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ภาคผนวก ก

การพัฒนาสมการอธิบายการไหล

จาก Camp Dresser & Mckee (CDM)

ก. Developed Forms of Continuity and Momentum Equation for the Hydraulic Routing Model.

(ก-1) Finite approximation in distance. As already mentioned above in the discussion of flow representation, it is assumed that the flow in the canal system will be gradually varied, unsteady, free-surface flow in the subcritical range. Differential equations expressing the governing relationships for this type of flow have been written and are readily available in engineering literature (6)[1]. To obtain numerical solutions for particular flow problems, these equations are written in finite difference form, and computations are carried out using small increments of time and distance. Such numerical procedures are presented in considerable detail in the literature (18, 21), but generally the application is limited to flow in a single channel or a simple junction of two channels flowing into a third. One or more of these applications might be applicable for flow in a small number of channels and junctions, but would hardly be suitable for subsystems of the magnitude required.

Equations for a system somewhat similar to Bangkok's have been developed for a study of flow in the network of the Sacramento-San Jaoaqin Delta (4), but the mathematical model for that application used a representation of flow considerably different from the one described above. In that representation, all of the channel storage was concentrated at the nodes, and the flow in the channels accounted only for energy losses and accelerations. The storage at the node was equal to half the storage in the canals flowing to or from that node. While such a representation may be suitable for flow in a set of existing channels, it was felt to be inadequate for a study where design was a primary objective and many properties of the channel were yet to be selected. For example, if the design of a channel were changed, the storage function at the nodes at either end of the channel would have to be recomputed. Furthermore, the examinations of the equations in that study indicated that they were essentially the same as other finite-difference equations where the increment of distance was assumed to be small. No special allowances were made for the possibility of considerable variation in the length of links between nodes.

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1 Numbers in parentheses in the body of the text refer to citations in the list of references.

For the mathematical model used in this study, it is apparent that the length L between nodes is the equivalent of the finite increment of x used in past applications. Since the distance between nodes may be expected to have any value, the finite increment cannot be made constant. Furthermore, it cannot be assumed beforehand that this length will be small as is done in normal finite difference calculations. Therefore, it was decided to write the equations of motion in a form specifically suited to the representation of flow used in this mathematical model.

The essential aspect of this finite approximation can be most easily presented by considering an example with the aid of Figure 7. In the figure, the amount of water stored in the channel during the increment T of time is represented by the volume enclosed between the water surface shown by the solid line for time 0 and that shown by the broken line for time T. In the normal finite difference approximation this volume might be estimated as the product of the length of the channel, the average width of the water surface at time 0 and the average change in depth. The expression for this volume might be

$$\frac{L}{2}(B_{00} + B_{L0}) \left(\frac{Y_{0T} + Y_{LT}}{2} - \frac{Y_{00} + Y_{L0}}{2}\right)$$

In the finite approximations for this mathematical model, however, the volume of storage is obtained by treating x as a variable between the values 0 and L. An infinitesimal increment of volume at any value of x is written as the product of the rate of change of water surface elevation and the width of the water surface at x. This product is integrated with respect to x and t from 0 to L and 0 to T, respectively. The resulting expression for the storage during the time increment becomes

$$\int_0^T \int_0^L \frac{\partial Y}{\partial t} B(x, t)\,dx\,dt$$

In this expression, assumptions are made about the variations in y and B, and the integration is actually carried out to obtain an expression for the storage.

Π-2 <u>First-order approximation in time</u>. In the mathematical model, the values of V and h are the unknowns to be found at the end of a time increment, given the values at the beginning. In the equations, the coefficients will involve such variables as width B and cross section area A, which vary with x and t as the water surface elevation varies. From the expression for the finite approximation given in the preceding paragraph, it can be anticipated that the final form of the equations will involve values of variables such as B and A at time T, and these will depend on the values of h at that time. Thus, in the equations, the coefficients of the unknowns will contain the unknowns themselves or variables that depend upon the values of the unknowns. Therefore, the equations for the finite approximation are non-linear.

The general approach for solving these equations is by iteration. In the first step of the iteration, the values of the unknowns at the beginning of the time increment are used to compute the values of the coefficients. The equations become linear and can be solved for the values of the unknowns which are only first estimates of the actual values. In recomputing the coefficients for the second step of the iteration, the value of any variable is taken as the average of the value at the beginning of the time increment and the first estimate of the value at the end. Again, the equations become linear and are solved for the second estimate of the unknowns. For the third step, the coefficients are computed using the average of values at the beginning of time increment and the second estimate of the values at the end. The iteration continues until successive estimates of the unknowns are within some prescribed limit of error. The resulting estimate is taken as the value of the unknowns at the end of that time increment. When this complete iteration is carried out for each time increment, the resulting values of the unknowns are second order approximations in time because the values at the end of the time increment were considered in the coefficients. When the process is stopped after the first step of the iteration, the resulting values are first order approximations in time because only the values at the beginning of the time increment are used in the coefficients.

While the x increment is determined by the length between nodes and must vary throughout the system, the time increment can be chosen arbitrarily and made constant throughout the system. In choosing the time increment, it is necessary to balance the factors that contribute to efficiency of computation. Quite clearly, the second order of approximation will require several steps of iteration for each time increment, thus increasing the amount of computation for a given number of increments. On the other hand, the second order approximation generally allows longer time increments to be used for the same degree of accuracy. Thus, for a given amount of time, fewer time increments are required. It was anticipated that for the Bangkok drainage system, the use of a first-order approximation with smaller time increments would be more efficient than the second-order approximation with longer increments. Therefore, as the equations were developed, it was assumed that only first-order approximations in time would be necessary. This has an important bearing upon which terms in the finite approximations are retained and which are dropped.

B-3 Continuity equation for a link. The equation of continuity for flow in a link is obtained by using a control volume that can be seen in Figure 7. The control surface enclosing the volume consists of the bottom and sides of the channel, the cross section areas at the upstream and downstream end and the water surface at time t = 0. With this fixed control volume, the change in channel storage shown in Figure 7 between times 0 and T is treated as flux of fluid upward through the top of the control surface during the time increment T. Fixing the control surface to the water surface at the beginning of the time increment is well-suited to the assumption of first-order approximation in time, because the areas, widths, and volumes associated with the control surface are those at the beginning of the time increment.

Continuity requires that the sum of the inflows and outflows through the control surface is zero, and the outflows are treated as positive in order to establish a sign convention. From Figure 7, the expression for outflows at the ends of the channel can be written down by inspection as

$$\left[\frac{1}{2}(V_{L0} + V_{LT})A_{L0} - \frac{1}{2}(V_{00} + V_{0T})A_{00}\right]T$$

The possibility of inflow distributed along the length L is accounted for by the term -qL where q is the volume of inflow per unit of length of channel per unit of time, and the negative sign indicates that the numerical value of q will be positive when the flow is into the channel. The remaining term in the outflows is the flux through the top of the control surface.

The double integral expressing this flux was given in Paragraph a above. To evaluate the integral, it is necessary to assume some relationship for the term in the integrand. To obtain such an expression for y the value y_{00} is used as the reference value and the value at x and t is obtained by expansion to give

$$y(x,t) = y_{00} + \left(\frac{\partial y}{\partial x}\right)_{00} x + \left\{\left(\frac{\partial y}{\partial t}\right)_{00} + \frac{x}{L}\left[\left(\frac{\partial y}{\partial t}\right)_{L0} - \left(\frac{\partial y}{\partial t}\right)_{00}\right]\right\} t \quad (1)$$

The subscripts on the partial derivatives indicate that they are evaluated at time 0. Because y is assumed to vary linearly with x and t, the partial derivatives are treated as constants. To simplify the type script, a new set of constants is defined as follows:

$$\eta_1 = y_{00} \quad (2a)$$

$$\eta_2 = \left(\frac{\partial y}{\partial x}\right)_{00} \quad (2b)$$

$$\eta_3 = \left(\frac{\partial y}{\partial t}\right)_{00} \quad (2c)$$

$$\eta_4 = \left(\frac{\partial y}{\partial t}\right)_{L0} - \left(\frac{\partial y}{\partial t}\right)_{00} \quad (2d)$$

and Equation 1 becomes

$$y(x,t) = y_{00} + \eta_2 x + \eta_3 t + \eta_4 \frac{x}{L} t \quad (3)$$

Similarly, the width of water surface can be expanded as

$$B(x,t) = B_{00} + \left[\left(\frac{\partial B}{\partial x}\right)_{00} + \left(\frac{\partial B}{\partial Y}\right)_{00} \left(\frac{\partial Y}{\partial x}\right)_{00} \right] x + \left\{ \left(\frac{\partial B}{\partial Y}\right)_{00} \left(\frac{\partial Y}{\partial t}\right)_{00} + \frac{x}{L} \left[\left(\frac{\partial B}{\partial Y}\right)_{L0} \left(\frac{\partial Y}{\partial t}\right)_{L0} - \left(\frac{\partial B}{\partial Y}\right)_{00} \left(\frac{\partial Y}{\partial t}\right)_{00} \right] \right\} t \quad (4)$$

