASE FLOW OPTION (WATER DEPTH:1,DISCHARGE:2)
 - (A) ENTER THE BASE WATER DEPTH OF THE CHANNEL
 - (B) ENTER THE BASE DISCHARGE OF THE CHANNEL
- (7) ENTER THE DISCHARGE FOR LATERAL INFLOW & DURATION
- (8) SELECT UPSTREAM BOUNDARY OPTION (CONS.:1,SINU.:2,LIN.:3)
 - (A) ENTER THE DISCHARGE IN UPSTREAM BOUNDARY CONDITION
 - (B) ENTER PARAMETERS FOR THE SINUSOIDAL UPSTREAM BOUNDARY
 - (C) ENTER THE PARAMETERS FOR LINEAR UPSTREAM BOUNDARY

VI. CASE STUDIES

The two models, KINSC1 and KINSC2, have been applied to three case studies. The first case study was applied to show the comparison of development of the wave front with time between two models. The development of the wave front by KINSC2 propagates faster than KINSC1. This means that the convergence by KINSC2 is faster than KINSC1.

The second case study, chosen from Viessman, was applied to show the attenuation and consistence of two models through the comparison of the hydrographs between upstream and downstream.

The third case study, chosen from Crawford & Linsley, was applied to show the comparison between the observed hydrograph and the simulated hydrographs by the models. The third case study indicates that these models have relatively good agreement with observed data.

In general, KINSC2 using the double sweep method has about 40% decreased computing time compared to KINSC1 using the iterative method. The physical characteristics of each case study are presented in the following table.

Description	Case #1	Case #2	Case #3
Source	-	Viessman	Crawford & Linsley
Analysis	-	-	Observed
-----	-----	-----	-----
Length	1000 ft	20 miles	460 ft
Width	100 ft	20 ft	100 ft
Slope	0.01	0.0025	0.02
Manning's n	0.03	0.02 - 0.04	0.014
Space increment	100 ft	2 miles	46 ft
Time increment	10 sec.	10 min.	30 sec.
Time limit	100 sec.	10 hr	15 min.
Base flow	2.5 ft	800 cfs	1 cfs
Lateral inflow	-	-	.00017cfs/ft
Upstream	constant	linear	
B.C.	Q=1000 cfs	T1=4 hr T2=10 hr QM=2000 cfs	-

6.1 Case Study #1 Wave Front Propagation

We start with an example of a simple rectangular stream channel for propagation from the simple to the more complex studies. This example illustrates the propagation of the wave front with time.

A constant discharge of 1000 cfs was imposed on a impervious surface for 100 seconds with a surface roughness of 0.03 (Manning's roughness coefficient) and a slope of 0.01 ft/ft. The channel reach is 100 ft long and 100 ft wide. The time and space increment are 10 seconds and 100 ft, respectively.

Data	Length	: 1000 ft
	Width	: 100 ft
	Slope	: 0.01 ft/ft
	Manning's n	: 0.03
	Space increment	: 100 ft
	Time increment	: 10 seconds
	Time limit	: 100 seconds
	Base flow depth	: 2.5 ft
	Upstream discharge	: 1000 cfs

