Documentation of a Computer Program (Streamlink) to Represent Direct-Flow Connections in a Coupled Ground-Water and Surface-Water Model

By Eric D. Swain

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BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
DALLAS L. PECK, Director

For additional information, write to:

District Chief
U.S. Geological Survey
Suite 3015
227 North Bronough Street
Tallahassee, Florida 32301

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Conversion Factors and Vertical Datum

Multiply	By	To obtain
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
foot per day (ft/d)	0.3048	meter per day
foot squared per day (ft^2/d)	0.09290	meter squared per day
cubic foot per second (ft^3/s)	0.028317	cubic meter per second
cubic foot per second per foot per foot [$(ft^3/s)/(ft/ft)$]	0.3048	cubic meter per second per meter per meter
cubic foot per second per mile per foot [$(ft^3/s)/(mi/ft)$]	0.05773	cubic meter per second per kilometer per meter

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [$(ft^3/d)/ft^2$]ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

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ABSTRACT

The MODFLOW finite-difference ground-water flow model has been coupled with three surface-water packages--the River, Stream, and MODBRANCH packages--to simulate surface flows and its interaction with ground water. The River package was developed to simulate leakage between the aquifer and the river with a constant head. The Stream package simulates the leakage and also routes the flow downstream with an optional calculation of river heads by Manning's equation. Finally, the most sophisticated representation of riverflow and aquifer leakage came with the coupling of the unsteady riverflow model BRANCH with the MODFLOW model through the MODBRANCH package.

To facilitate wider and more flexible uses of the packages, a computer program (Streamlink) was developed and added to MODFLOW, allowing direct flows to occur between any of the packages and MODFLOW. These flows can be calculated on the basis of water levels, by a transfer of boundary discharge, or by simply equating water levels at the interface depending on the individual configuration of each package. Streamlink is especially beneficial when simultaneously using the River, Stream, or MODBRANCH packages or when modeling a river flowing directly into or out of a wetlands in direct connection with the aquifer.

INTRODUCTION

The U.S. Geological Survey (USGS) three-dimensional ground-water flow model, MODFLOW, was introduced in 1984 as a versatile simulator of aquifer flow (McDonald and Harbaugh, 1988). The modular design of MODFLOW separates the model functions into packages. Packages are composed of modules, which are sets of subroutines. The modular design makes it easy to add new packages to widen the scope and improve the accuracy of the MODFLOW model. In addition to the packages that simulate aquifer flow, other packages are designed to simulate factors affecting the ground water such as surficial recharge, wells, surface drains, evapotranspiration, and head boundaries. Leakage to and from channels was originally simulated by the River package, which maintains a constant stage in the channel and models leakage across a confining riverbed. Flow in the channel is not modeled, and the channel behaves as an infinite source or sink.

The Stream package was developed to represent the flow conditions in the channel (Prudic, 1989). Inflows and leakages are routed instantaneously downstream, and the channel stages can be specified by the user or determined by Manning's equation, which represents steady, uniform flow. When the leakage exceeds total discharge in a channel reach, the channel is set dry, and leakage is set to the available discharge. Thus, the Stream package maintains the mass conservation between the channel and aquifer and routes the flow downstream in a more realistic way than the River package.

Although it is an improvement over the River package, the Stream package cannot model time-variant flows, backwater conditions, river junctions with varying flows in and out, reversals of flow, or nonrectangular cross sections. The USGS unsteady riverflow model, BRANCH, can simulate all of these conditions because of its use of the full dynamic flow equations (Schaffranek and others, 1981). Unlike the River and Stream packages, the BRANCH model was originally developed independent of the MODFLOW model and had to be modified to interface with MODFLOW. The leakage term was added to the equations in the BRANCH model and was coupled through the leakage quantity to the MODFLOW model by the MODBRANCH package (Swain and Wexler, 1991; 1993).

The River, Stream, and MODBRANCH packages represent successive steps in increasing the sophistication of modeling channel-flow and aquifer interaction with the MODFLOW model. The increased sophistication increases the computational time, and the simpler packages might be faster to use when their results are adequate for the situation. The surface-water packages can be used simultaneously when modeling an area with several channels--some adequately modeled with a simpler package but others requiring a more complex scheme. The only available connections between packages, however, are the leakages to and from the MODFLOW model. If the channels modeled with different packages connect to each other, no facility exists in the MODFLOW model to represent these connections, which will be referred to here as "direct" connections.

Many channel-aquifer flows are leakage through a confining layer or riverbed. Another type of connection that needs representation is that in which a channel either discharges to or gains inflow directly from a specified region of the aquifer, referred to as an aquifer block (fig. 1). In this case, there is no leakage across a porous media bed, the flow is controlled by the channel geometry, and the head is at the connection point. This is referred to here as a "direct" connection. If a wetlands or lake is being represented as a high-conductivity aquifer layer, any channel that flows in or out must be represented as a direct connection (Merritt, 1993).

The algorithm development and resultant package to represent these direct connections are described in this report. The package development is part of a study by the USGS, in cooperation with the South Florida Water Management District, to model the channel-wetlands-aquifer interactions in southern Dade County, Fla.

Purpose and Scope

This report documents a computer program added to the MODFLOW model that creates direct connections between the three channel-flow packages (the River, Stream, and MODBRANCH packages) and the MODFLOW model. This connection allows more versatility in applying the MODFLOW model and the ability to simulate a larger variety of situations, including the canal connections to wetlands and using the three channel-flow packages in conjunction with each other.

The computer program, referred to as Streamlink, is a package for the MODFLOW model consisting of modules that provide six connection types: MODBRANCH to MODFLOW, MODBRANCH to River, MODBRANCH to Stream, Stream to MODBRANCH, Stream to MODFLOW, and Stream to River. These connections involve passing water-level or discharge rates between packages, depending on the package configuration. This report includes theoretical examples of these connections and comparison with field measurements.

Methodology

If the MODFLOW model and the River, Stream, and MODBRANCH packages are viewed as separate systems, the direct connections between packages involve defining the stage or discharge boundary conditions in one package with the corresponding boundary in another package. Thus, the end of a channel in one package is the beginning of a channel in another package or the edge of an aquifer block in the MODFLOW model.

The boundary information passed depends on the formulation in each package. Thus, the MODFLOW model can pass aquifer head, which it calculates, to another package or receive recharge-discharge rates from another package, which MODFLOW uses to calculate head. The River package has no direct-flow information to pass to another package because it does not calculate heads nor surface-water flows, but the River package can receive boundary stages to which stages in some or all of its reaches can be set. The Stream package calculates surface-water flows at its downstream boundary that can be passed to another package, or surface-water flows from other packages can be used as upstream inflow. Stream can also calculate stages so the downstream stage can be used as a boundary stage

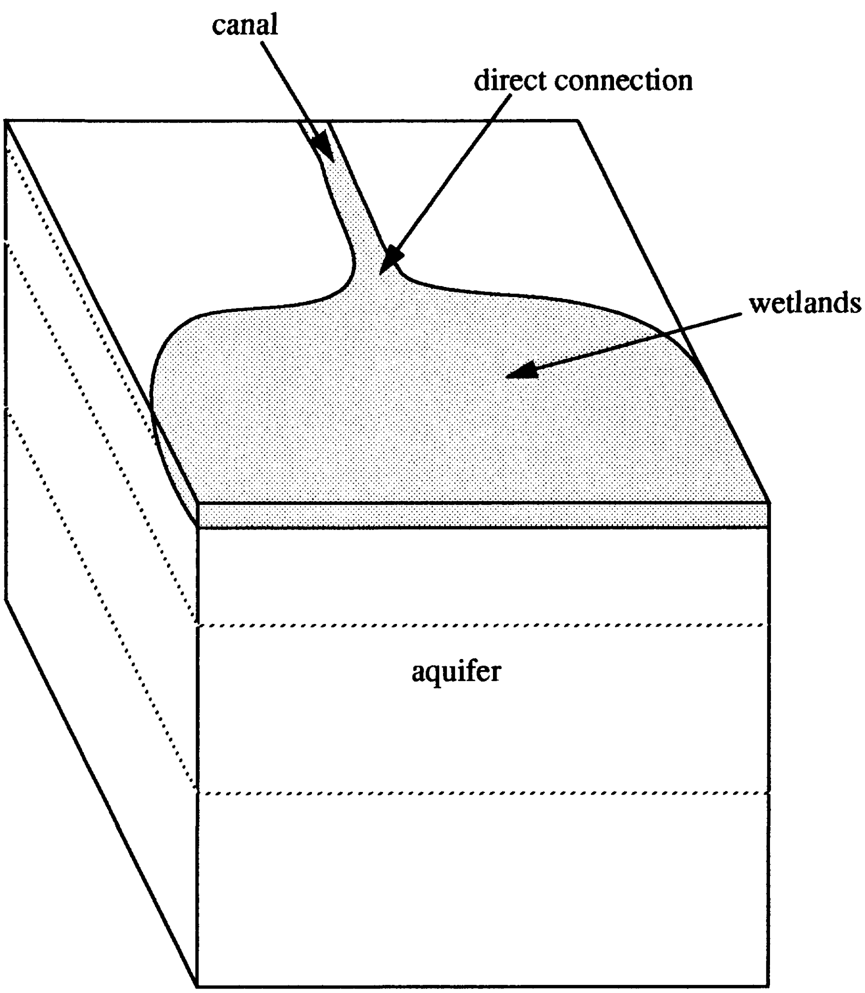


Figure 1. Channel, wetlands, and aquifer with direct connection.

in another package. Stream cannot take stage as an upstream input, however, when using Manning's equation. The BRANCH model (the surface-water computational part of the MODBRANCH package) solves the flow equations with either stage or discharge as boundary conditions. Thus, the BRANCH model can take water levels or discharge as input or output, and surface-water flow directions can be in or out of the boundary.