Defining a new set of constants to replace the partial derivatives by

$$\beta_1 = B_{00} \quad (5a)$$

$$\beta_2 = \left(\frac{\partial B}{\partial x}\right)_{00} + \left(\frac{\partial B}{\partial Y}\right)_{00} \left(\frac{\partial Y}{\partial x}\right)_{00} \quad (5b)$$

$$\beta_3 = \left(\frac{\partial B}{\partial Y}\right)_{00} \left(\frac{\partial Y}{\partial t}\right)_{00} \quad (5c)$$

$$\beta_4 = \left(\frac{\partial B}{\partial Y}\right)_{L0} \left(\frac{\partial Y}{\partial t}\right)_{L0} - \left(\frac{\partial B}{\partial Y}\right)_{00} \left(\frac{\partial Y}{\partial t}\right)_{00} \quad (5d)$$

and Equation 4 becomes

$$B(x,t) = \beta_1 + \beta_2 x + \beta_3 t + \beta_4 \frac{x}{L} t \quad (6)$$

The double integral expressing the channel storage or flux through the top of the control surface can be evaluated by substituting Equations 3 and 6 into the integrand and remembering that in the first-order approximation B is evaluated at the beginning of the time increment. The result is

$$\int_0^T \int_0^L \frac{\partial Y}{\partial t} B\,dx\,dt = \int_0^T \int_0^L \left(\eta_3 + \eta_4 \frac{x}{L}\right) \left(\beta_1 + \beta_2 x\right) dx\,dt$$

$$= LT \left[\left(\beta_1 + 1/2\, \beta_2 L\right) \eta_3 + \left(1/2\, \beta_1 + 1/3\, \beta_2 L\right) \eta_4 \right] \quad (7)$$

The product of an appropriate partial derivative with L or T will give the difference between values of y or B at the two ends of the link or the two ends of the time increment. Thus, Equation 7 can be written as

$$\int_0^T \int_0^L \frac{\partial y}{\partial t} B\,dx\,dt = \frac{L}{6}(y_{OT} - y_{00})\ (2B_{00} + B_{LO}) + \frac{L}{6}(y_{LT} - y_{LO})\ (B_{00} + 2B_{LO}) \qquad (8)$$

The resulting first-order continuity equation becomes

$$-(V_{00} + V_{OT})A_{00} + (V_{LO} + V_{LT})A_{LO} - 2qL + \frac{L}{3T}\left[(y_{OT} - y_{00})\ (2B_{00} + B_{LO}) + (y_{LT} - y_{LO})\ (B_{00} + 2B_{LO})\right] = 0 \qquad (9)$$

Since the water-surface elevations, rather than the depths, are matched at the nodes, it is convenient to write Equation 9 in terms of elevation by substituting h - z for y. All terms containing z cancel, and the resulting equation is identical to Equation 9 with y replaced by h. Furthermore, in order to keep the values of h from being too large, it is possible to subtract a constant value from all h. This constant can be treated as a datum elevation from which h is measured. Representing it by Z, y could be replaced by h - z in Equation 9.

II-4 Momentum equation for a link. The equation of momentum is obtained using the same control volume as was used for the continuity equations. The momentum equation is a vector equation, but since the flow is assumed to be one dimensional and in one direction, only forces and momentum changes in the x-direction need to be considered. Since the momentum equation for the finite approximation is developed directly from the definitions rather than from the differential equation, it seems more appropriate here to state the momentum relationship in words rather than in a differential equation. This relationship can be expressed as

(Pressure forces + weight forces - friction forces)$_x$

= (efflux of x-momentum at downstream end)

- (influx of x-momentum at upstream end)

+ (efflux of x-momentum through top surface)

+ (x-acceleration of fluid inside control volume)

The subscript x on the forces indicates that the components in the direction of flow are used. For the mathematical model, a finite approximation was found for each of these items.

The pressure force in the x-direction is equal to the total pressure of the cross section on the upstream end minus that at the downstream end. In order to evaluate this force, an expression was written for the difference in pressure forces on two cross sections a small distance, dx, apart. This force can be written as

$$- \gamma A \frac{\partial y}{\partial x} dx$$

The necessary expression for A is given by

$$A = a_1 + a_2 x + a_3 t + a_4 \frac{x}{L} t \quad (10)$$

where

$$a_1 = A_{00} \quad (11a)$$

$$a_2 = \left(\frac{\partial A}{\partial x}\right)_{00} + \left(\frac{\partial A}{\partial y}\right)_{00} \left(\frac{\partial y}{\partial x}\right)_{00} \quad (11b)$$

$$a_3 = \left(\frac{\partial A}{\partial y}\right)_{00} \left(\frac{\partial y}{\partial t}\right)_{00} \quad (11c)$$

$$a_4 = \left(\frac{\partial A}{\partial y}\right)_{L0} \left(\frac{\partial y}{\partial t}\right)_{L0} - \left(\frac{\partial A}{\partial y}\right)_{00} \left(\frac{\partial y}{\partial t}\right)_{00} \quad (11d)$$

In the above expression for the pressure forces on the infinitesimal length, the first-order approximation for A is obtained from the first two terms on the right-hand side of Equation 10. The approximation for y is obtained by differentiating Equation 3 with respect to x.

With these substitutions, the expression is integrated with respect to x from 0 to L to obtain a finite approximation for the difference between the pressure forces at the two ends of the channel. In order to find the average value over the length of the time increment, the expression is also integrated with respect to t from 0 to T, and the result is divided by T. The integration is carried out and substitutions are made in the same manner as in deriving Equation 8 for the channel storage. The result is

$$\frac{-\gamma}{T}\int_0^T\int_0^L A(x,0)\frac{\partial y}{\partial x}\, dx = \frac{\gamma}{4}(A_{00} + A_{L0})(y_{00} + y_{0T} - y_{L0} - y_{LT}) \qquad (12)$$

For the weight forces, the volume enclosed by the control surface was estimated as the product of the length and the average of the two end areas. Letting S_0 represent the slope of the bottom of the channel in the direction of flow, the expression for the weight force is

$$\frac{\gamma L}{2} S_0(A_{00} + A_{L0})$$

In deriving an expression for the friction forces, it was assumed that the energy gradient due to friction varied linearly with distance along the channel and time. This assumption leads to

$$S_f(x,t) = s_1 + s_2 x + s_3 t + s_4 \frac{xt}{L} \qquad (13)$$

where the constants s_1, s_2, s_3 and s_4 have definitions analogous to the constants in Equations 5 and 11. This definition is not exactly equivalent to the assumptions that the roughness factor varies linearly with x. However, as will be seen from the actual expression derived, only the values of the roughness factor and energy slope at the ends of the channel are used in the first-order approximation. In between the ends, whether the slope varies linearly or the roughness factor varies linearly, is immaterial.