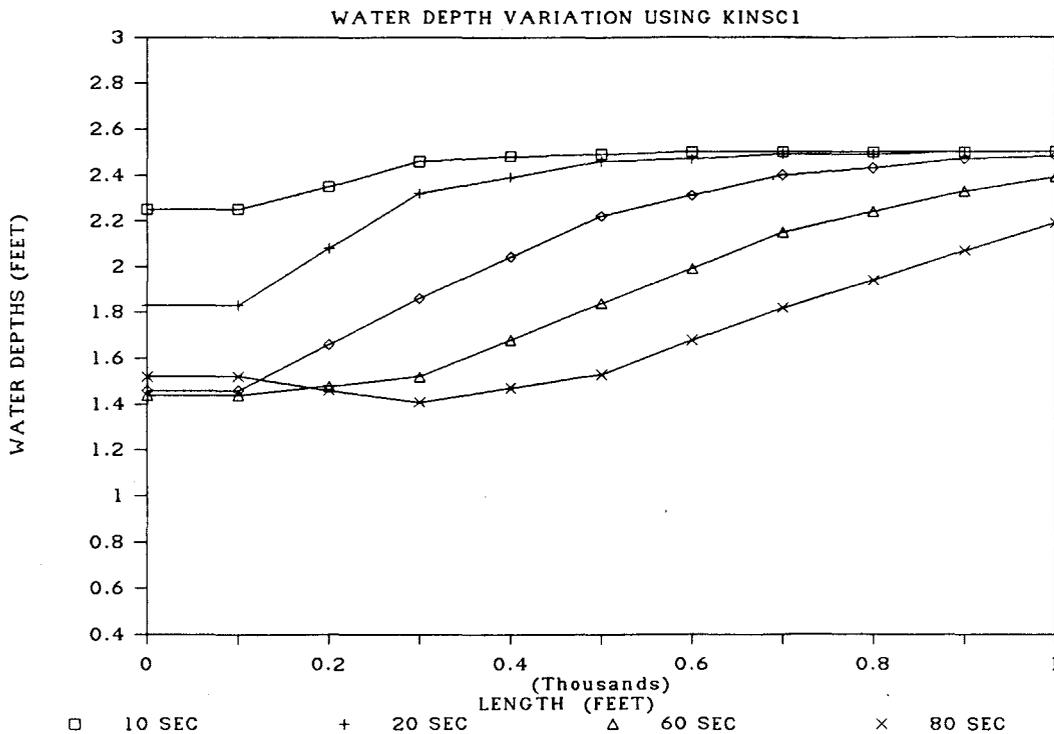


Figure 6.1 Water depth variation using KINSC1

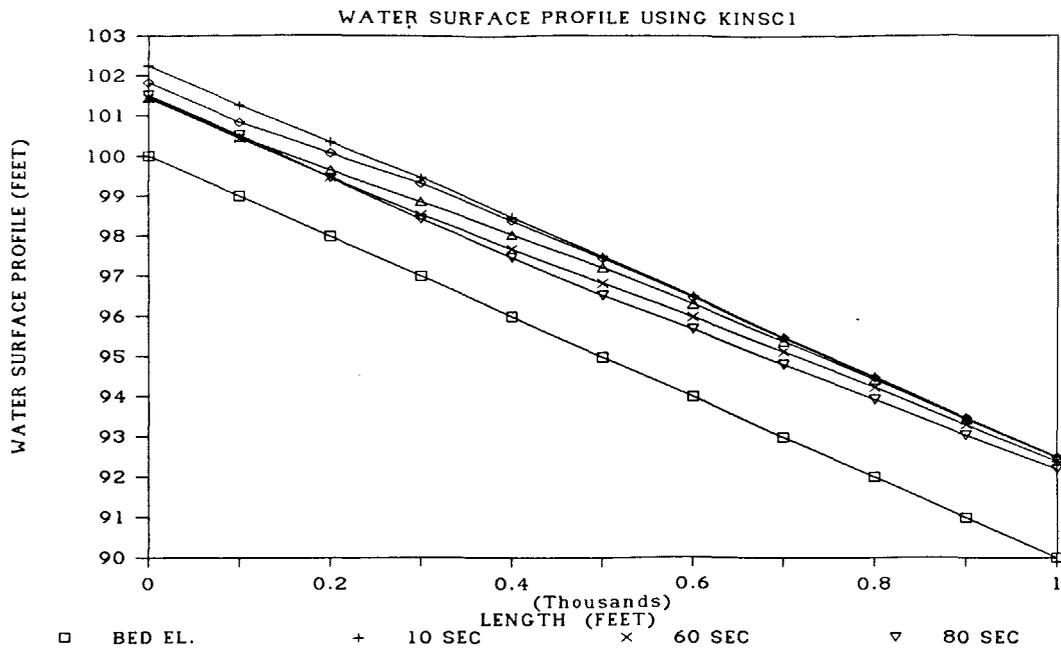


Figure 6.2 Water surface profile using KINSC1

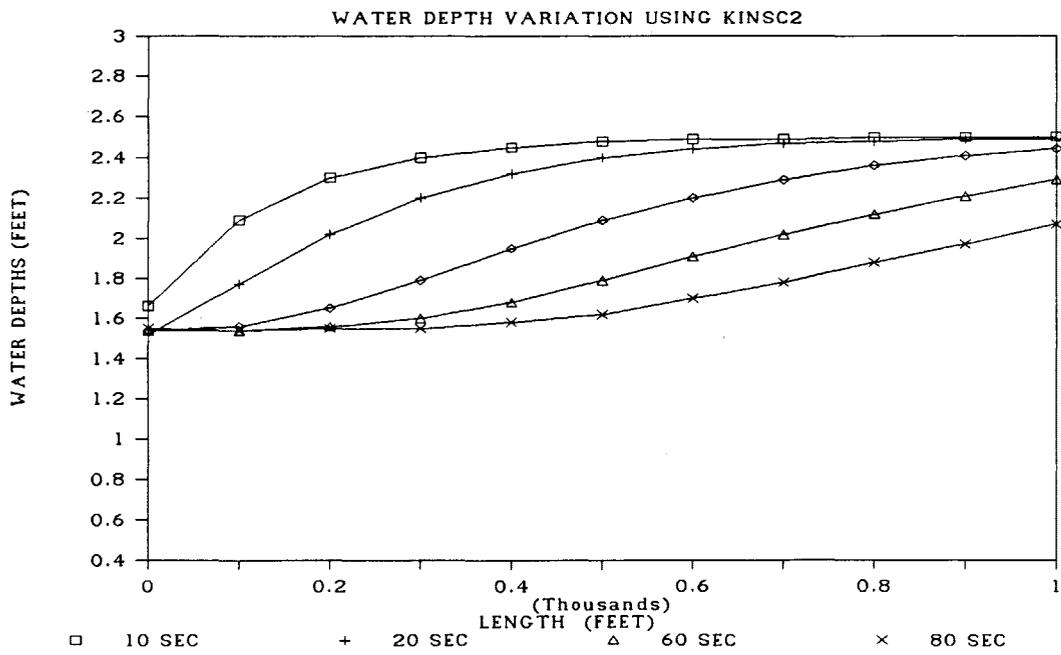


Figure 6.3 Water depth variation using KINSC2

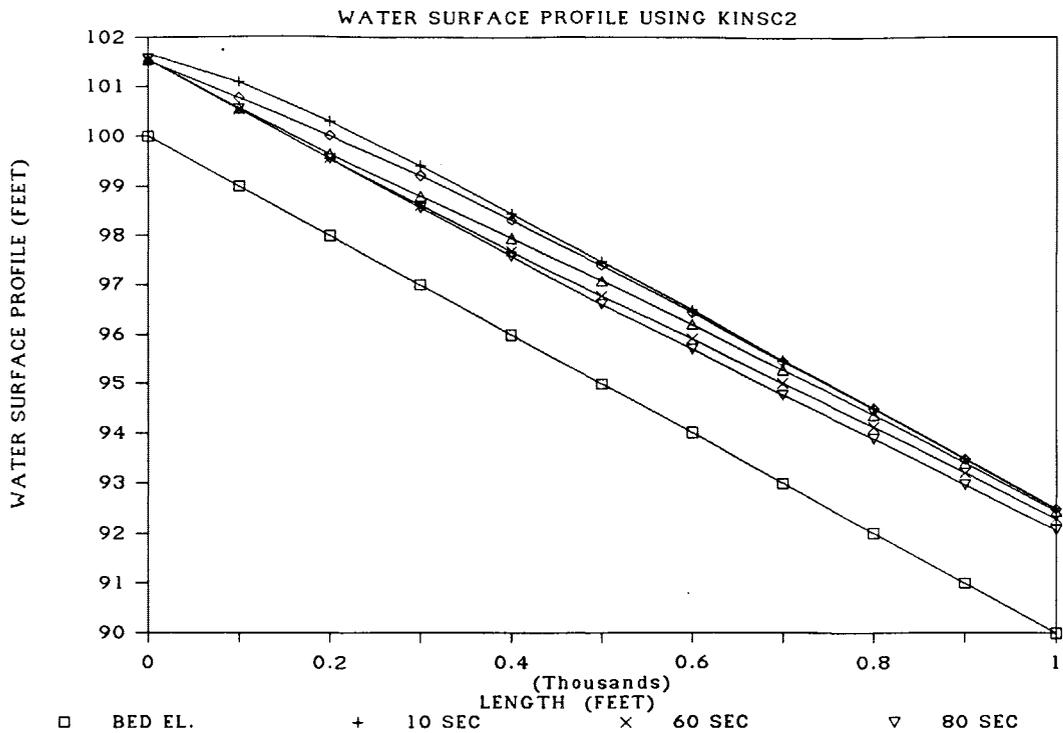


Figure 6.4 Water surface profile using KINSC2

Plots of two computed values of water depth and water surface profile with time are given in Figure 6.1-6.4. These Figures indicate different rates of convergence between two models. Convergence of KINSC2 is faster than KINSC1. Computational time is 1.98 seconds for KINSC1 and 1.26 seconds for KINSC2.

6.2 Case Study #2 Linearly Varied Flood Simulation

This case study, which is taken from Viessman(1977) and adjusted for the kinematic wave criteria, was analyzed to compare hydrographs resulting from these models. A 20 ft wide rectangular channel 20 miles long having a uniform flow discharge of 800 cfs is subjected to an increase of discharge of 2000 cfs in a period of 4 hours. This flow then decreases uniformly to the initial flow depth in an additional period of 6 hours. The channel has a bottom slope of 0.0025 ft/ft.

Data	Length	: 20 miles
	Width	: 20 ft
	Slope	: 0.0025 ft/ft
	Manning's n	: 0.04
	Space increment	: 10560 ft
	Time increment	: 10 min.
	Time limit	: 10 hr
	Base flow depth	: 800 cfs
	Peak upstream discharge	: 2000 cfs