From the restrictions described above, a scheme of connections becomes apparent. The connections possible between the MODFLOW model and the River, Stream, and MODBRANCH packages are shown in figure 2. Dashed lines represent the leakage flows already existing between the channel packages and the MODFLOW model; solid lines represent the direct-flow connections presented in this report. Six direct-flow connections are possible. Connection 1 (fig. 2) is the representation of a channel modeled by MODBRANCH with a direct-flow connection to an aquifer block. This has the most significance when the aquifer block is representing a wetlands, lake, or overland flow layer. Connection 1 is the only direct connection with arrows on both ends, indicating that information is passed in both directions interactively.

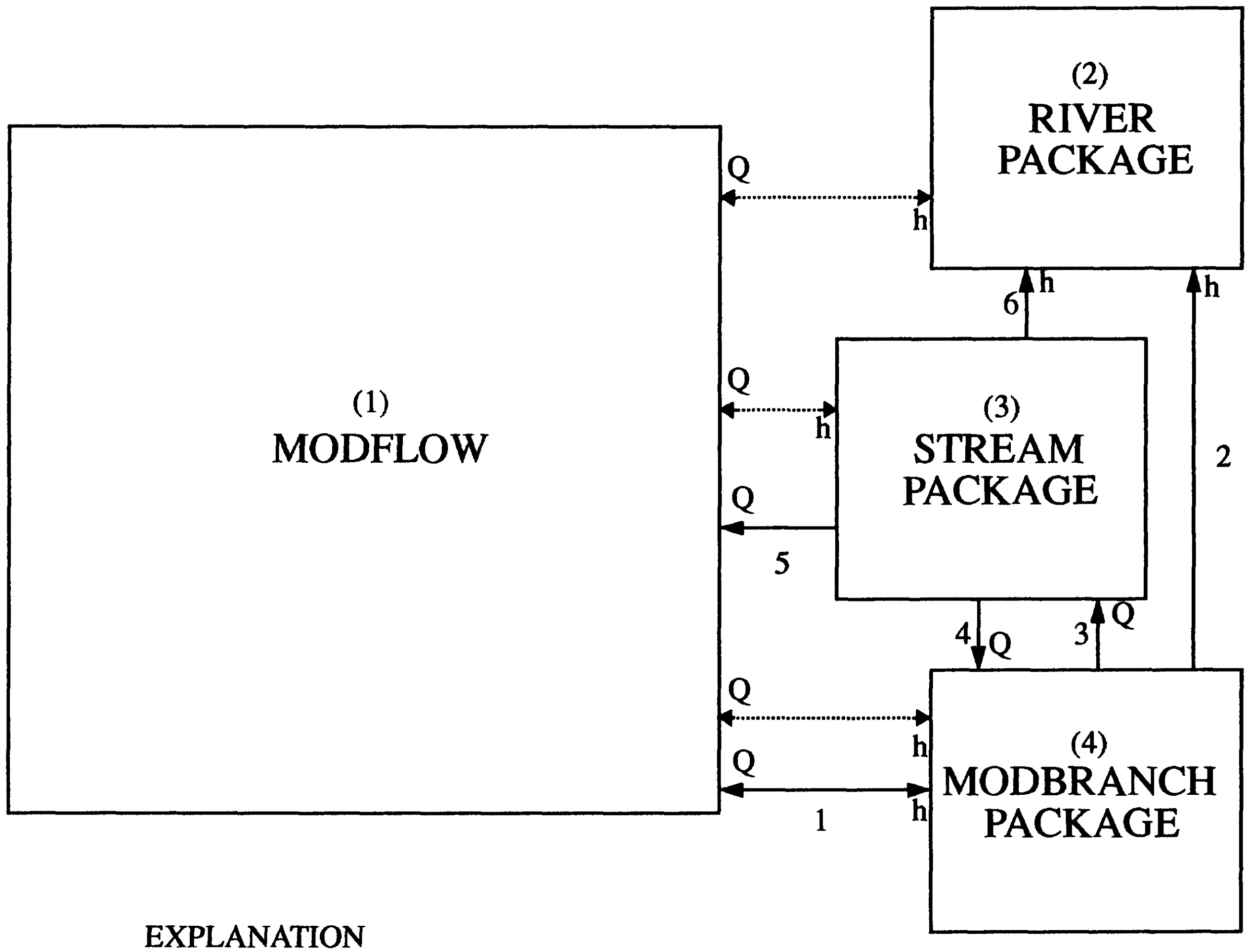
MODFLOW and MODBRANCH use an iterative solution with each program solving alternatively until a solution for a given time is converged upon (fig. 3). When connection 1 is in effect by the use of MODBRANCH, a channel boundary in MODBRANCH is defined as connecting to an aquifer block in MODFLOW. When MODFLOW calculates a value of head in the aquifer block representing the wetlands, the stage at the channel boundary in MODBRANCH is set to this value. Thus, the water level where the channel ends at the wetlands equals the water level in the wetlands. MODBRANCH uses this boundary stage when calculating stages and discharges in the entire channel network (Schaffranek and others, 1981), and a discharge value is calculated at the boundary. This discharge might be in or out of the channel, so it must be added to or subtracted from the water budget in the aquifer block representing the wetlands. By subtracting the quantity from the right-hand side of the MODFLOW flow equation (McDonald and Harbaugh, 1988, p. 2-26, eq. 26), the following is obtained:

$$V_{i,j,k-\frac{1}{2}} h^m_{i,j,k-1} + C_{i-\frac{1}{2},j,k} h^m_{i-1,j,k} + R_{i,j-\frac{1}{2},k} h^m_{i,j-1,k} + \left(-V_{i,j,k-\frac{1}{2}} - C_{i-\frac{1}{2},j,k} - R_{i,j-\frac{1}{2},k} - R_{i,j+\frac{1}{2},k} - C_{i+\frac{1}{2},j,k} - V_{i,j,k+\frac{1}{2}} + HCOEF_{i,j,k} \right) h^m_{i,j,k} + R_{i,j+\frac{1}{2},k} h^m_{i,j+1,k} + C_{i+\frac{1}{2},j,k} h^m_{i+1,j,k} + V_{i,j,k+\frac{1}{2}} h^m_{i,j,k+1} = RHS_{i,j,k} - Q \tag{1}$$

where V, C, R, HCOEF, and RHS are coefficients derived by McDonald and Harbaugh (1988, p. 2-26), h is head in aquifer block, subscripts i, j, and k are spatial coordinates, superscript m is MODFLOW time level, and Q is volumetric inflow from MODBRANCH.

MODFLOW then solves equation 1, which creates the wetlands head value to which the MODBRANCH channel boundary stage is equated. This procedure iterates according to figure 3 until a solution is converged upon. This solution satisfies the conditions that: (1) the aquifer-wetlands flow equations in MODFLOW are satisfied with the inflow-outflow calculated in MODBRANCH, and (2) the channel flow equations in MODBRANCH are satisfied with the boundary stage equivalent to the head calculated in MODFLOW.

One consideration in this connection is that the timesteps in MODBRANCH probably will be shorter than MODFLOW with multiple surface-water timesteps occurring in one ground-water timestep. When this occurs, the discharges calculated by MODBRANCH at the point of connection are added and averaged for the number of MODBRANCH timesteps corresponding to the MODFLOW timestep. This is the value passed to MODFLOW to include in the connected aquifer block. The heads calculated in MODFLOW at the beginning and end of the timestep are stored in the boundary condition array in MODBRANCH. Thus, values are interpolated in MODBRANCH for intermediate times, as it would for any boundary values. MODFLOW receives the average discharge from MODBRANCH, and MODBRANCH interpolates the heads received from MODFLOW. Because of the sophistication of both MODFLOW and MODBRANCH, this is an interactive solution. The solution in each model depends on the other. All the other direct connections involve the simpler Stream and River packages, and information can only be passed one way.



EXPLANATION

(1) MODFLOW — Package name and number

Q ◄·····► h — Existing leakage connection and direction of information transfer

—6—► Q — New direct connection, index number, and direction of information transfer

Q — Transfer of discharge between packages

h — Transfer of head between packages

Figure 2. Connections between MODFLOW and the River, Stream, and MODBRANCH packages.