As with the pressure forces, the friction force is first written for an infinitesimal length of channel. Following the normal procedure for deriving the momentum equation for unsteady flow, the forces due to friction are assumed to be proportional to the friction loss over the length multiplied by the cross-sectional area of the channel, giving an expression of

$$-\gamma S_f A(x,0)dx$$

where the minus sign indicates that the friction forces always oppose the flow. Substituting the appropriate values for S_f and A for a first-order approximation, integrating with respect to x, collecting terms and substituting as indicated for preceding expressions leads to the following result.

$$-\int_0^L \gamma\,(s_1 + s_2x)\,(a_1 + a_2x)dx$$

$$= \frac{-\gamma L}{6}\left[S_{00}(2A_{00} + A_{L0}) + S_{L0}(A_{00} + 2A_{L0})\right] \qquad (14)$$

In a first-order finite approximation for the momentum flux through the ends of the control volume, the cross section areas at the beginning of the time increment are used. However, the velocity of flow is assumed to vary with distance and time according to

$$V(x,t) = v_1 + v_2x + v_3t + v_4\,\frac{x}{L}\,t \qquad (15)$$

where v_1, v_2, v_3 and v_4 are defined in a manner analogous to Equations 5 and 11. The average flux over the time increment is obtained by integrating with respect to t and dividing by T. With the sign convention that flux out of the control volume is positive, the expression for the net momentum flux through the ends is derived as follows:

$$\frac{\rho}{T}\int_0^T [A_{L0}V^2(L,t) - A_{00}V^2(0,t)]\,dt$$

$$= \frac{\rho}{T}\int_0^T [A_{L0}(v_1 + v_2L + v_3t + v_4t) - A_{00}(v_1 + v_3t)]\,dt$$

$$= \rho A_{L0}\left[V^2_{L0} + V_{L0}(V_{LT} - V_{L0}) + 1/3(V_{LT} - V_{L0})^2\right]$$

$$- \rho A_{00}\left[V^2_{00} + V_{00}(V_{0T} - V_{00}) + 1/3(V_{0T} - V_{00})^2\right] \qquad (16)$$

The last term in each of the brackets on the right hand side of Equation 16 represents the square of the difference between the velocities at the beginning and end of the time increment. Therefore, they are second-order terms and should be neglected in the first-order approximation. The final form of the expression becomes

$$\rho\left[A_{L0}V_{L0}V_{LT} - A_{00}V_{00}V_{0T}\right] = \rho\left[Q_{L0}V_{LT} - Q_{00}V_{0T}\right] \qquad (17)$$

The flux of x-momentum through the top of the control surface is similar to the flux of fluid for channel storage, except that the x-velocity of the fluid as it passes upward through the surface must be taken into account. Therefore, the integrand for the flux in Equation 7 must be multiplied by velocity, as expressed in Equation 15. The substitution, integration, and replacement of appropriate terms can be summarized as follows:

$$\frac{\rho}{T}\int_0^T\int_0^L V(x,t)\,\frac{\partial y}{\partial t}\,B(x,0)\,dxdt$$

$$= \frac{\rho}{T}\int_0^T\int_0^L (v_1 + v_2 x + v_3 t + v_4 \frac{x}{L} t)(\eta_3 + \eta_4 \frac{x}{L})(\beta_1 + \beta_2 x)\,dxdt$$

$$= \frac{\rho L}{24T}(y_{0T} - y_{00})\Big[B_{00}(3V_{00} + 3V_{0T} + V_{L0} + V_{LT})$$

$$+ B_{L0}(V_{00} + V_{0T} + V_{L0} + V_{LT})\Big]$$

$$+ \frac{\rho L}{24T}(y_{LT} - y_{L0})\Big[B_{00}(V_{00} + V_{0T} + V_{L0} + V_{LT})$$

$$+ B_{L0}(V_{00} + V_{0T} + 3V_{L0} + 3V_{LT})\Big] \qquad (18)$$

Equation 18 is still non-linear because it contains products of the unknown depth and the unknown velocity at the end of the time increments. It must be assumed that either the change in depth or the change in velocity over the increment is negligible. Selecting the change in depth as negligible is inappropriate because the very reason for this flux of momentum is the change in water depth. Thus, as would be expected, with no change in depth, the right hand side of Equation 18 becomes zero. Therefore, it was decided to treat the brackets containing terms with widths and velocity as coefficients of the depths in the parentheses. In this case, the appropriate assumption for the first-order approximation is that the velocity of the fluid passing upward through the control surface is essentially constant, or that the change in velocity during the time increment is negligible. With this assumption, the final first order expression for this part of the momentum flux becomes

$$\frac{\rho}{T}\int_0^T\int_0^L V\frac{\partial y}{\partial t}\,B\,dxdt = \frac{\rho L}{12T}(y_{0T} - y_{00})\Big[B_{00}(3V_{00} + V_{L0}) + B_{L0}(V_{00} + V_{L0})\Big]$$

$$+ \frac{\rho L}{12T}(y_{LT} - y_{L0})\Big[B_{00}(V_{00} + V_{L0}) + B_{L0}(V_{00} + 3V_{L0})\Big] \qquad (19)$$

The final term in the momentum equation is the x-acceleration of the fluid inside the control surface. The average rate of this momentum change during the time intervals can be written as

$$\frac{\rho}{T}\int_0^T\int_0^L \frac{\partial v}{\partial t} A(x,0)dxdt = \frac{\rho}{T}\int_0^T\int_0^L (v_3 + v_4 \frac{x}{L})\ (a_1 + a_2 x)dxdt$$

$$= \frac{\rho L}{6T} (V_{0T} - V_{00})\ (2A_{00} + A_{L0})$$

$$+ \frac{\rho L}{6T} (V_{LT} - V_{L0})\ (A_{00} + 2A_{L0}) \qquad (20)$$

The expressions for forces and momentum changes are collected together for the equation of momentum. The effect of inflow along the sides of the channel are not considered explicitly because this inflow is considered to have no x-momentum since it enters perpendicular to the direction of flow. The fact that this side-channel inflow is accelerated inside the control volume is taken into account when the continuity equation and the momentum equation are solved together. As with the continuity equation, water surface elevation is a more convenient variable than water depth because the elevations are matched at nodes. By substituting h-z for y, the momentum equation has the following form

$$\left[-\frac{A_{00}V_{00}}{g} + \frac{L}{6Tg}(2A_{00} + A_{L0})\right] V_{0T}$$

$$+ \left[\frac{A_{L0}V_{L0}}{g} + \frac{L}{6Tg}(A_{00} + 2A_{L0})\right] V_{LT}$$

$$+ \left\{\frac{-(A_{00}+ A_{L0})}{4} + \frac{L}{12Tg}\left[B_{00}(3V_{00} + V_{L0}) + B_{L0}(V_{00} + V_{L0})\right]\right\} h_{0T}$$

$$+ \left\{\frac{A_{00} + A_{L0}}{4} + \frac{L}{12Tg}\left[B_{00}(V_{00} + V_{L0}) + B_{L0}(V_{00} + 3V_{L0})\right]\right\} h_{LT}$$

$$= -\frac{(A_{00} + A_{L0})}{4} (h_{L0} - h_{00})$$

$$+ \frac{L}{12Tg}\left\{ h_{00}\left[B_{00}(3V_{00} + V_{L0}) + B_{L0}(V_{00} + V_{L0})\right] + h_{L0}\left[B_{00}(V_{00} + V_{L0}) + B_{L0}(V_{00} + 3V_{L0})\right]\right\}$$

$$+ \frac{L}{6Tg}\left[V_{00}(2A_{00} + A_{L0}) + V_{L0}(A_{00} + 2A_{L0})\right]$$

$$- \frac{L}{6}\left[S_{f00}(2A_{00} + A_{L0}) + S_{fL0}(A_{00} + 2A_{L0})\right] \qquad (21)$$

Just as in Equation 9, h in Equation 21 could be replaced by h - Z, the elevation of the water surface above some datum Z.

Π-5 Continuity at nodes. Since the representation of the canals in the mathematical model assume no storage of water at the nodes, continuity at a node requires that the sum of all rates of flow into the node is equal to the sum of all rates out. During the increment of time, the velocity of flow from the node to a channel, and the cross-section area of the channel at the node, both change. With this variation, there are two possible statements for continuity. One is that the total volume of outflow or the average rate of outflow is equal to the total volume or average rate of inflow. The other is that the outflows must equal inflows at some instant of time.

In the mathematical model the second alternative is used, and the instant of time is the end of the time increment. The flow from a node to a channel at the end of the time increment can be written in terms of values at the beginning in the following manner:

$$
\begin{aligned}
Q_T &= V_T A_T \\
&= (V_0 + \Delta V)\ (A_0 + \Delta A) \\
&= [V_0 + (V_T - V_0)]\ [A_0 + (A_T - A_0)] \\
&= V_0 A_0 + A_0(V_T - V_0) + V_0(A_T - A_0) + (A_T - A_0)\ (V_T - V_0) \quad (22)
\end{aligned}
$$

Only a single subscript, 0 or T, is needed at the node to designate values at the beginning and end of the time increment, respectively.