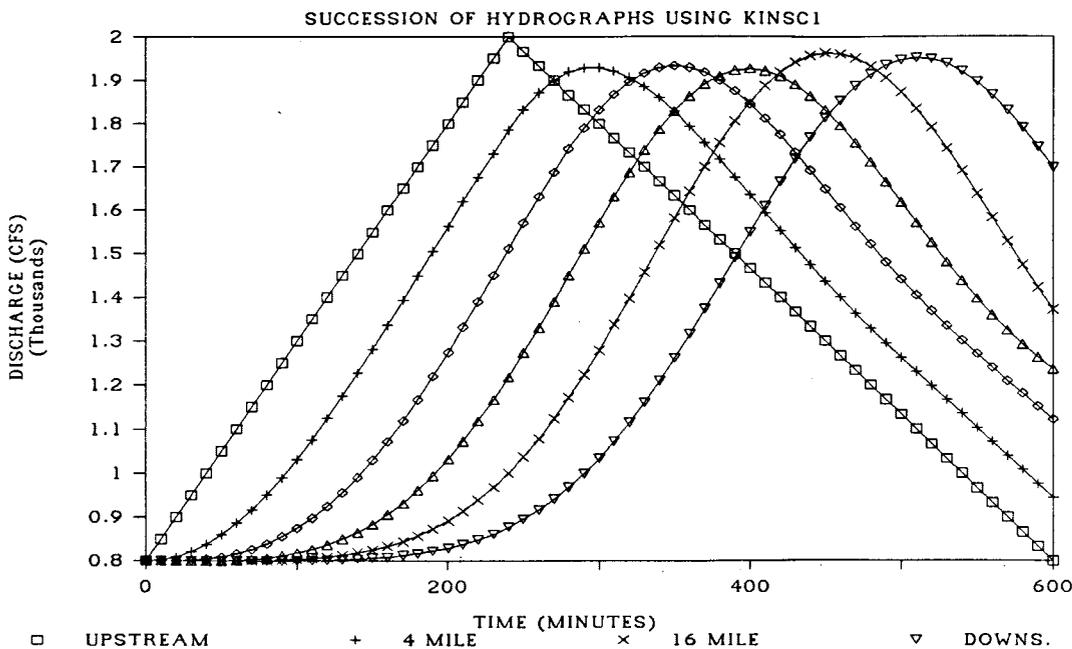


Figure 6.5 Succession of hydrographs using KINSC1

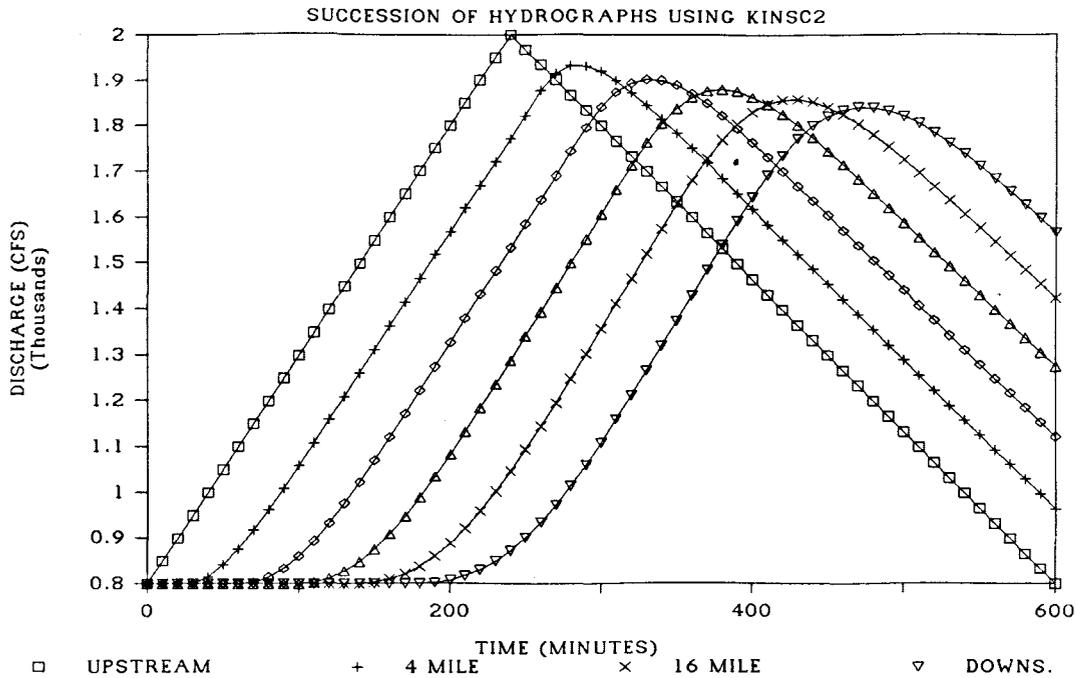


Figure 6.6 Succession of hydrographs using KINSC2

Comparison was made for a succession of simulated hydrographs from upstream to 4, 8, 12, 16 and 20 miles downstream as shown in Figure 6.5-6.6. The simulated hydrographs between two models show fair agreement within 5% difference.

In Figure 6.5, the peak discharge of the hydrograph simulated by KINSC1 shows an almost constant value within the fluctuation of about 1% difference. On the other hand, the peak discharge by KINSC2 shows a little attenuation by advancing from upstream to downstream. This is because the attenuation in the kinematic wave theory is not allowed because the kinematic wave theory does not consider dynamic effects (described by the pressure gradient and acceleration terms in the full dynamic equation). However, discretization in KINSC2 allows the part of the dynamic effects and this component of dynamic effects allows a little attenuation in the discretized model.

The rising and falling limbs of the hydrographs simulated by KINSC2 indicate a more consistent interval between the succession of hydrographs than KINSC1. In Figure 6.7-6.8, the comparison of the hydrographs for different roughnesses (Manning's n) was made at 10 miles downstream. Resulting hydrographs between two models show agreement within 5% difference. Computing time is average 12.10 seconds for KINSC1 and average 7.25 seconds for KINSC2.