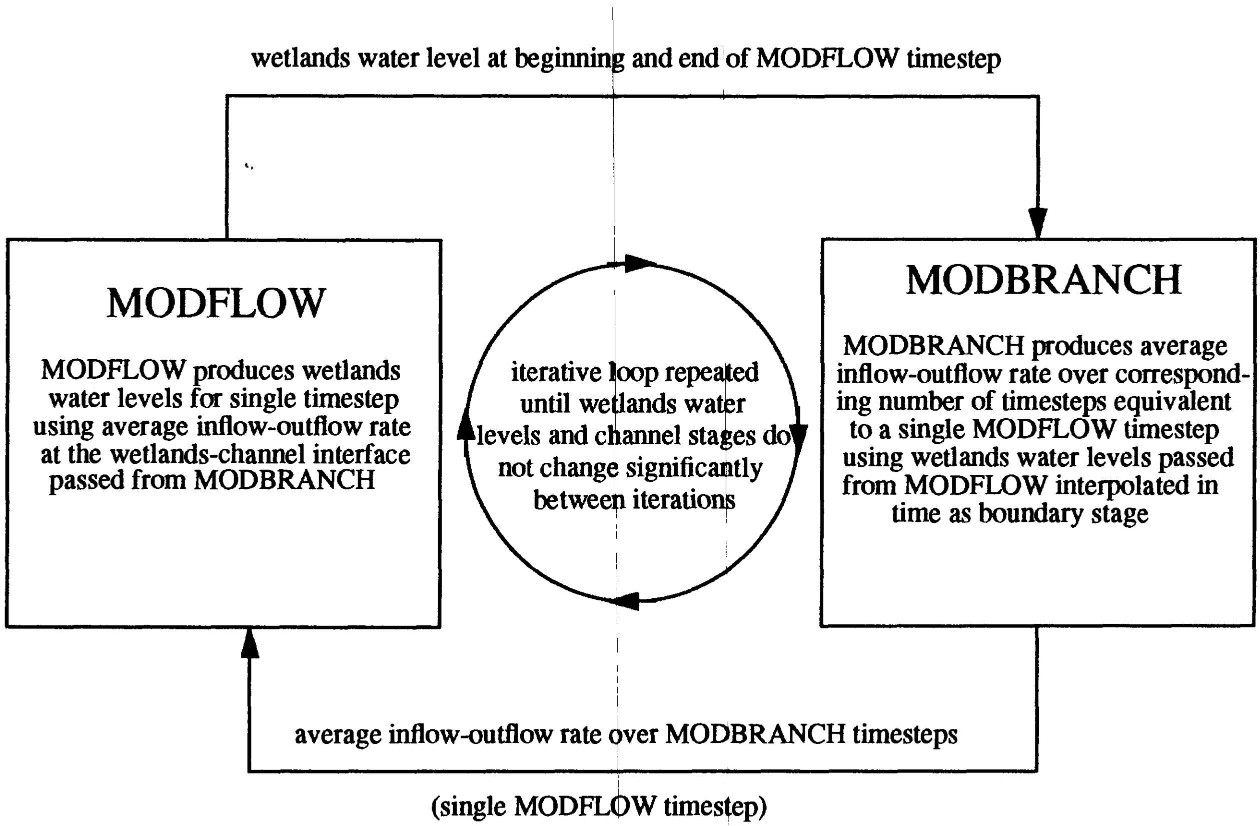


Figure 3. Iterative procedure between MODFLOW and MODBRANCH.

Connections 2, 3, and 4 (fig. 2) adjoin MODBRANCH with the Stream or River packages. These connections allow a channel network to be modeled with more than one channel package at a time. Thus, each section of the network can be modeled with the appropriate sophistication. A multiple channel junction with varying flow directions can be modeled with MODBRANCH, whereas a channel reach some distance downstream can be modeled with the Stream package. Significant computational effort can be saved by using the simpler packages when acceptable. MODBRANCH can operate as a "controller" to model key reaches in a channel network with the Stream package routing the flows delivered from MODBRANCH and calculating leakages. The River package can be used when flow routing is not of interest but leakage is needed.

Connection 2 (fig. 2) equates the stage in specified reaches in the River package to the stage at a boundary in MODBRANCH. This type of connection is useful where the water-surface profile is flat for a length of channel, controlled by upstream conditions, and the discharge routed through the flat reach is not of interest. The formulation is simple; the stages in the River package that normally remain constant reset each time a MODFLOW iteration occurs (fig. 3) to the stage calculated at the last MODBRANCH timestep. Leakage to and from channels is calculated by the River package according to this stage.

Connection 3 (fig. 2) allows discharge at a specified MODBRANCH boundary to be introduced as an upstream boundary discharge in the Stream package. Because MODBRANCH might run multiple timesteps during the MODFLOW timestep, but the Stream package only cycles once, the discharge is averaged over the multiple MODBRANCH timesteps and passed to Stream. If the option is selected in the Stream package to calculate stages by Manning's equation (Prudic, 1989), only discharge is passed from MODBRANCH to the Stream package. If the calculation of stage is not used in the Stream package, the stages in the stream reach are set to the MODBRANCH boundary stage at the end of the MODFLOW timestep. If the discharge at the MODBRANCH boundary is positive (flow into the Stream package), flow is routed normally downstream in the Stream package with leakage quantities added or subtracted normally. If the discharge at the MODBRANCH boundary is negative (flow out of the Stream package), and the calculation of stage in the Stream package is not selected, the Stream package has been modified to allow a negative or reverse discharge to be input. These reverse discharges are routed downstream, equivalent to positive flows moving upstream. Leakages are included appropriately. This negative flow option cannot be used if it is selected in the Stream package to calculate stage by Manning's equation; reversal of flows creates an error message.

Connection 4 (fig. 2) allows discharge from the downstream boundary of a channel simulated with the Stream package to be input as a MODBRANCH boundary, the reverse of connection 3. Stages are calculated in MODBRANCH, and continuity of stage across the Stream package-MODBRANCH interface is not maintained. The continuity of discharge connects the packages. If multiple MODBRANCH timesteps occur within one MODFLOW (Stream package) timestep, the discharge at the boundary is set to the flow rate in the Stream package for the MODBRANCH timesteps.

Connections 5 and 6 (fig. 2) only involve MODFLOW and the simpler Stream and River packages. These connections are included for completeness, although simulations using only the River and Stream packages without MODFLOW would be less common. Connection 5 connects the discharge at a downstream boundary of the Stream package to an aquifer block in MODFLOW. This allows a channel represented in the Stream package to connect to a wetlands, as the MODBRANCH model does in connection 1. The Stream package, however, cannot detect the backwater effects from the wetlands as does MODBRANCH, so the channel flow into the wetlands is only affected by upstream conditions in the Stream package. Connection 6 sets the stages in specified reaches of the River package to a boundary stage in the Stream package. Thus, a length of stream where volumetric budgeting is not important can be attached to a Stream package representation.

Application Criteria

The six connections (fig. 2) allow the use of MODFLOW and the River, Stream, and MODBRANCH packages in virtually any logical combination. For each channel-aquifer system, the appropriate package and connections must be selected. The most thorough and computationally time-consuming scheme would model the entire channel system with BRANCH using the MODBRANCH package. The scheme using the least computational time, but with the most simplistic representation of the channel, would be to represent the entire channel system with the River package. The appropriate scheme would be a reasonable compromise between these objectives and would require relating the channel conditions to the package that is most appropriate.

An example of a channel network with junctions; long, straight reaches; and small drainage channels is shown in figure 4. Different channel packages and flow connections are used to model the various sections and junctions of the channel network (fig. 4). Connections 1 to 4 are numbered according to the previous section (fig. 2). Connections 5 and 6 are not used. The channel junctions and boundaries are modeled by MODBRANCH, so that the distribution of flows at junctions with possible backwater effects that only MODBRANCH can simulate accurately will be determined properly. The boundaries might have reversal of flows as at the lake, wetlands, and ocean, or they might be dead ends (no flow) as shown in figure 4. MODBRANCH is also appropriate for some boundaries. The other boundaries shown in figure 4 are free flow (no backwater) and are properly modeled with the Stream package.

The Stream package is used for the long, uninterrupted reaches; therefore, this configuration would be inappropriate if abrupt flood waves were passing down the channel (for example, a dam break). The Stream package would route these waves instantaneously. The Stream package channels should be replaced by MODBRANCH in this case.

The River package is used on the small drainage channels shown in figure 4. When using the River package, these channels are assumed to be so small that the flows are insignificant compared to the flow in the main channels. Much computational effort is saved by representing these channels with the River package. To model such a crisscross network with MODBRANCH would greatly increase the size of the solution matrix and computational time.

Caution and thought must be used in applying the different channel packages. The criteria described above are valid, but analysis of the flow patterns in the channels needs to be considered to ensure that an overly simplistic package is not being used for a complex flow regime or that a complex package is not being used unnecessarily.

DOCUMENTATION OF THE COMPUTER PROGRAM (STREAMLINK)

The direct-flow connection (Streamlink) package is arranged in a format similar to the other packages in MODFLOW. In addition to using existing variables in MODFLOW and the MODBRANCH, Stream, and River packages, several new variables were created for the Streamlink package.

A code was developed to define the connection type. A number is assigned to each unit as follows: 1, MODFLOW; 2, River package; 3, Stream package; and 4, MODBRANCH package. Thus, a two-digit connection number defines the two packages connected. The connections described in the "Methodology" section are coded as follows: 41, MODBRANCH boundary connected to aquifer block; 42, MODBRANCH boundary connected to River package reaches; 43, MODBRANCH boundary connected to Stream package upstream boundary; 34, downstream Stream package boundary connected to MODBRANCH boundary; 31, downstream Stream package boundary connected to aquifer block; and 32, downstream Stream package boundary connected to River package reaches. These codes are stored in the variable NCODE described later.

Implementation in MODFLOW

The connection package is divided into allocation, read and process, formulation, and budget modules (similar in format to the other packages in MODFLOW). The main program in MODFLOW must be modified to call the four modules in the connection package. If the main program has not already been modified to call the MODBRANCH package (Swain and Wexler, 1993), MODBRANCH cannot be used and only connections 31 and 32 are valid.