Equation 22 is non-linear because it contains a term in which the unknown velocity at the end of the time increment is multiplied by the unknown area. However, this term is the product of the change in velocity and the change in area over the time increment, which makes it second order in time. Therefore, the term can be dropped from the equation. Since water-surface elevation is to be one of the unknowns, the difference $A_T - A_0$ can be replaced by the product of the channel width and the rise in elevation. Although the channel width is not constant throughout the rise, if the expression is to be first order, the width at the beginning of the time increment is used. Thus, Equation 22 becomes

$$Q_T = A_0 V_T + V_0 B_0 (h_T - h_0) \quad (23)$$

With this type of expression for each section of channel at the node, the continuity for the node becomes

$$\sum \left[A_0 V_T + V_0 B_0 (h_T - h_0) \right] + Q_{out} = 0 \quad (24)$$

The summation sign includes both inflows and outflows with the sign convention that outflow is positive. The term Q_{out} refers to any flow to or from the node that is not via the channels, again with the sign convention that outflow is positive.

ภาคผนวก ข

โปรแกรมคอมพิวเตอร์

ข-1

LISTING OF HYDROLOGIC SURFACE RUNOFF PROGRAM

```
/SYS REG=300
/SYS TIME=MAXIMUM
/FILE 12  NAME(HYDRO5Y.2) RSIZ(133) NEW(REPL)
/FILE 6 NAME(PHYDRO5Y.2) RSIZ(133) NEW(REPL)
/LOAD FORTG1
C
C
C
C
      COMMON AREA(100),TC(100),CCEF(100),NODE,N,NCOMB(10),L,K,DWFLOW(90)
     +, IFRE,FAC,FREEFL(100),REDUCE
      READ(5,5)IFRE,FAC,NODE,REDUCE
    5 FORMAT (1X,I7,F8.4,I8,F8.4)
      WRITE(6,7)IFRE,FAC,REDUCE
    7 FORMAT(1X,'RETURN PERIOD = ',I8,/,1X,'AREA REDUCTION FACTOR  =',
     +F8.5,/,1X,'REDUCE FLOW FACTOR =',F8.5)
      WRITE(6,6) NODE
    6 FORMAT (5X,'TOTAL NUMBER OF NODES = ',I3)
      DO 200 K = 1,NODE
      READ(5,10) MANE,N
   10 FORMAT (1X,I7,I8)
      WRITE(6,15)
   15 FORMAT(1H1,1X,'*******************************  INPUT DATA  *****
     1*************************',/)
      WRITE(6,16) MANE
   16 FORMAT(10X,'NODE  NUMBER ',I3)
      DO 100 L = 1,N
      READ(5,20)TC(L),AREA(L),CCEF(L),DWFLOW(L),NCOMB(L)
   20 FORMAT (1X,F7.3,3F8.3,I8)
C
C PRINT
C
      WRITE(6,30) L
   30 FORMAT (5X,'SUB-CATMENT INDEX          = ',I3)
      WRITE(6,40) TC(L)
   40 FORMAT (5X,'TIME OF CONCENTRATION     = ',F10.2)
      WRITE(6,50) AREA(L)
   50 FORMAT (5X,'AREA                       = ',F10.2,3X,'KM2')
      WRITE(6,60) CCEF(L)
   60 FORMAT (5X,'ROUGHTNESS CCEFICIENT      = ',F10.2)
      WRITE(6,70) DWFLOW(L)
   70 FORMAT (5X,'WAST WATER FLOW            = ',F10.2,3X,'M3/DAY/KM2')
  100 CONTINUE
      CALL LFLOW
  200 CONTINUE
      STOP
      END
C SUBROUTINE TO CALCULATE LOCAL INFLOW
C
      SUBROUTINE LFLOW
      COMMON AREA(100),TC(100),CCEF(100),NODE,N,NCOMB(10),L,K,DWFLOW(90)
     +,IFRE,FAC,FREEFL(100),REDUCE
      DIMENSION INTEN(100),HYDRC(100),C(20,100),ATEMP(1000)
      DIMENSION TCC(50),STEP(90),ITC(100)
      IC = 0
      DO 500 I=1,20
      DO 500 J=1,100
```

```
          Q(I,J)=0
  500     CONTINUE
          DO 2000 L = 1,N
          M = 90
          HYDRO(1) = DWFLOW(L)/86400.*AREA(L)
          ATEM=0
          ITC(1)=0
          DO 1100 I = 2,M
          ATEM = ATEM+TC(L)
          IF(IFRE.EQ.2) GO TO 980
 C    5   YEAR RETURN PEROID  FROM JICA
          ITC(I) = 7600/(ATEM+40)
          GO TO 990
 C    2   YEAR RETURN PEROID  FROM JICA
  980     ITC(I) = 5690/(ATEM+37)
  990     K1=I-1
          K2=K1-1
          INTEN(I)=K1*ITC(I)-K2*ITC(I-1)
          IF(INTEN(I).LT.0.) INTEN(I)=0.
          IF(ATEM.GT.360) INTEN(I)=0
          HYDRO(I) = COEF(L)*INTEN(I)*AREA(L)*FAC/3.6+DWFLOW(L)/86400.*AREA(
         +L)
          IF(I.EQ.2) GO TO 1100
          IF(HYDRO(I-1).LT.HYDRO(I)) HYDRO(I)=HYDRO(I-1)
 1100     CONTINUE
          IC=IC+1
          Q(IC,1) = HYDRO(1)
          TIME=0
          STEP(1)=0
          DT = 10
          DO 1200 I = 2,90
          TIME = TIME+DT
          STEP(I)=TIME
          IF(TIME.GT.TC(L)) GO TO 1110
          Q(IC,I) = HYDRO(1)+(HYDRO(2)-HYDRO(1))*TIME/TC(L)
          GO TO 1200
 1110     DO 1115 NI=2,50
          TCC(NI)=NI*TC(L)
 1115     CONTINUE
          DO 1117 NX=1,50
          IF(TCC(NX).GT.TIME) GO TO 1118
 1117     CONTINUE
 1118     NX=NX+1
          Q(IC,I) = HYDRO(NX)-(HYDRO(NX)-HYDRO(NX+1))
        1               *(TIME-(NX-1)*TC(L))/TC(L)
 1200     CONTINUE
          X1=0
          X2=0
          VOL1=0
          Y1=0
          Y2=0
          VOL2=0
          TIME=0
          FREEFL(L)=REDUCE*HYDRO(2)
          DO 3500 I = 2,100
          TIME=TIME+DT
          IF(Q(IC,1).LT.FREEFL(L)) GO TO 3000
```

```
      X1=Q(IC,I)-FREEFL(L)
      VOL1=VOL1+(X1+X2)/2*DT
      X2=X1
      GO TO 3100
 3000 IF(Q(IC,I).LT.FREEFL(L).AND.TIME.LT.TC(L))GO TO 3500
      Y1=FREEFL(L)-Q(IC,I)
      VOL2=VOL2+(Y1+Y2)/2*DT
      Y2=Y1
 3100 IF(Q(IC,I).GT.FREEFL(L))Q(IC,I)=FREEFL(L)
      IF(Q(IC,I).LT.FREEFL(L).AND.TIME.GT.TC(L))Q(IC,I)=FREEFL(L)
      IF(VOL2.GT.VOL1) GO TO 1210
 3500 CONTINUE
 1210 IF (NCOMB(L).EQ.1) GO TO 2000
      DO 1230 I = 1,90
      ATEMP(I) = 0
 1230 CONTINUE
      NB = NCOMB(L)
      DO 1250 J = 1,NB
      DO 1250 I = 1,90
      ATEMP(I) = ATEMP(I)+Q(J,I)
 1250 CONTINUE
      IC = 1
      DO 1260 I = 1,90
      Q(IC,I) = ATEMP(I)
 1260 CONTINUE
 2000 CONTINUE
      WRITE(6,2200)
 2200 FORMAT(/,1X,'********************************  OUTPUT DATA  ****
     1********************************',/)
      DO 2350 NN=1,90
      IF(Q(IC,NN)) 2310,2310,2350
 2310 Q(IC,NN)=0.
 2350 CONTINUE
      WRITE(6,2400) K,DT
 2400 FORMAT(5X,'INFLOW TO NODE ',I3,10X,'TIME STEP  ',F5.1,5X,'MIN')
      WRITE(12,2410)(STEP(I),I=1,90)
      WRITE(12,2410)(Q(IC,I),I=1,90)
      WRITE(6,2410)(STEP(I),I=1,90)
      WRITE(6,2410)(Q(IC,I),I=1,90)
 2410 FORMAT(/,5X,10F10.2)
      RETURN
      END
```