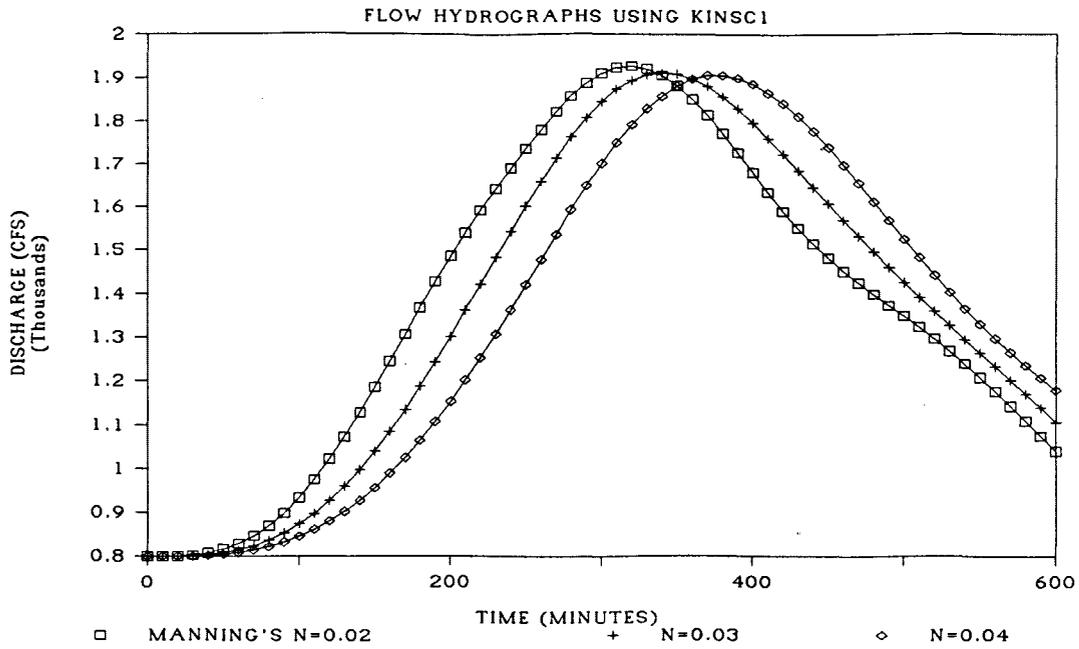


Figure 6.7 Hydrographs for different roughnesses using KINSC1

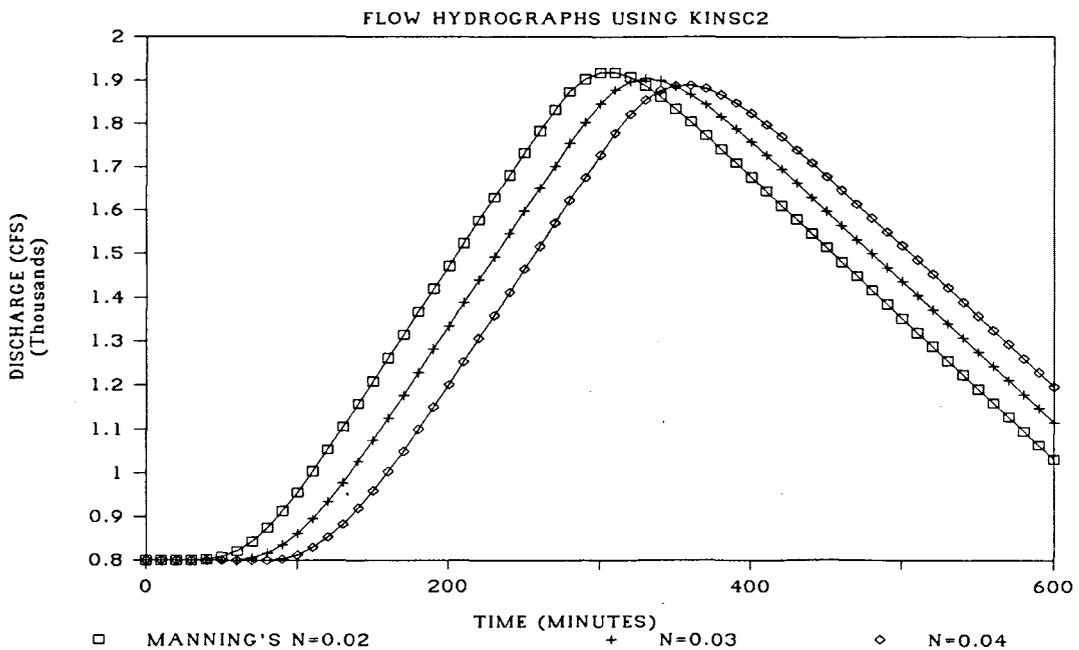


Figure 6.8 Hydrographs for different roughnesses using KINSC2

6.3 Case Study #3 Simulation by Constant Lateral Inflow

This case study from Crawford and Linsley(1966) was applied to compare the observed hydrograph and the hydrographs simulated using two models. This is the same case of channel flow over a impervious surface as perviously modeled by Crawford and Linsley. The lateral inflow of 0.00017 cfs/ft continues during 8 minutes, and the slope and Manning's n are 0.02 ft/ft and 0.014, respectively. The accompanying data is listed below. Note that this case study used a 100 ft rectangular channel, whereas Crawford and Linsley used a 1 foot wide channel.

Data	Length	: 460 ft
	Width	: 100 ft
	Slope	: 0.02 ft/ft
	Manning's n	: 0.014
	Space increment	: 46 ft
	Time increment	: 30 seconds
	Time limit	: 15 min.
	Lateral inflow	: 0.00017 cfs/ft

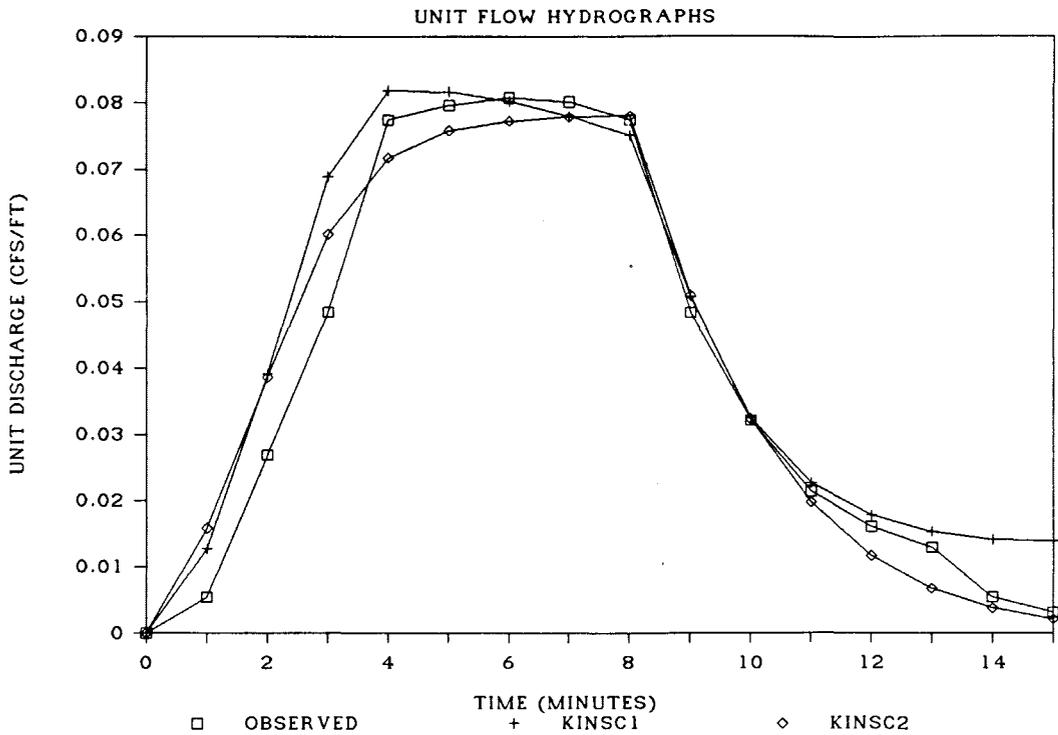


Figure 6.9 Comparison of the flow hydrographs

In the Figure 6.9, the hydrographs simulated by two models show good agreement with the observed hydrograph. The comparison between three hydrographs in the plateau and falling limb shows especially good agreement. In the rising limb, the difference between the observed discharge and discharge simulated by KINSC1 is much greater than the difference between the observed and KINSC2.

VII. CONCLUSIONS

In this manual, a nonlinear iterative model (KINSC1) based on the Abbott-Ionescu implicit scheme and a fully linear model (KINSC2) based on the four point implicit scheme are introduced.

Two governing equations, which are continuity and momentum equations, are derived in the section called "Fundamentals of Channel Flow". General finite difference descriptions, schemes, algorithms, program organizations, and flow charts for two models are given in the section called "Finite Difference Formulations". The general knowledge required to execute the program and to input data are presented in the sections called "Before Using the Program" and "How to Use the Program".

Three case studies, which are wave front propagation, linearly varied flood simulation, and simulation by constant lateral inflow, show the application of the models in the section called 'Case Studies'. The comparison of two models is made in terms of convergence, boundary conditions, presentation of phenomena in the channel, and computational time. These case studies produce the following four conclusions. First, it is concluded that the convergence of KINSC2 is faster than KINSC1, as shown in the case study #1. Second, two models require two boundary conditions (upstream and downstream). The discharge or water depth variation is applied as upstream boundary condition in both models. On the other hand, Manning's equation is applied as a downstream boundary condition. When this downstream boundary condition is applied in KINSC1, interpolation between different computational points is necessary since Q and h are not known at the same location. However, in KINSC2 interpolation is not necessary since Q and h are known at the same location. That is, the error by this interpolation exists in KINSC1 but does not exist in KINSC2. Third, case study #2 and #3 show that both models present the variation of water depth or discharge very well. Fourth, the computational time using KINSC2 is about 60% that of KINSC1.

From these comparisons, it is concluded that KINSC2 is the more applicable model than KINSC1. The model KINSC2 will be the core of a dendritic channel network.

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IX. APPENDIX I - PROGRAM LISTINGS