The call to the connection package is made by assigning a positive integer to a selected element of the 24 element array IUNIT. The value of the IUNIT element used to call the connection package is the FORTRAN unit number assigned to the connection package data set. This value is read by MODFLOW during execution of the Basic package (McDonald and Harbaugh, 1988, p. 4-9 to 4-12). The following FORTRAN statements must be present within the main section of MODFLOW to call the connection package. The notation IUNIT(??) indicates that any element of IUNIT from 13 to 24 might be used. Elements 1 to 12 are already being used in most implementations of MODFLOW.

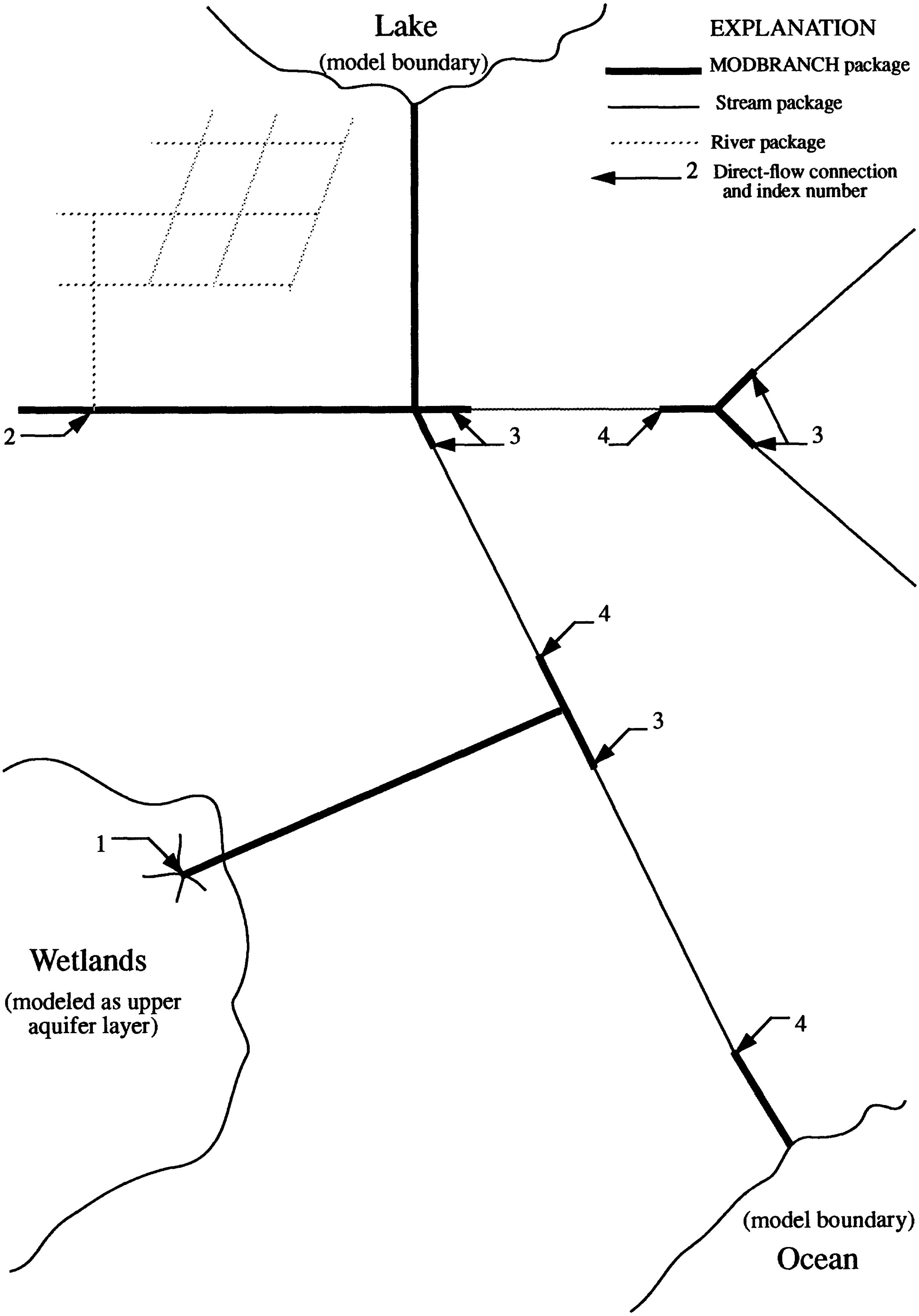


Figure 4. Typical channel-wetlands-aquifer system.

SLK1AL allocates space in main array for variables used in the connection package. The FORTRAN call for SLK1AL is:

```
IF (IUNIT(??).GT.0) CALL SLK1AL (ISUM, LENX, MAXCON, LNCODE,
1 LNFROM, LNTO, IUNIT(??), IOUT)
```

SLK1RP reads in the number and type of connections and locations where connections occur. The FORTRAN call for SLK1RP is:

```
IF (IUNIT(??).GT.0) CALL SLK1RP (MAXCON, NCON, X(LNCODE),
1 X(LNFROM), X(LNTO), IUNIT(??), IOUT, IUNIT, LZQ, LIBJNC,
2 LQLSUM, LIJF, LIJT, LZN, LXSKT, LNSEC, NBND, MAXZBD,
3 MXTDBC, MXJN, MAXS, MXBH, NBCH, LCRIVR, MXRIVR, LCSTRM,
4 LCSTRM, MXSTRM, LENX, LENY)
```

SLK1FM transfers head and flow values at connection points. The FORTRAN call for SLK1FM is:

```
IF (IUNIT(??).GT.0) CALL SLK1FM (NCON, X(LNCODE), X(LNFROM),
2 X(LNTO), Y(LZQ), Y(IBJNC), X(LCHNEN), X(LCRHS), X(LQLSUM),
3 X(LCIBOU), NCOL, NROW, NLAY, NBND, MAXZBD, MXTDBC, MXJN,
4 MAXCON, MAXS, TFCTR, ZDATUM, X(LCHOLD), NELAP, MXBH, MXRIVR,
5 Y(LIJF, Y(LIJT), Y(LXSKT), X(LCRIVR), Y(LZN), NBCH, X(ICSTRM),
6 X(LCSTRM), MXSTRM, Y(LNSEC), NSTREM, ICALL)
```

SLK1BD calculates volumetric budgets at connections between surface water and ground water. The FORTRAN call for SLK1BD is:

```
IF (IUNIT(??).GT.0) CALL SLK1BD (NCON, X(LNCODE), X(LNFROM),
1 X(LNTO), Y(LIBJNC), MAXCON, MAXS, Y(LQLSUM), X(LCIBOU), NCOL, NROW, NLAY,
2 NBND, MXJN, VBVL, VBNM, MSUM, TFCTR, DELT, NSTREM, MXSTRM,
3 X(ICSTRM), X(LCSTRM)
```

The user must specify a number between 13 and 24 for IUNIT(??), which is defined in the Basic package (McDonald and Harbaugh, 1988, p. 4-9 to 4-12). For the example main program, 14 was selected for the connection package. When the connection package is used, a positive number is specified at the proper location in the Basic package. This number corresponds to the FORTRAN unit number assigned to the connection package input data set.

The SLK1AL call statement is added where space is allocated to the X array (between comments C4 and C5 in the main program). The SLK1RP call statement is added where information for a package is read and prepared for each stress period (between comments C7B and C7C in the main program) after the calls to RIV1RP and STR1RP. The SLK1FM call statement is added where the finite difference equations are formulated for each timestep (between comments C7C2A and C7C2B) before the calls to RIV1FM, STR1FM, and BRC1FM. The SLK1BD call is added where budget terms are calculated for each timestep (between comments C7C4 and C7C5 in the main program).

Input Instructions

For each simulation:

SLK1AL

1 Data: MAXCON	Format: I10

For each stress period:

SLK1RP

2 Data: ITMP	Format: I10
3 Data: NCODE(I)	Format: I10
NFROM(I,1)	I10
NFROM(I,2)	I10
NFROM(I,3)	I10
NTO(I,1)	I10
NTO(I,2)	I10
NTO(I,3)	I10

Item 3 is repeated for the number of connections (I=1 to NCON) to write the three data arrays (NCODE, NFROM, AND NTO).

The following is an explanation of fields used in input instructions:

MAXCON The maximum number of connections that can exist during the simulation.

ITMP A flag and a counter. If ITMP is negative, the connections will be the same as in the last stress period. If ITMP is greater than or equal to zero, ITMP will be the number of connections in the current stress period (NCON).

NCODE(NCON) Connection number. A two digit integer array specifying the type of connections.

NCODE	CONNECTS
31	STREAM DOWNSTREAM BOUNDARY TO MODFLOW BLOCK
32	STREAM DOWNSTREAM BOUNDARY TO RIVER REACHES
34	STREAM DOWNSTREAM BOUNDARY TO MODBRANCH BOUNDARY
41	MODBRANCH BOUNDARY TO MODFLOW BLOCK
42	MODBRANCH BOUNDARY TO RIVER REACHES
43	MODBRANCH BOUNDARY TO STREAM UPSTREAM BOUNDARY

NFROM(NCON,1) For the Stream package (NCODE = 31, 32, or 34) the segment number (Prudic, 1989) that flows into the direct connection. For the MODBRANCH package (NCODE = 41, 42, or 43) the junction number (Schaffranek and others, 1981) that has outflow and inflow to the direct connection.