ข-2

LISTING OF HYDRAULIC ROUTING PROGRAM

```
/SYS REG=500
/SYS TIME=MAXIMUM
/FILE 12 NAME(HY5Y.2I.COM) RSIZ(133) OLD
/LOAD WATFIV
CFILE 6 NAME(P6.3.2Y5W.5B12) RSIZ(133) NEW(REPL)
C      ****************************************************************************
C      *                                                                          *
C      *        A MATHEMATIC MODEL FOR EVALUATION AND REHABILITATION              *
C      *             OF THE CANAL DRAINAGE SYSTEM IN HUA MAK AREA                 *
C      *                                                                          *
C      ****************************************************************************
C      *                                                                          *
C      *                      DEVELOPED BY MR. SURAPONG                           *
C      *                                                                          *
C      ****************************************************************************
C
C
       DIMENSION R(59),C(59,59),ATEMT(59),GP(59,59),
      *B(100),WID(100),Z(100),H(1000),BUT(100),Y(100),A(100),P(100),
      *RN(100),SF(100),RR(100),V(100),DL(100),NODE(100),RA(100),
      *NODED(100),NODEU(100),HN(100),WTS(1000),ELEU(100),ELED(100)
       DIMENSION CDEU(100),CDED(100),WBOTU(100),WBOTD(100),SIDESU(100),
      *SIDESD(100),VELU(100),VELD(100),XL(100),H1(1000),C1(59,59),
      *R1(59),INDEX(56),QOUT(60),Y1(59),B1(59),A1(59),VLINK(59)
      *,QU(59),QD(59),TWTUM(59),WWTUM(59),WVELUM(59),WQUM(59)
       DIMENSION TVEUM(59),VWTUM(59),VVELUM(59),VQUM(59),TQUM(59)
      *,QWTUM(59),QVELUM(59),QQUM(59),TWTDM(59),WWTDM(59),WVELDM(59)
      *,WQDM(59),TVEDM(59),VWTDM(59),VVELDM(59),VQDM(59),TQDM(59)
      *,QWTDM(59),QVELDM(59),QQDM(59)
       COMMON    INN(90),NHY(90),TINF(90,90),QINF(90,90),TGP(90,90)
      *,QGP(90,90),NBC(90),TYPY(90,90),INNODE(90,90),ITYPE(90,90)
      *,CRUN(90),AREAW(90),QOUT1(22),QOUT2(22),QIN(23),NP(59),NNODE
      *,NGP(10),TT,FAC,SQINT,T,SQINC,IPRI,IOUTP
C        NOTE:ARRAY DIMENSION SHOLD BE RELATED TO NUMBER OF NODE
C
C... COMMENT CARD
C
       WRITE(6,10)
    10 FORMAT(1H1,///,20X,'**********************************************
      1*************************',//)
       WRITE(6,12)
    12 FORMAT(30X,'FLOOD CONTROL SIMULATION MODEL (FCSMODEL)',/,40X,
      1 'PROGRAM VERSION "1985"  ')
       WRITE(6,14)
    14 FORMAT(//,20X,'**********************************************
      1*****************',//)
C
C... GROUP 1--COMMENT CARDS
C
       DO 150 I=1,10
       READ(5,110)(ATEMT(J),J=1,15)
   110 FORMAT(1X,15A4)
       WRITE(6,110)(ATEMT(J),J=1,15)
   150 CONTINUE
C
C... GROUP 2--CHANNEL GEOMETRY
C
```

```
      READ(5,160)NL
  160 FORMAT(1X,I7)
      DO 200 I=1,NL
      READ(5,170)NODEU(I),NODED(I),XL(I)
  170 FORMAT(1X,I7,I8,F8.2)
      READ(5,180)NODEU(I),ELEU(I),COEU(I),WBOTU(I),SIDESU(I)
  180 FORMAT(1X,I7,F8.2,F8.3,2F8.2)
      READ(5,180)NODED(I),ELED(I),COED(I),WBOTD(I),SIDESD(I)
  200 CONTINUE
C
C... GROUP  3--CONSTANT
C
      READ(5,210)G,DATUM,FAC
  210 FORMAT(1X,F7.2,2F8.2)
C
C... GROUP 4--HYDROGRAPH OF STORM INFLOW
C
      READ(5,195)N1
  195 FORMAT(1X,I7)
C     READ(5,240)INN(I),NHY(I),CRUN(I),AREAW(I)
      DO 305 I=1,N1
      AREAW(I)=1
      CRUN(I)=1
C 240 FORMAT(1X,I7,I8,2F8.4)
      NHY(I)= 90
      READ(12,250)(TINF(I,J),J=1,90)
      READ(12,250)(QINF(I,J),J=1,90)
  250 FORMAT(/,5X,10F10.2)
  305 CONTINUE
C
C... GROUP 5--BOUNDARY CONDITIONS FOR PUMPING STATION AND GATE
C
      READ(5,310)NBCO
  310 FORMAT(1X,I7)
      IG=0
      DO 350 I=1,NBCO
      IG=IG+1
      READ(5,320)INO,NGP(I)
  320 FORMAT(1X,I7,I8)
      N=NGP(I)
      READ(5,330)(TGP(IG,J),J=1,N)
      READ(5,330)(QGP(IG,J),J=1,N)
  330 FORMAT(1X,F7.2,9F8.2)
  350 CONTINUE
C
C... GROUP 6--BOUNDARY CONDITIONS FOR NODES
C
      DO 800 I=1,N1
      READ(5,750)NBC(I)
  750 FORMAT(1X,I7)
      N2=NBC(I)
      DO 780 J=1,N2
      READ(5,760)ITYPE(I,J)
      IF(ITYPE(I,J).EQ.2) GO TO 765
      READ(5,760)INNODE(I,J)
  760 FORMAT(1X,I7)
      GO TO 780
```

```
  765 READ(5,665)GP(I,J)
  665 FORMAT(4X,A4)
  780 CONTINUE
  800 CONTINUE
C
C...   GROUP 7-- INITIAL CODITION
C
      READ(5,510)NLINK,NNODE
  510 FORMAT(1X,I7,I8)
      DO 600 I=1,NLINK
      READ(5,520)NODEU(I),NODED(I),VELU(I),VELD(I)
  520 FORMAT(1X,I7,I8,2F8.2)
  600 CONTINUE
      DO 640 I=1,NNODE
      READ(5,610)NODE(I),HTS(NODE(I))
  610 FORMAT(1X,I7,F8.2)
  640 CONTINUE
C
C... GROUP--8  CONTROL CARD AND TIME INCREMENT
C
      READ(5,650)IINP,IOUTP
  650 FORMAT(1X,I7,I8)
      READ(5,655)IT1,TINCR1,IT2,TINCR2,IT3,TINCR3,IT4,TINCR4
  655 FORMAT(1X,I7,F8.2,3(I8,F8.2))
C
C... PRINT SUMMARY OF INPUT
C
      IF(IINP.EQ.0) GO TO 30
      WRITE(6,801)
  801 FORMAT(//,30X,'SUMMARY OF INPUT')
      DO 820 I=1,NL
      WRITE(6,805)NODEU(I),NODED(I),XL(I)
  805 FORMAT(/,15X,'LINK',1X,I3,',',I3,4X,'L=',F8.2,' METERS')