9.1 APPENDIX I.1 - KINSC1

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C
C                               KINSC1                               C
C
C   THIS IS A CHANNEL ROUTING PROGRAM USING KINEMATIC WAVE THEORY   C
C   AND ABBOTT-IONESCU SCHEME DEVELOPED BY GYE WOON CHOI           C
C                                                                    C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
  DIMENSION Q(2,100),H(2,100),LENG(10),SLOP(10),TOP(10)
  DIMENSION B(10),K(2,100),REACH(100),Z(100),SO(100),A(2,100)
  DIMENSION TLEN(10),R(2,100),Y(2,100),QQ(2,100),T(100)
  CHARACTER FNAME*50
  REAL LENG,MAN,K,KAVE
C
C   READ FILE NAME AND PARAMETERS
C
  G=32.2
  WRITE (*,'(A)\')
+ '... ENTER THE OUTPUT FILE NAME (DEV:FNAME.EXT) ...'
  READ (*,'(A)\') FNAME
  OPEN (1,FILE=FNAME,STATUS='UNKNOWN')
  TLEN(1)=0.
  WRITE (*,'(A)\')
+ '... ENTER NO. OF SEGMENT HAVING DIFF. BED SLOPE & TIME LIMIT ..'
  READ (*,*) L,TLIM
  WRITE (*,'(A)\')
+ '... ENTER TOP ELEVATION AND ROUGHNESS OF THE CHANNEL ...'
  READ (*,*) TOP(1),MAN
  DO 188 I=1,L
  WRITE (*,'(A)\')
+ '... ENTER SEGMENT NO.,LENGTH,SLOPE & WIDTH IN EACH SEGMENT ...'
  READ (*,*) IJ,LENG(I),SLOP(I),B(I)
  IF(I.EQ.1) GO TO 151
  IF(I.GE.2) TOP(I)=TOP(I-1)-LENG(I-1)*SLOP(I-1)
151 TLEN(I+1)=TLEN(I)+LENG(I)
  IF (I.EQ.L) TOT=TLEN(I+1)
188 CONTINUE
  WRITE (*,'(A)\')
+ '... ENTER THE INTERVAL OF LENGTH AND TIME FOR CALCULATION ...'
  READ (*,*) DELX,DELT
C
C   CALCULATION OF CHANNEL GEOMETRY (LENGTH,WIDTH,BED SLOPE AND
C   BED ELEVATION) AT EVERY POINTS.
C
  NS=TOT/DELX+1
  DELX=TOT/(NS-1)
  THETA=DELT/DELX
  J=1
  REACH(1)=0.
  Z(1)=TOP(1)
  T(1)=B(1)
  SO(1)=SLOP(1)
  DO 301 I=2,NS
351 REACH(I)=REACH(I-1)+DELX
  IF(REACH(I)-TLEN(J+1)) 305,305,350
305 Z(I)=TOP(J)-(REACH(I)-TLEN(J))*SLOP(J)
  SO(I)=SLOP(J)
  T(I)=B(J)
  GO TO 301
350 J=J+1
  GO TO 351
301 CONTINUE
  T(NS+1)=T(NS)
  SO(NS+1)=SO(NS)
C
C   INITIAL CONDITION
C

```

```

WRITE(*,'(A\)' )
+'... SELECT THE BASE FLOW OPTION (WATER DEPTH:1,DISCHARGE:2) ...'
READ(*,*)JJ
IF(JJ.EQ.1) THEN
  WRITE(*,'(A\)' )
+ '... ENTER THE BASE WATER DEPTH OF THE CHANNEL ...'
  READ(*,*) H(1,1)
  A(1,1)=T(1)*H(1,1)
  R(1,1)=A(1,1)/(T(1)+2.*H(1,1))
  Y(1,1)=H(1,1)+Z(1)
  K(1,1)=1.486/MAN*R(1,1)**(2./3.)*A(1,1)
  Q(1,1)=K(1,1)*SO(1)**0.5
ELSE
  WRITE(*,'(A\)' )
+ '... ENTER THE BASE DISCHARGE OF THE CHANNEL ...'
  READ(*,*) Q(1,1)
  H(1,1)=(MAN*Q(1,1)/(1.486*T(1)*SO(1)**0.5))**(3./5.)
  K(1,1)=Q(1,1)/SO(1)**0.5
  CC=1.486**1.5*T(1)**2.5/(MAN**1.5)
  L=0
833  L=L+1
      IF(L.GT.20) GO TO 1000
      FUN=T(1)*K(1,1)**1.5+2.*K(1,1)**1.5*H(1,1)-CC*H(1,1)**2.5
      FF1=2.*K(1,1)**1.5-2.5*CC*H(1,1)**1.5
      HC=H(1,1)
      H(1,1)=H(1,1)-FUN/FF1
      IF(ABS(H(1,1)-HC).LT.0.001) GO TO 377
      GO TO 833
377  A(1,1)=T(1)*H(1,1)
      R(1,1)=A(1,1)/(T(1)+2.*H(1,1))
      Y(1,1)=H(1,1)+Z(1)
      END IF
      DO 102 I=2,NS+1
      Q(1,I)=Q(1,1)
      H(1,I)=H(1,1)
      Y(1,I)=H(1,I)+Z(I)
      A(1,I)=A(1,1)
      R(1,I)=R(1,1)
      K(1,I)=K(1,1)
      Q(2,I)=Q(1,I)
      H(2,I)=H(1,I)
      Y(2,I)=Y(1,I)
      A(2,I)=A(1,I)
      R(2,I)=R(1,I)
      K(2,I)=K(1,I)
102  CONTINUE
      QO=Q(1,1)
      WRITE(*,'(A\)' )
+'... ENTER THE DISCHARGE FOR LATERAL INFLOW & DURATION ...'
      READ(*,*)E1,TD
C
C  UPSTREAM BOUNDARY CONDITION
C
      WRITE(*,'(A\)' )
+'... SELECT UPSTREAM BOUNDARY OPTION (CONS.:1,SINU.:2,LIN.:3) ..'
      READ(*,*) JJJ
      IF(JJJ.EQ.1) THEN
        WRITE(*,'(A\)' )
+ '... ENTER THE DISCHARGE IN UPSTREAM BOUNDARY CONDITION ...'
        READ(*,*) Q(2,1)
      ELSE
        IF(JJJ.EQ.2) THEN
          WRITE(*,'(A\)' )
+ '... ENTER PARAMETERS FOR THE SINUSOIDAL UPSTREAM BOUNDARY ..'
          READ(*,*)D1,D2,D3,TL
        ELSE
          WRITE(*,'(A\)' )
+ '... ENTER THE PARAMETERS FOR LINEAR UPSTREAM BOUNDARY ...'
          READ(*,*)T1,T2,QM
        END IF
      END IF

```

```

END IF
C
C
C
C
CALCULATION OF DISCHARGE & WATER DEPTH USING ABBOTT-IONESCU SCHEME
C
TIME=0.
CALL GETTIM(IHR,IMIN,ISEC,I100TH)
STIME=IHR*3600.+IMIN*60.+ISEC+I100TH/100.
601 TIME=TIME+DELT
IF(JJJ.EQ.1) THEN
  Q(2,1)=Q(2,1)
ELSE
  IF(JJJ.EQ.2) THEN
    Q(2,1)=(D1+D2*COS(3.14*TIME/(3600.*D3)))*T(1)
    IF(TIME.GT.TL) THEN
      Q(2,1)=Q0
    END IF
  ELSE
    IF(TIME.LE.T1) THEN
      Q(2,1)=Q0+(QM-Q0)*TIME/T1
    ELSE
      IF(TIME.GT.T1.AND.TIME.LE.T2) THEN
        Q(2,1)=QM-(TIME-T1)*(QM-Q0)/(T2-T1)
      ELSE
        Q(2,1)=Q0
      END IF
    END IF
  END IF
END IF
END IF
IF(TIME.GT.TLIM) GO TO 1000
KK=0
611 KK=KK+1
IF(KK.GT.200) GO TO 701
GO TO 602
701 WRITE(1,504)KK
504 FORMAT(5X,'ITERATION NO.',5X,15,3X,'NOT CONVERGED')
GO TO 1000
602 NSEC=NS/2
NNSEC=NSEC*2
C
C
C
LATERAL INFLOW
IF(TIME.LE.TD) THEN
  QQ2=E1*T(1)
ELSE
  QQ2=0.
END IF
QQAVE=0.
DO 111 I=2,NS,2
C
C
C
CONTINUITY EQUATION (FORWARD)
IF(I.EQ.NS) GO TO 604
C1=4.*T(I)*DELX
C2=DELT*Q(2,I+1)/C1
C3=DELT*Q(2,I-1)/C1
C4=DELT*(Q(1,I+1)-Q(1,I-1))/C1
H(2,I)=H(1,I)-C2+C3-C4+QQ2*DELT/T(I)
IF(I.EQ.2) HCHK=H(2,I)
C
C
C
MOMENTUM EQUATION (FORWARD)
A(2,I)=T(I)*H(2,I)
R(2,I)=A(2,I)/(T(I)+2.*H(2,I))
K(2,I)=1.486*R(2,I)**(2./3.)*A(2,I)/MAN
KAVE=(K(1,I)+K(1,I+2)+K(2,I)+K(2,I+2))/4.
Q(2,I+1)=(0.5*(SO(I)+SO(I+1))+QQAVE/(G*T(I)*H(2,I)))*KAVE**2/
1Q(1,I+1)
IF(I.EQ.2) QCHK=Q(2,I+1)

```