NFROM(NCON,2) AND NFROM(NCON,3) Presently not used. In future modifications, the layer, row, and column of an aquifer block might be indicated as a direct connection source by the three NFROM elements.

NTO(NCON,1) The column number of an aquifer block in MODFLOW (NCODE = 31 or 41) or the first of up to three reach numbers in the River package (NCODE = 32 or 42), or the segment number that receives inflow for the Stream package (NCODE = 43), or the junction number that receives inflow for the MODBRANCH package (NCODE = 34).

NTO(NCON,2) The row number of an aquifer block in MODFLOW (NCODE = 31 or 41), or the second of up to three reach numbers in the River package (NCODE = 32 or 42).

NTO(NCON,3) The layer number of an aquifer block in MODFLOW (NCODE = 31 or 41), or the third of up to three reach numbers in the River package (NCODE = 32 or 42).

Module SLK1AL

Module SLK1AL allocates space in the MODFLOW X array for the NCODE, NFROM, and NTO arrays. The size of these arrays is determined from the user input value of MAXCON. NCODE specifies the type of connection, NFROM specifies where it comes from, and NTO specifies where it goes. A flowchart of the module SLK1AL is shown in figure 5. The steps in the flowchart are described below.

1. ***Identify package and initialize maximum number of connections (MAXCON).*** The package description is printed to the output file, and the value of the maximum number of connections that will occur during the simulation is read in (MAXCON).

2. ***Add amount of space used by Streamlink to X array.*** The space used by the NCODE, NFROM, and NTO arrays is allocated in MODFLOW's main X array.

3. ***Print number of spaces used by Streamlink.*** The amount of space used by the connection package is printed, and, if space is not sufficient in the X array, an error message appears.

4. ***Return.*** Return to main program in MODFLOW.

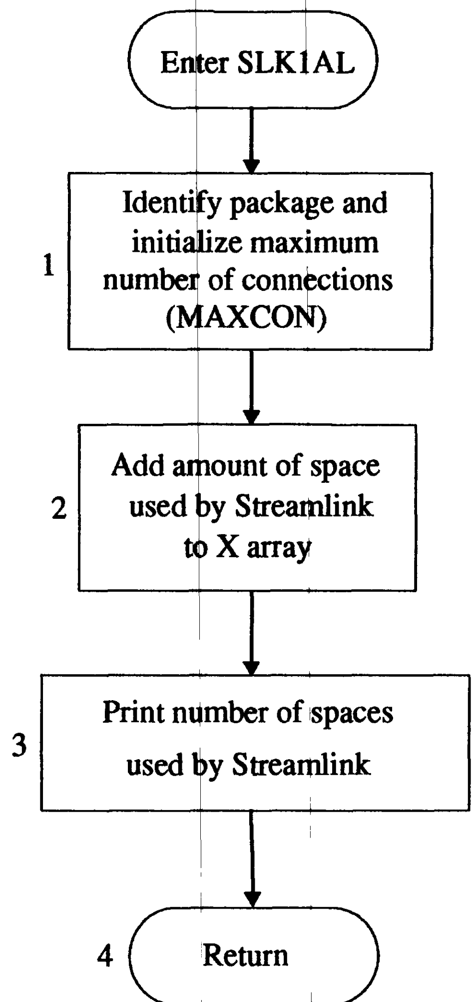


Figure 5. Flowchart of module SLK1AL (numbers refer to steps).

Module SLK1RP

Module SLK1RP reads in the data, specifying connection types and locations. It also initializes values of variables used in the formulation module. A flowchart of the module SLK1RP is shown in figure 6. The steps in the flowchart are described below.

1. ***Read and test ITMP***. The value of ITMP is read in. If the value is less than zero, connection values from the last stress period are used. If it is greater than or equal to zero, ITMP is the number of connections in the present stress period and NCON is set at ITMP.

2. ***Check NCON and print values.*** If NCON is greater than MAXCON, an error message is printed and execution is stopped. The value of NCON is printed, and, if it is zero, control returns to the main program.

3. ***Read and print connection types and input-output locations.*** For each of the NCON connections, the type of connection (NCODE), the input location (NFROM), and the output location (NTO) are read in. The values of these variables are printed.

4. ***Variables for surface-water packages not used are set to dummy values.*** If any of the surface-water packages (River, Stream, or MODBRANCH) are not used, their variables will be not initialized. However, dummy values are assigned, and their values are passed to the formulation module.

5. ***Return***. Return to main program.

Module SLK1FM

Module SLK1FM passes head or discharge values at connections between packages. A flowchart of the module SLK1FM is shown in figure 7. The steps in the flowchart are described below.

1. ***If NCON is less than or equal to zero, return to main program.***

2. ***If NCODE equals 41, equate MODBRANCH stage to aquifer head and aquifer inflow-outflow to MODBRANCH discharge.*** When NCODE equals 41, a connection between a channel modeled by MODBRANCH and an aquifer block is signified. If the specified aquifer block is designated inactive in MODFLOW, no transfer is made. The MODBRANCH stage boundary data at the connection is set to the aquifer heads at the beginning and end of the MODFLOW timestep for interpolation by MODBRANCH. The value of average flowrate across the connection, stored in the MODBRANCH variable QLSUM, is subtracted from the RHS value in the MODFLOW aquifer block, thus, contributing this flow to the aquifer.

3. ***If NCODE equals 42, equate River stage to MODBRANCH stage for all River reaches specified.*** After locating the MODBRANCH junction specified by NFROM, the stages in the River reaches specified by NTO (up to three reaches specified) are set to the stage value at the MODBRANCH junction at the end of the MODFLOW timestep.

4. ***If NCODE equals 43, set Stream upstream boundary discharge to MODBRANCH downstream discharge.*** If heads are not calculated by Stream, Stream heads are assigned from MODBRANCH. The MODBRANCH junction specified by NFROM is located. If stages are being calculated (ICALC greater than zero) in the Stream package, and the flow at the MODBRANCH junction is negative (into MODBRANCH), an error message states that Stream stages cannot be calculated and the program stops. If the program continues, the flow at the entrance of the Stream segment specified by NTO is set to the flow at the specified MODBRANCH junction (QLSUM). Also, if heads are not calculated in Stream (ICALC less than zero), the heads in the entire Stream segment specified by NTO are set to the value at the MODBRANCH junction.

5. ***Is flow negative***? If flow is negative, an error message is printed and execution is stopped. If it is not negative, return to the main program.

6. ***If NCODE equals 34, set MODBRANCH upstream boundary discharge to Stream downstream boundary discharge.*** The MODBRANCH junction specified in NTO is located. The flow at this MODBRANCH junction is set to the flow at the downstream end of the Stream segment specified by NFROM. The sign convention (flow in or out) is maintained.

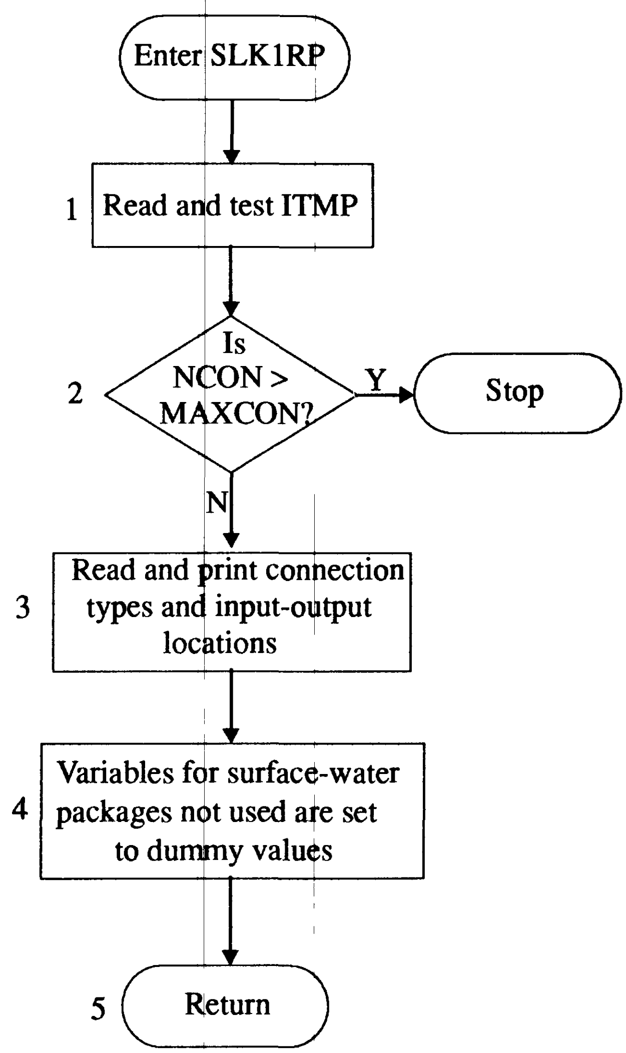


Figure 6. Flowchart of module SLK1RP (numbers refer to steps).