      WRITE(6,806)NODEU(I),ELEU(I),WBOTU(I),SIDESU(I)
  806 FORMAT(5X,'U/S NODE ',I3,', Z=',F6.3,', B=',F6.2,', SIDE SLOPE=',
     1F6.3)
      WRITE(6,807)NODED(I),ELED(I),WBOTD(I),SIDESD(I)
  807 FORMAT(5X,'D/S NODE ',I3,', Z=',F6.3,', B=',F6.2,', SIDE SLOPE=',
     1F6.3)
      WRITE(6,808)VELU(I),VELD(I)
  808 FORMAT(5X,'AT TIME T= 0.000 , V(U/S)=',F6.3,', V(D/S)=',F6.3)
  820 CONTINUE
      DO 840 I=1,NNODE
      WRITE(6,825)NODE(I)
  825 FORMAT(15X,'NODE',I4)
      WRITE(6,828)NBC(I)
  828 FORMAT(5X,I3,' BOUNDARY CONDITION(S)')
      N2=NBC(I)
      DO 835 J=1,N2
      IF(ITYPE(I,J).EQ.1) GO TO 830
      IF(ITYPE(I,J).EQ.2) GO TO 832
  830 WRITE(6,831)INNODE(I,J)
  831 FORMAT(5X,'STORM INFLOWS FROM PT. ',I4)
      GO TO 835
  832 WRITE(6,833)GP(I,J)
  833 FORMAT(5X,'B.C.TYPE(2), ',A4)
  835 CONTINUE
```

```
      WRITE(6,838)WTS(NODE(I))
  838 FORMAT(5X,'AT TIME T=0.000 , H=',F6.3)
  840 CONTINUE
C
C... CONSTANT
C
      WRITE(6,850)G,DATUM,FAC
  850 FORMAT(//,5X,'GRAVITY FORCE=',F6.3,/,5X,'MAXIMUM KLONG INVERT=',
     1F6.3,/,5X,'AREA REDUCTION FACTOR=',F6.3)
C
C
C... BEGINNING OF CALCULATION
C
C
      NZ=NNODE+1
   30 DO 35 I=1,NZ
      QIN(I)=0
      QOUT1(I)=0
      QOUT2(I)=0
   35 CONTINUE
      IPR=0
      IPR1=0
      M=NLINK
      N=NNODE
      ML=2*M
      MN=2*M+N
      M1=ML+1
      DO 25 I=1,M1
      WWTUM(I)=0
      WVELUM(I)=0
      WQUM(I)=0
      TWTUM(I)=0
      WWTDM(I)=0
      WVELUM(I)=0
      WQDM(I)=0
      TWTDM(I)=0
      VWTUM(I)=0
      VVELUM(I)=0
      VQUM(I)=0
      TVEUM(I)=0
      VWTDM(I)=0
      VVELDM(I)=0
      VQDM(I)=0
      TVEDM(I)=0
      QWTUM(I)=0
      QVELUM(I)=0
      QQUM(I)=0
      TQUM(I)=0
      QWTDM(I)=0
      QVELDM(I)=0
      QQDM(I)=0
      TQDM(I)=0
   25 CONTINUE
      T=0
      TP=0
      SQINC=0
      SVC=0
```

```
      QIN(23)=0
      WRITE(6,36)
   36 FORMAT(//,30X,'..................OUTPUT......................',/)
      DO 9900 IT =1,3
      IF(IT.LE.IT1) T=TINCR1
      IF(IT.GT.IT1.AND.IT.LE.IT2) T=TINCR2
      IF(IT.GT.IT2.AND.IT.LE.IT3) T=TINCR3
      IF(IT.GT.IT3.AND.IT.LE.IT4) T=TINCR4
      IF(IT.GT.200)T=180
      TP=TP+T
      TT=TP/60
      AT=TT-T/(2*60)
      IPR=IPR+1
      IF(IPR.GT.ICUTP) IPR=0
      IPR1=IPR1+1
      IF(IPR1.GT.IOUTP)IPR1=0
      IF(IPR1.NE.IOUTP) GO TO 37
      WRITE(6,38)AT
   38 FORMAT(/,5X,'AT TIME ',F6.2,' MINUTES')
      WRITE(6,40)TT
   40 FORMAT(/,5X,'SOLUTION FOR TIME T=',F10.2,'  MINUTES')
   37 CALL BCOND
      DO 50 I=1,NNODE
      HA(NODE(I))=WTS(NODE(I))+DATUM
      INDEX(I)=0
   50 CONTINUE
      MN1=MN+1
      DO 100 I=1,MN1
      R(I)=0
      DO 100 J=1,MN1
      C(I,J)=0
  100 CONTINUE
      DO 105 I=1,MN
      DO 105 J=1,MN1
      R1(J)=0
      C1(I,J)=0
  105 CONTINUE
      C1(MN,MN1)=0
C
C
C... SUBROUTINE COEFF
C
C
      TEST=0
      NX=0
      DO 5000 I=1,M
      NX=NX+1
      NODEU(M+1)=0
      IC=2*I-1
      IM=2*I
      JU=2*I-1
      JD=2*I
      JNU=2*M+NX
      JND=JNU+1
      DL(I)=XL(I)
      BUT(JU)=ELEU(I)
      BUT(JD)=ELED(I)
```

```
      RR(JU)=COEU(I)
      RR(JD)=COED(I)
      WID(JU)=WBOTU(I)
      WID(JD)=WBOTD(I)
      Z(JU)=SIDESU(I)
      Z(JD)=SIDESD(I)
      H(JU)= HA(NODEU(I))
      H(JD)= HA(NODED(I))
      V(JU)=VELU(I)
      V(JD)=VELD(I)
      Y(JU)= WTS(NODEU(I))-BUT(JU)
      Y(JD)= WTS(NODED(I))-BUT(JD)
      B(JU)=WID(JU)+2*Z(JU)*Y(JU)
      B(JD)=WID(JD)+2*Z(JD)*Y(JD)
      A(JU)=Y(JU)*(WID(JU)+B(JU))/2
      A(JD)=Y(JD)*(WID(JD)+B(JD))/2
      P(JU)=WID(JU)+SQRT(Y(JU)**2+(Z(JU)*Y(JU))**2)*2
      P(JD)=WID(JD)+SQRT(Y(JD)**2+(Z(JD)*Y(JD))**2)*2
      RA(JU)=A(JU)/P(JU)
      RA(JD)=A(JD)/P(JD)
      SF(JU)=RR(JU)**2*ABS(V(JU))*V(JU)/(RA(JU)**1.33333)
      SF(JD)=RR(JD)**2*ABS(V(JD))*V(JD)/(RA(JD)**1.33333)
      C(IC,JU)=-A(JU)
      C(IC,JD)= A(JD)
      C(IC,JNU)=DL(I)/(3*T)*(2*B(JU)+B(JD))
      C(IC,JND)=DL(I)/(3*T)*(B(JU)+2*B(JD))
      R(IC)=(A(JU)*V(JU))-(A(JD)*V(JD))
     *  +DL(I)/(3*T)*((2*B(JU)+B(JD))*H(JU)+(B(JU)+2*B(JD))*H(JD))
      C(IM,JU)=-(A(JU)*V(JU))/G+DL(I)/(6*T*G)*(2*A(JU)+A(JD))
      C(IM,JD)=(A(JD)*V(JD))/G+DL(I)/(6*T*G)*(A(JU)+2*A(JD))
      C(IM,JNU)=-(A(JU)+A(JD))/4+DL(I)/(12*T*G)
     *            *(B(JU)*(3*V(JU)+V(JD))+B(JD)*(V(JU)+V(JD)))
      C(IM,JND)=(A(JU)+A(JD))/4+DL(I)/(12*T*G)*
     1            (B(JU)*(V(JU)+V(JD))+B(JD)*(V(JU)+3*V(JD)))
      R(IM)=-(A(JU)+A(JD))/4*(H(JD)-H(JU))
     1+DL(I)/(12*T*G)*(H(JU)*(B(JU)*(3*V(JU)+V(JD))+B(JD)*(V(JU)+V(JD))
     2 )+H(JD)*(B(JU)*(V(JU)+V(JD))+B(JD)*(V(JU)+3*V(JD))))
     3  +DL(I)/(6*T*G)*(V(JU)*(2*A(JU)+A(JD))+V(JD)*(A(JU)+2*A(JD)))
     4  -DL(I)/6*(SF(JU)*(2*A(JU)+A(JD))+SF(JD)*(A(JU)+2*A(JD)))
      JL=JU-1
      IF(TEST.EQ.0) GO TO 1500
      C(JNU,JL)=-A(JL)
      C(JNU,JU)=A(JU)
      C(JNU,JNU)=-(V(JL)*B(JL)-V(JU)*B(JU))
      R(JNU)=-(V(JL)*B(JL)-V(JU)*B(JU))*H(JU)+QIN(NX)
      IF(NODED(I).NE.NODEU(I+1)) GO TO 2000
      GO TO 1000