```

IF(I.EQ.NS-1) GO TO 777
111 CONTINUE
C
C CHECK AND ADJUSTMENT AT LAST SECTION (FOR EVEN LAST SECTION)
C
604 LL=0
610 LL=LL+1
CC1=0.25*THETA/T(I)
CC2=1.486*T(I)**(5./3.)*SO(I)**0.5/MAN
Q(2,I)=CC2*H(2,I)**(5./3.)/(T(I)+2.*H(2,I))**(2./3.)
Q(1,I)=CC2*H(1,I)**(5./3.)/(T(I)+2.*H(1,I))**(2./3.)
FUN1=H(2,I)-H(1,I)+CC1*CC2*H(2,I)**(5./3.)/(T(I)+2.*H(2,I))**
1(2./3.)-CC1*Q(2,I-1)+CC1*Q(1,I)-CC1*Q(1,I-1)-QQ(2,I)*DELT/T(I)
IF(ABS(FUN1).LT.0.000001) GO TO 609
FF1=1.+(5./3.*CC1*CC2*H(2,I)**(2./3.)*(T(I)+2.*H(2,I))**(2./3.)-
14.*CC1*CC2*H(2,I)**(5./3.)/(3.*(T(I)+2.*H(2,I))**(1./3.))
2/(T(I)+2.*H(2,I))**(4./3.)
HHC=H(2,I)
H(2,I)=H(2,I)-FUN1/FF1
IF(ABS(HHC-H(2,I)).LT.0.00001) GO TO 609
IF(LL.GT.90) GO TO 1000
GO TO 610
609 DO 112 I=NS,2,-2
IF(I.EQ.NS) GO TO 605
C
C CONTINUITY EQUATION (BACKWARD)
C
C1=4.*T(I)*DELX
C2=DELT*Q(2,I+1)/C1
C3=DELT*Q(2,I-1)/C1
C4=DELT*(Q(1,I+1)-Q(1,I-1))/C1
H(2,I)=H(1,I)-C2+C3-C4+QQ2*DELT/T(I)
IF(I.EQ.2) GO TO 606
C
C MOMENTUM EQUATION (BACKWARD)
C
605 A(2,I)=T(I)*H(2,I)
R(2,I)=A(2,I)/(T(I)+2.*H(2,I))
K(2,I)=1.486*R(2,I)**(2./3.)*A(2,I)/MAN
KAVE=(K(1,I)+K(1,I-2)+K(2,I)+K(2,I-2))/4.
Q(2,I-1)=(0.5*(SO(I)+SO(I-1))+QQAVE/(G*A(2,I)))*KAVE**2/Q(1,I-1)
112 CONTINUE
C
C CHECK AND ADJUSTMENT AT LAST SECTION (FOR ODD LAST SECTION)
C
777 LL=0
779 LL=LL+1
CC1=0.25*THETA/T(I+1)
CC2=1.486*T(I+1)**(5./3.)*SO(I+1)**0.5/MAN
Q(2,I+2)=CC2*H(2,I+2)**(5./3.)/(T(I+1)+2.*H(2,I+2))**(2./3.)
Q(1,I+2)=CC2*H(1,I+2)**(5./3.)/(T(I+1)+2.*H(1,I+2))**(2./3.)
FUN1=H(2,I+2)-H(1,I+2)+CC1*CC2*H(2,I+2)**(5./3.)/(T(I+1)+2.*
1H(2,I+2))**(2./3.)-CC1*Q(2,I+1)+CC1*Q(1,I+2)-CC1*Q(1,I+1)
2-QQ(2,I+1)*DELT/T(I+1)
IF(ABS(FUN1).LT.0.000001) GO TO 717
FF1=1.+(5./3.*CC1*CC2*H(2,I+2)**(2./3.)*(T(I+1)+2.*H(2,I+2))
1**(2./3.)-4.*CC1*CC2*H(2,I+2)**(5./3.)/(3.*(T(I+1)+2.*
2H(2,I+2))**(1./3.)))/(T(I+1)+2.*H(2,I+2))**(4./3.)
HHC=H(2,I+2)
H(2,I+2)=H(2,I+2)-FUN1/FF1
IF(ABS(HHC-H(2,I+2)).LT.0.00001) GO TO 717
IF(LL.GT.90) GO TO 1000
GO TO 779
717 DO 115 I=NS+1,2,-2
IF(I.EQ.NS+1) GO TO 705
C
C CONTINUITY EQUATION (BACKWARD)
C
C1=4.*T(I)*DELX
C2=DELT*Q(2,I+1)/C1

```

```

C3=DELT*Q(2,I-1)/C1
C4=DELT*(Q(1,I+1)-Q(1,I-1))/C1
H(2,I)=H(1,I)-C2+C3-C4+QQ2*DELT/T(1)
IF(I.EQ.2) GO TO 606
C
C   MOMENTUM EQUATION (BACKWARD)
C
705 A(2,I)=T(1)*H(2,I)
R(2,I)=A(2,I)/(T(1)+2.*H(2,I))
K(2,I)=1.486*R(2,I)**(2./3.)*A(2,I)/MAN
KAVE=(K(1,I)+K(1,I-2)+K(2,I)+K(2,I-2))/4.
Q(2,I-1)=(0.5*(SO(I)+SO(I-1))+QQAVE/(G*A(2,I)))*KAVE**2/Q(1,I-1)
115 CONTINUE
C
C   CHECK AND ADJUSTMENT AT UPSTREAM SECTION
C
606 CC3=0.25*THETA/T(1)
FUN2=HCHK-H(1,I)+CC3*(Q(2,I+1)-Q(2,I-1)+Q(1,I+1)-Q(1,I-1))
1-QQ(2,I)*DELT/T(1)
IF(ABS(HCHK-H(2,2)).LT.0.000001) GO TO 773
IF(ABS(FUN2).LT.0.000001) GO TO 773
GO TO 611
C
C   INTERPOLATION OF WATER DEPTH
C
773 DO 113 I=2,NS-1,2
H(2,I+1)=(H(2,I)+H(2,I+2))/2.
113 CONTINUE
H(2,1)=H(2,2)
C
C   INTERPOLATION OF DISCHARGE
C
DO 114 I=1,NS-1,2
Q(2,I+1)=(Q(2,I)+Q(2,I+2))/2.
114 CONTINUE
C
C   WRITE THE RESULTS
C
DO 550 I=1,NS+1
H(1,I)=H(2,I)
Q(1,I)=Q(2,I)
Y(1,I)=H(1,I)+Z(I)
K(1,I)=K(2,I)
550 CONTINUE
KK=TIME/10
PP=TIME/10.
IF(KK.EQ.PP) THEN
WRITE(1,888) TIME
888  FORMAT(//,10X,'TIME=',F8.1,2X,'SEC'/)
WRITE(1,333)
333  FORMAT(4X,'NO',7X,'LENGTH',8X,'BED EL.',6X,'WATER DEP',5X,
1  'ELEVATION',6X,'DISCHARGE'/)
DO 299 I=1,NS
WRITE(1,444) I,REACH(I),Z(I),H(1,I),Y(1,I),Q(1,I)
444  FORMAT(4X,I2,5X,F9.0,5X,F9.2,5X,F9.2,5X,F9.2,5X,F12.2)
299  CONTINUE
GO TO 601
ELSE
GO TO 601
END IF
1000 CALL GETTIM(IHR,IMIN,ISEC,I100TH)
EXTIME=IHR*3600.+IMIN*60.+ISEC+I100TH/100.-STIME
WRITE(1,446) EXTIME
446  FORMAT(//,20X,'EXECUTION TIME=',F9.2,2X,'SEC')
STOP
END