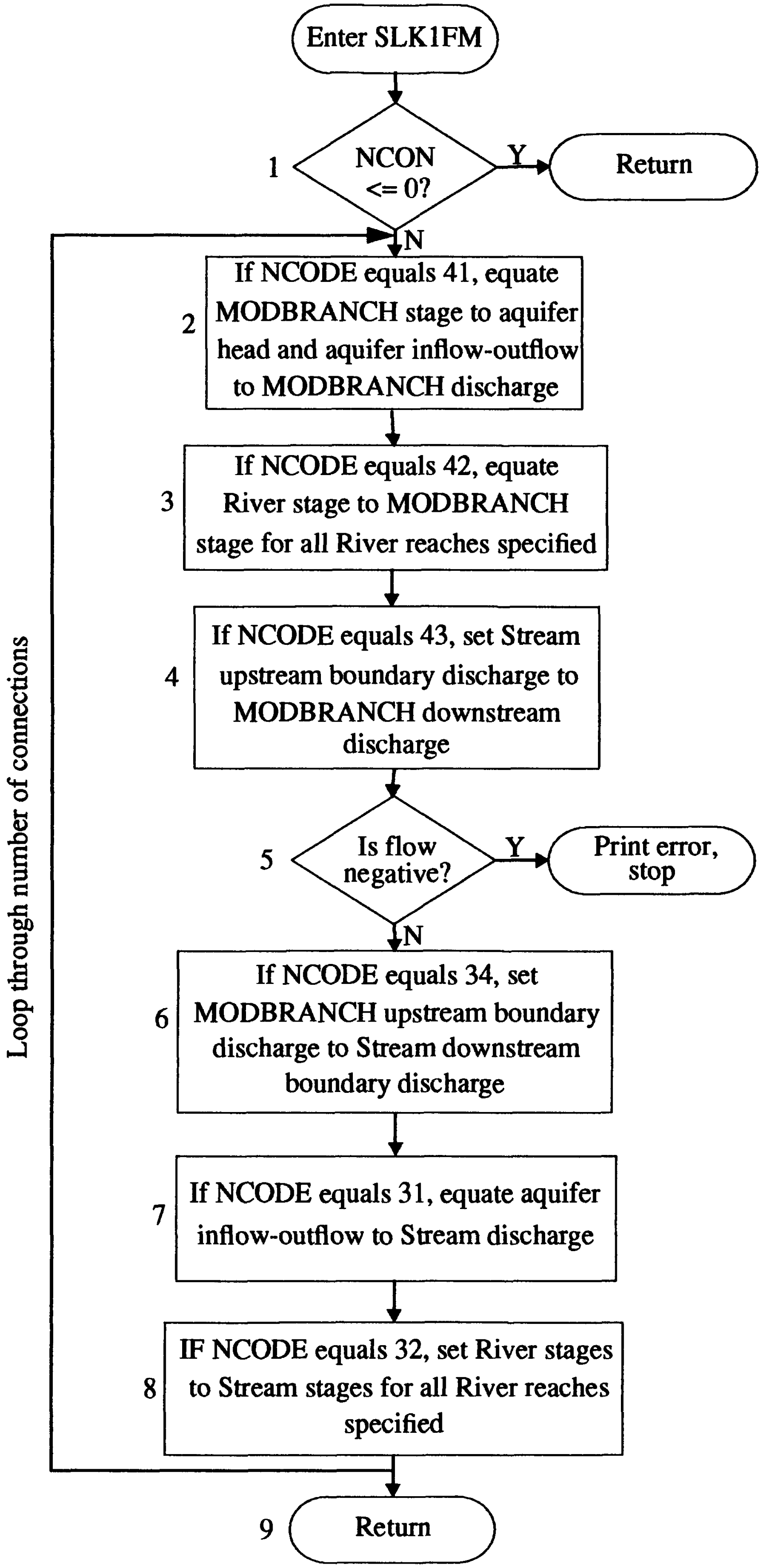


Figure 7. Flowchart of module SLK1FM (numbers refer to steps).

7. ***If NCODE equals 31, equate aquifer inflow-outflow to Stream discharge.*** Unless the aquifer block specified in NTO is designated inactive, the outflow from the Stream segment specified by NFROM is added to the aquifer block. This is done by subtracting the flow from the RHS value in MODFLOW.

8. ***If NCODE equals 32, set River stages to Stream stages for all River reaches specified.*** The stages in the River reaches specified by NTO (up to three reaches specified) are set to the stage value at the downstream end of the Stream segment specified by NFROM.

9. ***Return.*** Return to MODFLOW.

Module SLK1BD

Module SLK1BD calculates volumetric budgets between the aquifer and channels that occur through direct-flow connections. This only involves connections 41 and 31. A flowchart of the module SLK1BD is shown in figure 8. The steps in the flowchart are described below.

1. ***Clear RATIN, RATOUT, RATINS, AND RATOUS accumulators.*** The values for flow in and out of MODBRANCH (RATIN and RATOUT) and in and out of Stream (RATINS and RATOUS) are set to zero as well as flags, indicating whether connections 41 and 31 are made. If there are no connections, go to step 4.

2. ***Accumulate flows for aquifer-MODBRANCH connection.*** The flag indicating an aquifer-MODBRANCH connection is set (ISETB=1), and the locations of the MODBRANCH junction defined by NFROM and the aquifer block defined by NTO are indicated. If the aquifer block is inactive, it is ignored. Positive flows (flows into aquifer) are added to RATIN, and negative flows (flows out of aquifer) are added as positive values to RATOUT.

3. ***Accumulate flows for aquifer-Stream connection.*** The flag indicating an aquifer-Stream connection is set (ISET=1). If the aquifer block is inactive, it is ignored. Positive inflows (flow into aquifer) are added to RATINS, and negative flows (flows out of aquifer) are added as positive values to RATOUS.

4. ***Rates are stored for aquifer-MODBRANCH connection.*** The RATIN and RATOUT rates are moved in locations in the VBVL array for printing by the MODFLOW subroutine BAS1OT. The RATIN and RATOUT values are multiplied by the timestep and added to the accumulator locations in VBVL. The budget term labels are put in locations in the VBNM array for printing, and the budget term counter (MSUM) is incremented by one.

5. ***Rates are stored for aquifer-Stream connection.*** The RATINS and RATOUS rates are moved into the VBVL array for printing by the MODFLOW subroutine BAS1OT. The RATINS and RATOUS values are multiplied by the timestep and added to the accumulator locations in VBVL. The budget term labels are put in locations in the VBNM array for printing, and the budget term counter (MSUM) is increased by one.

6. ***Return.*** Return to MODFLOW.

Modifications to Stream Package

Several modifications were made to the Stream package to make it work with the connection package. The sole purpose of these modifications is to allow the Stream package to route flows in the reverse direction from the defined positive flow direction. The Stream package cannot use Manning's equation to calculate stages when flows are reversed, so this option is only used when stages are being assigned values from boundary stages in MODBRANCH (option 43).

As stated in step 4 of the narrative for module SLK1FM, the upstream input discharge in the Stream discharge package is set equal to the boundary discharge in MODBRANCH. If the discharge at the MODBRANCH boundary is into the channel modeled by MODBRANCH, a negative number is passed to the Stream package as the upstream discharge. This negative value is routed downstream, equivalent to positive flow being routed upstream. The leakage out of the channel is normally subtracted from the flow when the flow is positive. This is also correct when the flow is negative because the leakage out of the channel, when subtracted from the negative channel discharge, is seen as a loss of flow when the discharge direction and sign are reversed. Tributaries and diversions function the same as in the original code, except that negative tributary flows (actually a diversion) and negative diversion flows (actually a tributary) can be assigned. Normally, in this scheme, any tributary or diversion junction would be handled by MODBRANCH and not by the Stream package.

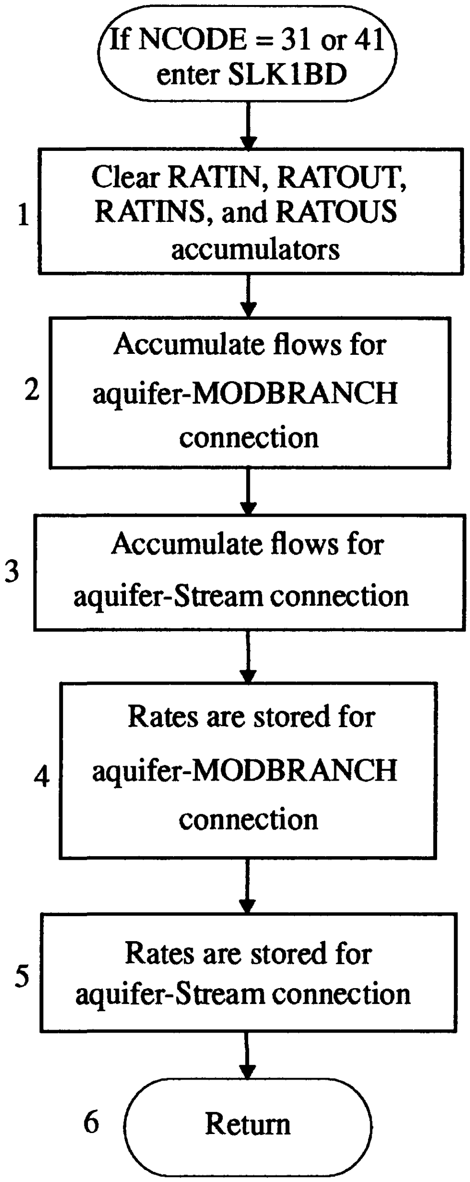


Figure 8. Flowchart of module SLK1BD (numbers refer to steps).

In the original Stream package code, when the discharge in a reach becomes zero, the reach is considered dry and the stage is set to the level of the riverbed. However, this is not desired when discharge is fed upstream from the MODBRANCH model and might become negative. The Stream package code was modified so that when Manning's equation is not being used (stage values assigned from MODBRANCH), the channels are not made dry when the discharge becomes zero or less.