 1500 C(JNU,JU)= A(JU)
      C(JNU,JNU)=V(JU)*B(JU)
      R(JNU)=V(JU)*B(JU)*H(JU)+ QIN(NX)
      TEST=1
C     IF(NODEU(I).EQ.14.AND.NODED(I).EQ.7)GO TO 2000
      GO TO 1000
 2000 INDEX(I)=1
      C(JND,JD)=-A(JD)
      C(JND,JND)=-V(JD)*B(JD)
      R(JND)=-(V(JD)*B(JD)*H(JD))+QIN(NX+1)
```

```
          NX=NX+1
          TEST=0
     1000 IS=0
          IK=I-2
          IF(IK.LE.0) GO TO 5000
          DO 300 K=1,IK
          IS=IS+1
          IF(NODED(I).NE.NODED(IS)) GO TO 300
          IA=2*M+IS+1
C         IF(NODEU(I).EQ.17.AND.NODED(I).EQ.1) IA=2*M+IS+2
          GO TO 2100
      300 CONTINUE
          GO TO 5000
     2100 C(IA,IA)=C(JND,JND)+C(IA,IA)
          C(JND,JND)=0
          C(IA,JD)=C(JND,JD)
          C(JND,JD)=0
          R(IA)=R(JND)+R(IA)-QIN(NX)
          R(JND)=0
          C(IC,IA)=C(IC,JND)
          C(IC,JND)=0
          C(IM,IA)=C(IM,JND)
          C(IM,JND)=0
          NX=NX-1
          GO TO 5000
     5000 CONTINUE
          DO 9300 I1=1,MN
          DO 9200 I2=1,MN
          C1(I1,I2)=C(I1,I2)
     9200 CONTINUE
          R1(I1)=R(I1)
C         WRITE(6,16)(C1(I1,I2),I2=1,MN),R1(I1)
C   16    FORMAT(8F10.2)
     9300 CONTINUE
          DO 9301 I3=1,MN
          C1(I3,MN1)=R1(I3)
     9301 CONTINUE
     5090 NS=MN
          NP=MN1
          NDIM=MN
          CALL ELIM(C1,NS,NP,NDIM)
C
C
C... SUBROUTINE OUTPUT
C
C
          DO 8000 IV=1,M
          IZ=2*IV
          IY=2*IV-1
          VELU(IV)=C1(IY,MN1)
          VELD(IV)=C1(IZ,MN1)
     8000 CONTINUE
          MH=ML+1
          I=0
          IF(IPR.NE.IOUTP) GO TO 8018
          WRITE(6,8015)
     8015 FORMAT(5X,'NODE',4X,'ELEVATION')
```

```
 8018 DO 8100 IH=MH,MN
      I=I+1
      WTS(NODE(I))=C1(IH,MIL)-DATUM
      HA(NODE(I))=C1(IH,MIL)
      IF(IPR.NE.IOUTP) GO TO 8100
      WRITE(6,8020)NODE(I),WTS(NODE(I))
 8020 FORMAT(5X,I3,4X,F9.5)
 8100 CONTINUE
      SVT=0
      IF(IPR.NE.IOUTP) GO TO 7007
      WRITE(6,7006)
 7006 FORMAT(5X,'LINK',13X,'VOLUME',11X,'NODE',6X,'VELOCITY',5X,'DISCHAR
     1NGE')
 7007 DO 7100 JA=1,NL
      IU=2*JA-1
      ID=2*JA
      Y1(IU)=WTS(NODEU(JA))-BUT(IU)
      Y1(ID)=WTS(NODED(JA))-BUT(ID)
      B1(IU)=WID(IU)+2*Z(IU)*Y1(IU)
      B1(ID)=WID(ID)+2*Z(ID)*Y1(ID)
      A1(IU)=Y1(IU)*(WID(IU)+B1(IU))/2
      A1(ID)=Y1(ID)*(WID(ID)+B1(ID))/2
      VLINK(JA)=(A1(IU)+A1(ID))/2*DL(JA)
      IF(Y1(IU).GT.0.OR.Y1(ID).GT.0.)GO TO 7005
      WRITE(6,7004)
 7004 FORMAT(/,5X,'ERROR "Y" LESS THAN 0')
      GO TO 7500
 7005 SVT=SVT+VLINK(JA)
      QU(JA)=A1(IU)*VELU(JA)
      QD(JA)=A1(ID)*VELD(JA)
      IF(IPR.NE.IOUTP) GO TO 7100
      WRITE(6,7010)NODEU(JA),NODED(JA),VLINK(JA),NODEU(JA),VELU(JA),
     1QU(JA)
 7010 FORMAT(2X,I3,',',I3,10X,F10.4,10X,I3,6X,F8.5,6X,F9.5)
      WRITE(6,7012)NODED(JA),VELD(JA),QD(JA)
 7012 FORMAT(39X,I3,6X,F8.5,6X,F9.5)
 7100 CONTINUE
      IF(IPR1.NE.IOUTP) GO TO 7111
      WRITE(6,7110)SVT
 7110 FORMAT(5X,'TOTAL VOLUME IN NETWORK =',F15.5,'  CUBIC METERS')
 7111 IF (IT.EQ.1) SVO=SVT
      DSVT=SVT-SVO
      SVO=SVT
      IF(IPR1.NE.IOUTP) GO TO 7112
      WRITE(6,7115)DSVT
 7115 FORMAT(5X,'CHANGE IN TOTAL VOLUME =',F15.5,'  CUBIC METERS')
C
C...  SUBROUTINE  MAXIMUM VALUE
C
 7112 DO 7300 I1=1,NL
      IF(WWTUM(I1).GT.WTS(NODEU(I1)))GO TO 7200
      WWTUM(I1)=WTS(NODEU(I1))
      WVELUM(I1)=VELU(I1)
      WQUM(I1)=QU(I1)
      TWTUM(I1)=TT
 7200 IF(WWTDM(I1).GT.WTS(NODED(I1)))GO TO 7210
      WWTDM(I1)=WTS(NODED(I1))
```

```
      WVELDM(I1)=VELD(I1)
      WQDM(I1)=QD(I1)
      TWTDM(I1)=TT
 7210 IF(ABS(VVELUM(I1)).GT.ABS(VELU(I1))) GO TO 7220
      VWTUM(I1)=WTS(NODEU(I1))
      VVELUM(I1)=VELU(I1)
      VQUM(I1)=QU(I1)
      TVEUM(I1)=TT
 7220 IF(ABS(VVELDM(I1)).GT.ABS(VELD(I1)))GO TO 7230
      VWTDM(I1)=WTS(NODED(I1))
      VVELDM(I1)=VELD(I1)
      VQDM(I1)=QD(I1)
      TVEDM(I1)=TT
 7230 IF(ABS(QQUM(I1)).GT.ABS(QU(I1)))GO TO 7240
      QWTUM(I1)=WTS(NODEU(I1))
      QVELUM(I1)=VELU(I1)
      QQUM(I1)=QU(I1)
      TQUM(I1)=TT
 7240 IF(ABS(QQDM(I1)).GT.ABS(QD(I1))) GO TO 7300
      QWTDM(I1)=WTS(NODED(I1))
      QVELDM(I1)=VELD(I1)
      QQDM(I1)=QD(I1)
      TQDM(I1)=TT
 7300 CONTINUE
 9900 CONTINUE
C
C
C... SUMMARY OF OUTPUT
C
C
 7500 WRITE(6,7510)
 7510 FORMAT(5X,'-----------------------SUMMARY OF RESULTS----------',/,
     11X,'FOR LINK / MAX. VALUE OF / AT NODE / TIME       HGL       VELOCI
     2TY      DISCHARGE')
      DO 7650 I=1,NL
      WRITE(6,7610)NODEU(I),NODED(I),NODEU(I),TWTUM(I),WWTUM(I),WVELUM(I
     *),WQUM(I)
 7610 FORMAT(5X,I3,',',I3,7X,'HGL',7X,I3,3X,F5.1,5X,F8.4,5X,F8.4,5X,
     *F8.4)
      WRITE(6,7615)NODEU(I),TVEUM(I),VWTUM(I),VVELUM(I),VQUM(I)
 7615 FORMAT(14X,'VELOCITY',7X,I3,3X,F5.1,5X,F8.4,5X,F8.4,5X,F8.4)
      WRITE(6,7620)NODEU(I),TQUM(I),QWTUM(I),QVELUM(I),QQUM(I)
 7620 FORMAT(13X,'DISCHARGE',7X,I3,3X,F5.1,3(5X,F8.4))
      WRITE(6,7610)NODEU(I),NODED(I),NODED(I),TWTDM(I),WWTDM(I),
     1WVELDM(I),WQDM(I)