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9.2 APPENDIX I.2 - KINSC2

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CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C                               KINSC2                               C
C
C   THIS IS A CHANNEL ROUTING PROGRAM USING KINEMATIC WAVE THEORY C
C   AND FOUR POINT FULLY IMPLICIT SCHEME BY GYE WOON CHOI       C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
  DIMENSION LENG(10),SLOP(10),TOP(10),B(10),REACH(100),Z(100)
  DIMENSION TLEN(10),QQ(2,100),SS(100),IJ(10)
  COMMON BB(8,100),A(2,100),SF(2,100),Q(2,100),K(2,100),T(100),
1    R(2,100),TT(100),SO(100),H(2,100),Y(2,100)
  COMMON /BLOCK1/MM(5,100),AA(5,100),ZZ(200),RR(200),XV(200)
  CHARACTER FNAME*50
  REAL LENG,MAN,K,KAVE,MM

C
C   READ FILE NAME AND PARAMETERS
C
  G=32.2
  WRITE (*,'(A)\')
+ '... ENTER THE OUTPUT FILE NAME (DEV:FNAME.EXT) ...'
  READ (*,'(A)') FNAME
  OPEN (1,FILE=FNAME,STATUS='UNKNOWN')
  TLEN(1)=0.
  WRITE (*,'(A)\')
+ '... ENTER NO. OF SEGMENT HAVING DIFF. BED SLOPE & TIME LIMIT ..'
  READ (*,*) L,TLIM
  WRITE (*,'(A)\')
+ '... ENTER TOP ELEVATION AND ROUGHNESS OF THE CHANNEL ...'
  READ (*,*) TOP(1),MAN
  DO 188 I=1,L
  WRITE (*,'(A)\')
+ '... ENTER SEGMENT NO.,LENGTH,SLOPE & WIDTH IN EACH SEGMENT ...'
  READ (*,*) IJ(I),LENG(I),SLOP(I),B(I)
  IF(I.EQ.1) GO TO 151
  IF(I.GE.2) TOP(I)=TOP(I-1)-LENG(I-1)*SLOP(I-1)
151 TLEN(I+1)=TLEN(I)+LENG(I)
  IF(I.EQ.L) TOT=TLEN(I+1)
188 CONTINUE
  WRITE (*,'(A)\')
+ '... ENTER THE INTERVAL OF LENGTH AND TIME FOR CALCULATION ...'
  READ (*,*) DELX,DELT

C
C   CALCULATION OF CHANNEL GEOMETRY (LENGTH,WIDTH,BED SLOPE AND
C   BED ELEVATION) AT EVERY POINTS.
C
  N =TOT/DELX+1
  DELX=TOT/(NS-1)
  J=1
  REACH(1)=0.
  Z(1)=TOP(1)
  T(1)=B(1)
  SO(1)=SLOP(1)
  DO 301 I=2,NS
351 REACH(I)=REACH(I-1)+DELX
  IF(REACH(I)-TLEN(J+1)) 305,305,350
305 Z(I)=TOP(J)-(REACH(I)-TLEN(J))*SLOP(J)
  SO(I)=SLOP(J)
  T(I)=B(J)
  GO TO 301
350 J=J+1
  GO TO 351
301 CONTINUE

C
C   INITIAL CONDITION
C
  WRITE (*,'(A)\')

```

```

+ '... SELECT THE BASE FLOW OPTION (WATER DEPTH:1,DISCHARGE:2) ...'
READ(*,*)JJ
IF(JJ.EQ.1) THEN
  WRITE(*,'(A)\')
+ '... ENTER THE BASE WATER DEPTH OF THE CHANNEL ...'
  READ(*,*) H(1,1)
  A(1,1)=T(1)*H(1,1)
  R(1,1)=A(1,1)/(T(1)+2.*H(1,1))
  Y(1,1)=H(1,1)+Z(1)
  K(1,1)=1.486/MAN*R(1,1)**(2./3.)*A(1,1)
  Q(1,1)=K(1,1)*SO(1)**0.5
ELSE
  WRITE(*,'(A)\')
+ '... ENTER THE BASE DISCHARGE OF THE CHANNEL ...'
  READ(*,*) Q(1,1)
  H(1,1)=(MAN*Q(1,1)/(1.486*T(1)*SO(1)**0.5))**(3./5.)
  K(1,1)=Q(1,1)/SO(1)**0.5
  CC=1.486**1.5*T(1)**2.5/(MAN**1.5)
  L=0
833 L=L+1
  IF(L.GT.20) GO TO 1000
  FUN=T(1)*K(1,1)**1.5+2.*K(1,1)**1.5*H(1,1)-CC*H(1,1)**2.5
  FF1=2.*K(1,1)**1.5-2.5*CC*H(1,1)**1.5
  HC=H(1,1)
  H(1,1)=H(1,1)-FUN/FF1
  IF(ABS(H(1,1)-HC).LT.0.001) GO TO 377
  GO TO 833
377 A(1,1)=T(1)*H(1,1)
  R(1,1)=A(1,1)/(T(1)+2.*H(1,1))
  Y(1,1)=H(1,1)+Z(1)
  END IF
  SF(1,1)=Q(1,1)*ABS(Q(1,1))/K(1,1)**2
  DO 102 I=2,NS
  Q(1,I)=Q(1,1)
  H(1,I)=H(1,1)
  Y(1,I)=H(1,I)+Z(I)
  A(1,I)=A(1,1)
  R(1,I)=R(1,1)
  K(1,I)=K(1,1)
  SF(1,I)=Q(1,I)*ABS(Q(1,I))/K(1,I)**2
102 CONTINUE
  QQ=Q(1,1)
  WRITE(*,'(A)\')
+ '... ENTER THE DISCHARGE FOR LATERAL INFLOW & DURATION ...'
  READ(*,*)E1,TD
C
C
C
  UPSTREAM BOUNDARY CONDITION
  WRITE(*,'(A)\')
+ '... SELECT UPSTREAM BOUNDARY OPTION (CONS.:1,SINU.:2,LIN.:3) ..'
  READ(*,*) JJJ
  IF(JJJ.EQ.1) THEN
    WRITE(*,'(A)\')
+ '... ENTER THE DISCHARGE IN UPSTREAM BOUNDARY CONDITION ...'
    READ(*,*) Q(2,1)
  ELSE
    IF(JJJ.EQ.2) THEN
      WRITE(*,'(A)\')
+ '... ENTER PARAMETERS FOR THE SINUSOIDAL UPSTREAM BOUNDARY ..'
      READ(*,*)D1,D2,D3,TL
    ELSE
      WRITE(*,'(A)\')
+ '... ENTER THE PARAMETERS FOR LINEAR UPSTREAM BOUNDARY ...'
      READ(*,*)T1,T2,QM
    END IF
  END IF
C
C
C
  CALCULATION OF DISCHARGE & WATER DEPTH USING DOUBLE SWEEP METHOD

```