Also, in the original Stream package code, a tributary is defined by setting the inflow discharge to a negative number. The program modifications then allow negative flows in the reach, so in the new scheme a tributary is defined by setting the inflow to a number greater than 5.0×10^{14}. The modified code is shown in the appendix with the new code in **bold**.

The modifications made to the Stream package described above are not necessary to many applications of the connection package. The modifications are only needed when reversal of flows occurs at an inflow connection with MODBRANCH.

REPRESENTING DIRECT-FLOW CONNECTIONS

Model runs were made to test the operation and functioning of the Streamlink package. Because MODFLOW and the River, Stream, and MODBRANCH packages have undergone testing in their documentation process, the main focus of these runs was to check that the quantities were being passed correctly through the connections. A small field situation, however, is included to show practical applications. The six possible connections were tested for computational accuracy. The test cases presented here do not include all of these tests. A more rigorous test of the connection package field capabilities will be made when a model of the southern part of Dade County is constructed using MODFLOW, the three channel packages, and the connection package.

Test Case 1: MODFLOW-MODBRANCH and MODBRANCH-River Connections

This section gives a general description of the channel-wetlands-aquifer. Results of test case 1 are also presented. This hypothetical channel-wetlands-aquifer scenario is shown in figures 9 and 10. The example shows how the MODFLOW-MODBRANCH and MODBRANCH-River connections function, and how they can be used to represent a canal filling and draining a wetlands.

General Description

The model area is 1,250 ft x 1,250 ft and features a surficial aquifer system completely overlain by an overland flow area (wetlands). The aquifer has a transmissivity of 240,000 ft^2/d (a normal value in southern Florida) and a storage coefficient of 0.00002. Land surface is 8.60 ft above sea level. The leakage coefficient between the overland flow and the underlying aquifer is 0.24 per day. A canal reaches from the northern boundary down past the center of the aquifer area. An impermeable levee is present on both sides of the canal; the levees and the canal terminate 300 ft from the southern boundary. Flow down the canal discharges into the wetlands at this point. A secondary channel connects to the main channel, 625 ft from the northern boundary and extends due east to the eastern boundary. The main channel is 25 ft wide, rectangular, with a slope of 0.0004. The bottom altitude of the channel is 8.60 ft above sea level at the northern boundary and 8.22 ft above sea level where the channel outflows into the wetlands. The secondary channel has a width of 10 ft and a flat slope with a bottom elevation of 8.34 ft above sea level. Manning's n for the channels is 0.030. The leakage coefficient for the riverbed is 8.64 per day.

For purposes of modeling, the aquifer was divided into seven rows and five columns as shown in figure 9. Narrow blocks are placed around the channels to obtain finer discretization of head. Two layers are used in the model. The upper layer represents the overland flow and is given a hydraulic conductivity of 3,000,000 ft/d and a specific yield of 1.0. (The hydraulic conductivity value was determined to work well for representing overland flow according to Merritt (1993). The model blocks in the first layer that contain the main and secondary channels are made into no-flow cells. This simulates the impermeable levees on the sides of the channels. The cross section that is represented is shown in figure 10.

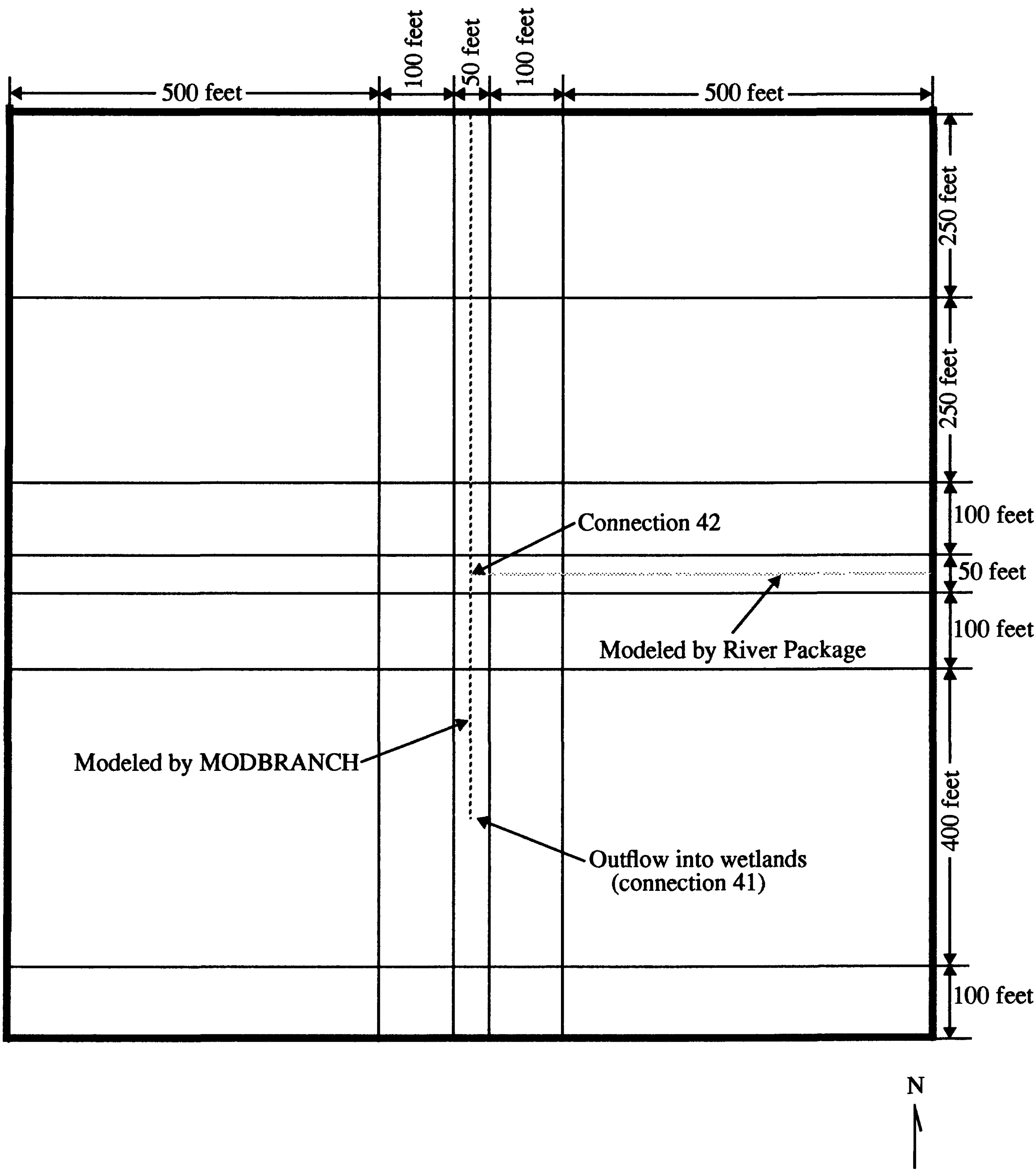


Figure 9. Channel-wetlands-aquifer system for test case 1.