      WRITE(6,7615)NODED(I),TVEDM(I),VWTDM(I),VVELDM(I),VQDM(I)
      WRITE(6,7620)NODED(I),TQDM(I),QWTDM(I),QVELDM(I),QQDM(I)
      WRITE(6,7630)
 7630 FORMAT(5X,'-----------------------------------------------------')
 7650 CONTINUE
      STOP
      END
C
C
C...  SUBROUTINE BCOND
C
C
```

```
      SUBROUTINE BCOND
      COMMON   NNI(90),NHY(90),TINF(90,90),QINF(90,90),TGP(90,90)
     *,QGP(90,90),NBC(90),TYPY(90,90),INNODE(90,90),ITYPE(90,9))
     *,CRJN(90),AREAW(90),QOUT1(22),QOUT2(22),QIN(23),NR(59),NNODE
     *,NGP(10),TT,FAC,SQINT,T,SQINC,IPR1,IOUTP
      ID=0
      IL=0
      SQINT=0
      DO 6000 I=1,NNODE
      NT=NBC(I)
      DO 6500 L=1,NT
      IF(ITYPE(I,L).EQ.1) GO TO 6200
      IF(ITYPE(I,L).EQ.2) GO TO 6100
 6100 ID=ID+1
      N=NGP(ID)
      DO 6150 K=1,N
      IF(TT.GT.TGP(ID,K)) GO TO 6150
      DY=TGP(ID,K)-TGP(ID,K-1)
      DX=TT-TGP(ID,K-1)
      DQ=QGP(ID,K)-QGP(ID,K-1)
      QOUT1(I)=QGP(ID,K-1)+DX/DY*DQ
      GO TO 6500
 6150 CONTINUE
      GO TO 6500
 6200 IL=IL+1
      NINF=NHY(I)
      DO 6400 K=1,NINF
      IF(TT.GT.TINF(I,K)) GO TO 6400
      DY=TINF(I,K)-TINF(I,K-1)
      DX=TT-TINF(I,K-1)
      DQ=QINF(I,K)-QINF(I,K-1)
      QOUT2(I)=QINF(I,K-1)+DX/DY*DQ
      GO TO 6500
 6400 CONTINUE
 6500 QIN(I)=-QOUT1(I)+QOUT2(I)
      SQINT=SQINT+QIN(I)
 6000 CONTINUE
      VOLQIN=(SQINC+SQINT)/2*T
      SQINC=SQINT
      IF(IPR1.NE.IOUTP) GO TO 47
      WRITE(6,34) QOUT1(12)
   34 FORMAT(5X,'CAPACITY OF PUMP  AT NODE 12  =',F8.2,'  CMS')
      WRITE(6,35) QOUT1(15)
   35 FORMAT(5X,'CAPACITY OF PUMP  AT NODE 15  =',F8.2,'  CMS')
      WRITE(6,36) QOUT1(18)
   36 FORMAT(5X,'CAPACITY OF PUMP  AT NODE 18  =',F8.2,'  CMS')
      WRITE(6,45)SQINT
   45 FORMAT(5X,'SUM OF KNOWN INFLOW AT NODES=',F15.5,'  CMS.')
      WRITE(6,46)VOLQIN
   46 FORMAT(5X,'VOLUME OF KNOWN INFLOWS AT NODES=',F15.5,'  CUBIC METER
     1S')
   47 RETURN
      END
C
C
C... SUBROUTINE ELIM
C
```

```
C
      SUBROUTINE ELIM (AB,N,NP,NDIM)
      DIMENSION AB(NDIM,NP)
C  THIS SUBROUTINE SOLVES A SET OF LINEAR EQUATIONS.
C  THE GAUSS ELIMINATION METHOD IS USED, WITH PARTIAL PIVOTING.
C  MULTIPLE RIGHT HAND SIDES ARE PERMITTED, THEY SHOULD BE SUPPLIED
C  AS COLUMNS THAT AUGMENT THE COEFFICIENT MATRIX.
C  PARAMETERS ARF -
C      AB        COEFFICIENT MATRIX AUGMENTED WITH R.H.S. VECTORS
C      N         NUMBER OF EQUATIONS
C      NP        TOTAL NUMBER OF COLUMNS IN THE AUGMENTED MATRIX.
C      NDIM      FIRST DIMENSION OF MATRIX AB IN THE CALLING PROGRAM.
C  THE SOLUTION VECTOR(S) ARE RETURNED IN THE AUGMENTATION
C  COLUMNS OF AB.
C
C  BEGIN THE REDUCTION
      NM1 = N- 1
      DO 35 I = 1,NM1
C  FIND THE ROW NUMBER OF THE PIVOT ROW. WE WILL THEN
C  INTERCHANGE ROWS TO PUT THE PIVOT ELEMENT ON THE DIAGONAL.
        IPVT = I
        IP1 = I + 1
        DO 10 J = IP1,N
          IF (ABS(AB(IPVT,I)).LT. ABS(AB(J,I))) IPVT = J
 10     CONTINUE
C  CHECK TO BE SURE THE PIVOT ELEMENT IS NOT TOO SMALL, IF SO
C  PRINT A MESSAGE AND RETURN.
        IF ((ABS(AB(IPVT,I)) .LT. 1.E-5)) GO TO 99
C  NOW INTERCHANGE, EXCEPT IF THE PIVOT ELEMENT IS ALREADY ON
C  THE DIAGONAL, DON'T NEED TO.
        IF (IPVT .EQ. I) GO TO 25
        DO 20 JCOL = I,NP
          SAVE = AB(I,JCOL)
          AB(I,JCOL) = AB(IPVT,JCOL)
          AB(IPVT,JCOL) = SAVE
 20     CONTINUE
C  NOW REDUCE ALL ELEMENTS BELOW THE DIAGONAL IN THE I-TH ROW. CHECK
C  FIRST TO SEE IF A XERO ALREADY PRESENT. IF SO,
C  CAN SKIP REDUCTION FOR THAT ROW.
 25     DO 32 JROW = IP1,N
          IF (AB(JROW,I).EQ. 0) GO TO 32
 5        RATIO = AB(JROW,I)/AB(I,I)
          DO 30 KCOL = IP1,NP
            AB(JROW,KCOL) = AB(JROW,KCOL) - RATIO*AB(I,KCOL)
 30       CONTINUE
 32     CONTINUE
 35     CONTINUE
C WE STILL NEED TO CHECK A(N,N) FOR SIZE.
        IF (ABS(AB(N,N)) .LT. 1.E-5) GO TO 99
C NOW WE BACK SUBSTITUTE
      NP1 = N + 1
      DO 50 KCOL = NP1,NP
       AB(N,KCOL) = AB(N,KCOL)/AB(N,N)
       DO 45 J = 2,N
         NVBL = NP1-J
         L = NVBL + 1
         VALUE = AB(NVBL,KCOL)
```

```
            DO 40 K = L,N
              VALUE = VALUE - AB(NVBL,K)*AB(K,KCOL)
   40     CONTINUE
          AB(NVBL,KCOL) = VALUE/AB(NVBL,NVBL)
   45     CONTINUE
   50     CONTINUE
          RETURN
C  MESSAGE FOR A NEAR SINGULAR MATRIX
   99     WRITE (6,100)IPVT,I,AB(IPVT,I),AB(N,N),N
  100     FORMAT(1X,'SOLUTION NOT FEASIBLE. A NEAR ZERO PIVOT WAS ENCOUNTER
        + ED. ','IPVT/I  ',2I5,' AB(IPVT,I) ',F10.5,' AB(N,N) ',F9.6,' N '
        + ,I5)
          RETURN
          END
```

ประวัติผู้ศึกษา

ชื่อ : นายสุรพงษ์ ธรรมพิทักษ์

เกิด : 16 พ.ย. 2499, เชียงราย

การศึกษา : วิศวกรรมศาสตรบัณฑิต (วศบ.โยธา) คณะวิศวกรรมศาสตร์ มหาวิทยาลัยเชียงใหม่, ปีการศึกษา 2523
เข้าศึกษาหลักสูตรวิศวกรรมศาสตรมหาบัณฑิต สาขาวิศวกรรมแหล่งน้ำ ภาควิชาวิศวกรรมโยธา คณะวิศวกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย, ปีการศึกษา 2525

การทำงาน : วิศวกรโยธา 4 กองสำรวจออกแบบ สำนักงานเร่งรัดพัฒนาชนบท