```

C      TIME=0.
      CALL GETTIM(IHR,IMIN,ISEC,I100TH)
      STIME=IHR*3600.+IMIN*60.+ISEC+I100TH/100.
601  TIME=TIME+DELT
      IF(TIME.GT.TLIM) GO TO 1000
      DO 150 I=1,NS-1
C
C      LATERAL INFLOW
C
      IF(TIME.LE.TD) THEN
          QQ2=E1*T(1)
      ELSE
          QQ2=0.
      END IF
      QQAVE=0.0
C
C      MOMENTUM EQUATION
C
      AAVE=0.5*A(1,I)+0.5*A(1,I+1)
      THETA=DELT/DELX
      VEL1=Q(1,I)/A(1,I)
      VEL2=Q(1,I+1)/A(1,I+1)
      DKDH1=K(1,I)/A(1,I)*(5.*T(I)/3.-4.*R(1,I)/3.)
      DKDH2=K(1,I+1)/A(1,I+1)*(5.*T(I+1)/3.-4.*R(1,I+1)/3.)
      CALL KINEM (AAVE,G,QQAVE,DKDH1,DKDH2,I)
C
C      CONTINUITY EQUATION
C
      BB(1,I)=-4.*THETA
      TAVE=(T(I)+T(I+1))/2.
      BB(2,I)=2.*TAVE
      BB(3,I)=4.*THETA
      BB(4,I)=2.*TAVE
      SS(I)=2.*TAVE*H(1,I)+2.*TAVE*H(1,I+1)+4.*DELT*QQ2
150  CONTINUE
C
C      DECISION OF MATRIX COEFFICIENTS.
C
C      AT INTERNAL POINTS
      DO 650 I=1,NS-1
          J=2*I
          AA(1,J)=BB(1,I)
          AA(2,J)=BB(2,I)
          AA(3,J)=BB(3,I)
          AA(4,J)=BB(4,I)
          RR(J)=SS(I)
          J=J+1
          AA(1,J)=BB(5,I)
          AA(2,J)=BB(6,I)
          AA(3,J)=BB(7,I)
          AA(4,J)=BB(8,I)
          RR(J)=TT(I)
650  CONTINUE
C
C      BY UPSTREAM BOUNDARY CONDITION
      AA(1,1)=0.
      AA(2,1)=0.
      AA(3,1)=1.
      AA(4,1)=0.
      IF(JJJ.EQ.1) THEN
          RR(1)=Q(2,1)
      ELSE
          IF(JJJ.EQ.2) THEN
              RR(1)=(D1+D2*COS(3.14*TIME/(3600.*D3)))*T(1)
              IF(TIME.GT.TL) THEN
                  RR(1)=QO
              END IF
          ELSE
              IF(TIME.LE.T1) THEN

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        RR(1)=QO+(QM-QO)*TIME/T1
    ELSE
        IF(TIME.GT.T1.AND.TIME.LE.T2) THEN
            RR(1)=QM-(TIME-T1)*(QM-QO)/(T2-T1)
        ELSE
            RR(1)=QO
        END IF
    END IF
END IF
END IF
END IF
C
C BY DOWNSTREAM BOUNDARY CONDITION
NN=2.*NS
DIR=(1.486/MAN)*T(NS)*(5./3.)*H(1,NS)**(2./3.)
AA(1,NN)=1.
AA(2,NN)=-Q(1,NS)*(5.*T(NS)-4.*R(1,NS))/(3.*A(1,NS))
AA(3,NN)=0.
AA(4,NN)=0.
RR(NN)=Q(1,NS)-Q(1,NS)*(5.*T(NS)-4.*R(1,NS))*H(1,NS)/(3.*A(1,NS))
C
C DOUBLE SWEEP METHOD
CALL MATRIX (NS)
DO 400 I=1,NS
Q(2,I)=XV(2*I-1)
H(2,I)=XV(2*I)
IF(H(2,I).LT.0.001) H(2,I)=0.1
400 CONTINUE
C
C WRITE THE RESULTS
C
DO 550 I=1,NS
H(1,I)=H(2,I)
Q(1,I)=Q(2,I)
Y(1,I)=H(1,I)+Z(I)
A(1,I)=T(I)*H(1,I)
R(1,I)=A(1,I)/(T(I)+2.*H(1,I))
K(1,I)=1.486/MAN*R(1,I)**(2./3.)*A(1,I)
SF(1,I)=Q(1,I)*ABS(Q(1,I))/K(1,I)**2
550 CONTINUE
KK=TIME/10
PP=TIME/10.
IF(KK.EQ.PP) THEN
    WRITE(1,888) TIME
888  FORMAT(/,10X,'TIME=',F8.1,2X,'SEC'/)
    WRITE(1,333)
333  FORMAT(4X,'NO',7X,'LENGTH',8X,'BED EL.',6X,'WATER DEP',5X,
1  'ELEVATION',6X,'DISCHARGE'/)
    DO 299 I=1,NS
        WRITE(1,444) I,REACH(I),Z(I),H(1,I),Y(1,I),Q(1,I)
444  FORMAT(4X,12,5X,F9.0,5X,F9.2,5X,F9.2,5X,F9.2,5X,F12.2)
299  CONTINUE
        GO TO 601
    ELSE
        GO TO 601
    END IF
1000 CALL GETTIM(IHR,IMIN,ISEC,I100TH)
EXTIME=IHR*3600.+IMIN*60.+ISEC+I100TH/100.-STIME
WRITE(1,446) EXTIME
446  FORMAT(/,20X,'EXECUTION TIME=',F9.2,2X,'SEC')
STOP
END
C
C THIS IS A SUBROUTINE FOR KINEMATIC WAVE THEORY
C
SUBROUTINE KINEM (AAVE,G,QQAVE,DKDH1,DKDH2,I)
COMMON BB(8,100),A(2,100),SF(2,100),Q(2,100),K(2,100),T(100),
1  R(2,100),TT(100),SO(100),H(2,100),Y(2,100)
REAL K
BB(5,I)=G*A(1,I)*SF(1,I)/Q(1,I)
BB(6,I)=-G*A(1,I)*SF(1,I)*DKDH1/K(1,I)

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BB(7,1)=G*A(1,1+1)*SF(1,1+1)/Q(1,1+1)
BB(8,1)=-G*A(1,1+1)*SF(1,1+1)*DKDH2/K(1,1+1)
TT(1)=0.5*G*AAVE*(SO(1)+SO(I+1))+0.5*G*A(1,1)*SF(1,1)+0.5*G*
1   A(1,1+1)*SF(1,1+1)-G*A(1,1)*SF(1,1)*DKDH1*H(1,1)/K(1,1)
2   -G*A(1,1+1)*SF(1,1+1)*DKDH2*H(1,1+1)/K(1,1+1)+QQAVE
RETURN
END

```

C
C
C

THIS IS A SUBROUTINE FOR MATRIX CALCULATION

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SUBROUTINE MATRIX (NS)
COMMON /BLOCK1/MM(5,100),AA(5,100),ZZ(200),RR(200),XV(200)
REAL MM
NN=2*NS
MM(3,1)=AA(3,1)
MM(4,1)=AA(4,1)
ZZ(1)=RR(1)
DO 200 I=2,NN
J=I/2*2
IF(I.EQ.J) GO TO 611
MM(2,I)=-AA(1,I)*MM(4,I-2)/MM(3,I-2)+AA(2,I)
MM(3,I)=-MM(2,I)*AA(3,I-1)/MM(2,I-1)+AA(3,I)
MM(4,I)=-MM(2,I)*AA(4,I-1)/MM(2,I-1)+AA(4,I)
ZZ(I)=-MM(2,I)*ZZ(I-1)/MM(2,I-1)-AA(1,I)*ZZ(I-2)/MM(3,I-2)+RR(I)
GO TO 200
611 MM(2,I)=-AA(1,I)*MM(4,I-1)/MM(3,I-1)+AA(2,I)
ZZ(I)=-AA(1,I)*ZZ(I-1)/MM(3,I-1)+RR(I)
200 CONTINUE
XV(NN)=ZZ(NN)/MM(2,NN)
DO 300 I=1,NN-1
KK=NN-I
J=KK/2*2
IF(KK.EQ.J) GO TO 612
XV(KK)=(ZZ(KK)-MM(4,KK)*XV(KK+1))/MM(3,KK)
GO TO 300
612 XV(KK)=(ZZ(KK)-AA(4,KK)*XV(KK+2)-AA(3,KK)*XV(KK+1))/MM(2,KK)
300 CONTINUE
RETURN
END

```