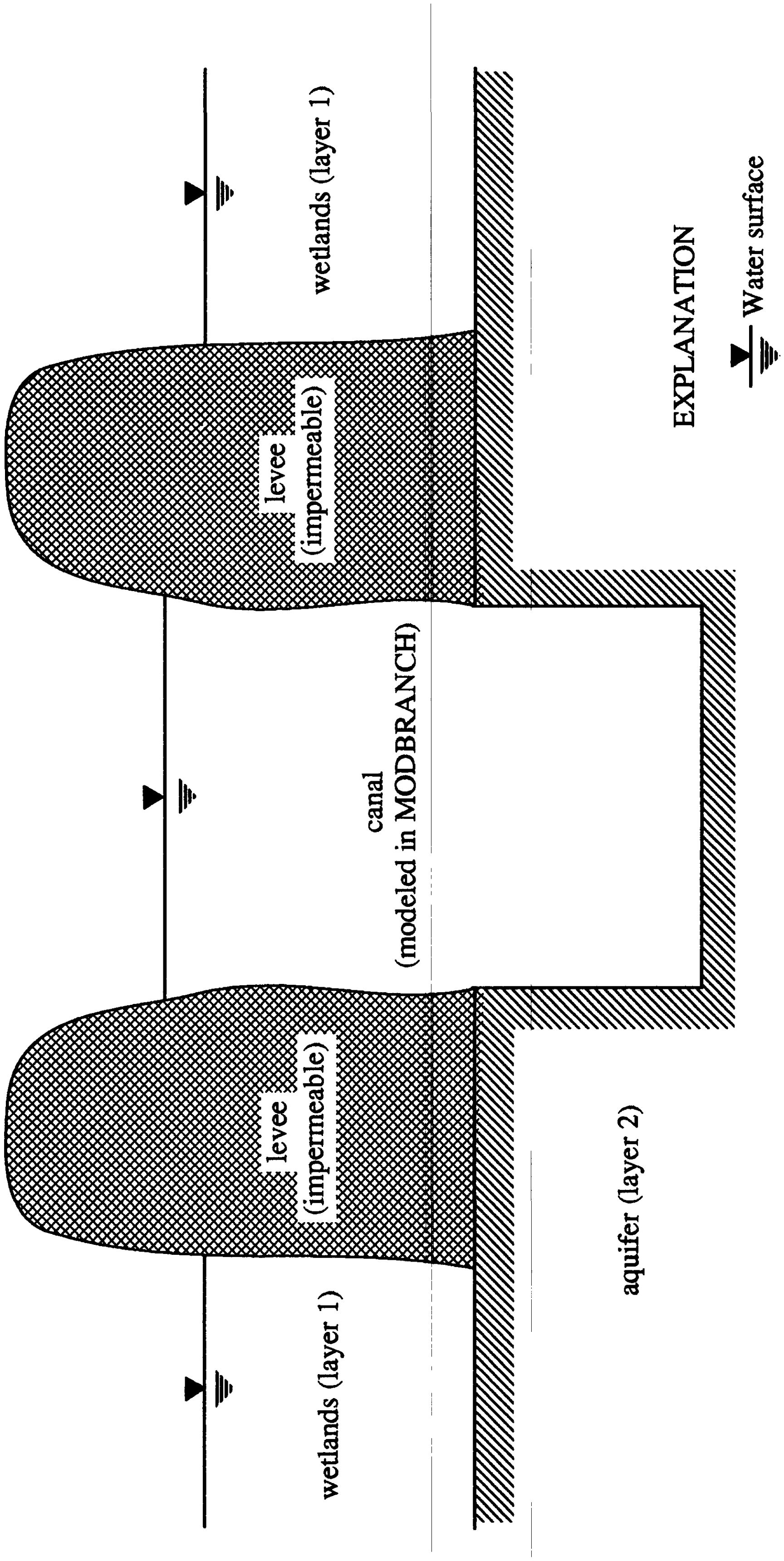


Figure 10. Channel cross section, levee, and wetlands.

Timesteps of 30 minutes in MODFLOW and 6 minutes in MODBRANCH are used. The main and secondary channels are specified to be in hydraulic connection with the second layer, simulating leakage only through the bottom of the channel to the aquifer.

The main channel is modeled with MODBRANCH, and Streamlink is used to connect the end of the main channel with the overland flow layer (connection 41). The secondary channel is modeled with the River package, adjoined with MODBRANCH by connection 42. Thus, the stage in the secondary canal is maintained equal to the stage at its boundary with the main channel. This should be a reasonable estimate if stage changes are not too rapid because the bottom of the secondary channel does not slope.

The aquifer boundaries on all sides are no flow, so water can only enter or leave the system by the channel inflows and outflows. The head in the aquifer and water level in the wetlands are set to an initial value of 9.22 ft above sea level. The initial discharge is 5 ft^3/s into the model at the upstream boundary of the main channel. The stage is initialized at a 1-ft depth throughout the main and secondary channels. The simulation lasts for 8 hours with the only change in boundary conditions being the inflow at the northern boundary of the channels. The flow is changed linearly from 5 ft^3/s at 1.5 hours to a flow of -5 ft^3/s (exiting the northern boundary) at 6.5 hours and is maintained throughout the rest of the simulation.

Results

The discharge hydrographs input to or produced by the MODBRANCH model at three points in the channel are shown in figure 11. The three points (fig. 9) are the northern inflow boundary, the point at which the channel discharges into the wetlands, and the point at which the main channel flows into the secondary channel (modeled by the River package). The inflow to the wetlands occurring in MODFLOW is also plotted in figure 11. Comparing the canal outflow to the wetlands in MODBRANCH with that computed in MODFLOW indicates a close match--the only difference resulting from the varying timesteps in the two models. Also, when discharge in the northern boundary begins to reduce, discharge to the secondary canal shows the quickest response (fig. 11). Flow to the wetlands remains constant longer. As the inflow to the channel reaches zero, flow to the wetlands drops dramatically and the wetlands discharge to the channel (to the north).

Water levels in the wetlands (layer 1) and heads in the underlying aquifer (layer 2) at 1, 4, 6, and 8 hours after the simulation begins are shown in figures 12 to 15. At 1 hour, flow from the main channel into the wetlands has caused a substantially higher water level around the inlet (fig. 12). Water levels in the wetlands in the northeastern part of the modeled area are not greatly affected because of the sheltering effects of the levees. The major effect on the aquifer heads seems to be downward seepage from the higher wetlands area. However, aquifer heads are higher near the main and secondary channels because of leakage from the channel and higher than water levels in the overlying wetlands in some areas.

Water levels in the wetlands and aquifer heads at 4 hours are shown in figure 13. Flow into the main channel from the northern boundary is almost zero at 4 hours; however, about 3.5 ft^3/s is still entering the wetlands (fig. 11). Water levels in the wetlands continue to rise, and the mound of water in the wetlands is propagating farther north with the northeastern area still protected from most of the overland flow effects by the levees (fig. 13). The underlying aquifer shows the combined effects of both downward seepage from the wetlands and leakage from the channels.

At 6 hours, flow in the main channel (fig. 11) was negative (to the north). A slight lowering of water levels in the wetlands has occurred at the channel mouth because of the flow into the channel (fig. 14). Heads in the underlying aquifer have become more uniform since this reversal of flow in the main channel.

At 8 hours, water levels in the wetlands levels have dropped sharply at the channel mouth as shown in figure 15. This also causes a concurrent lowering of heads in the aquifer below the channel mouth.

Test Case 2: MODBRANCH-Stream Connection

This section gives a general description of the channel-aquifer system used to test MODBRANCH-Stream connections. Results of neglecting backwater effects, as is the case when Stream or River are used separately, are also presented. This hypothetical channel-aquifer system is shown in figure 16.

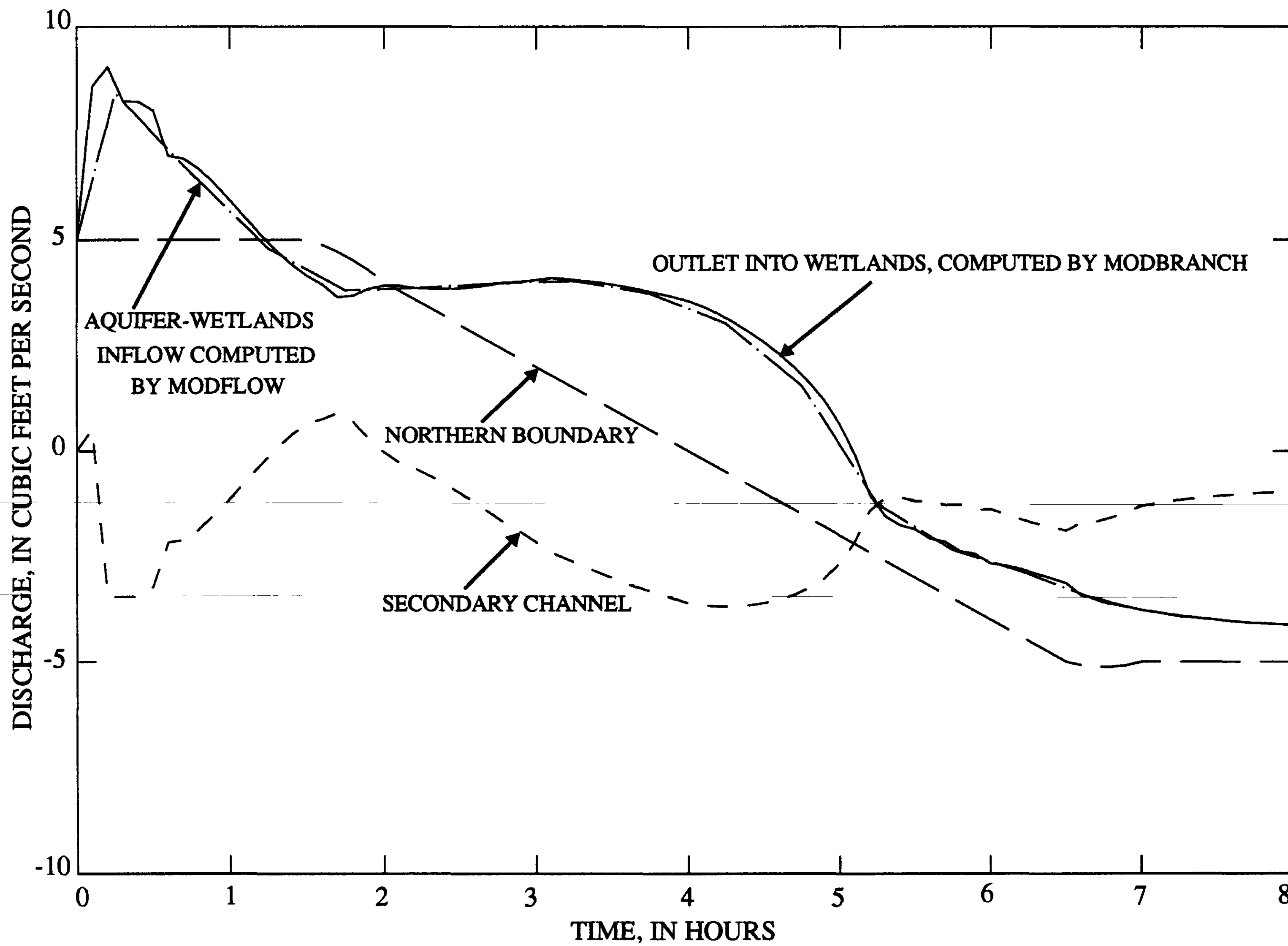


Figure 11. Hydrograph showing discharge in channel with wetlands inflow.

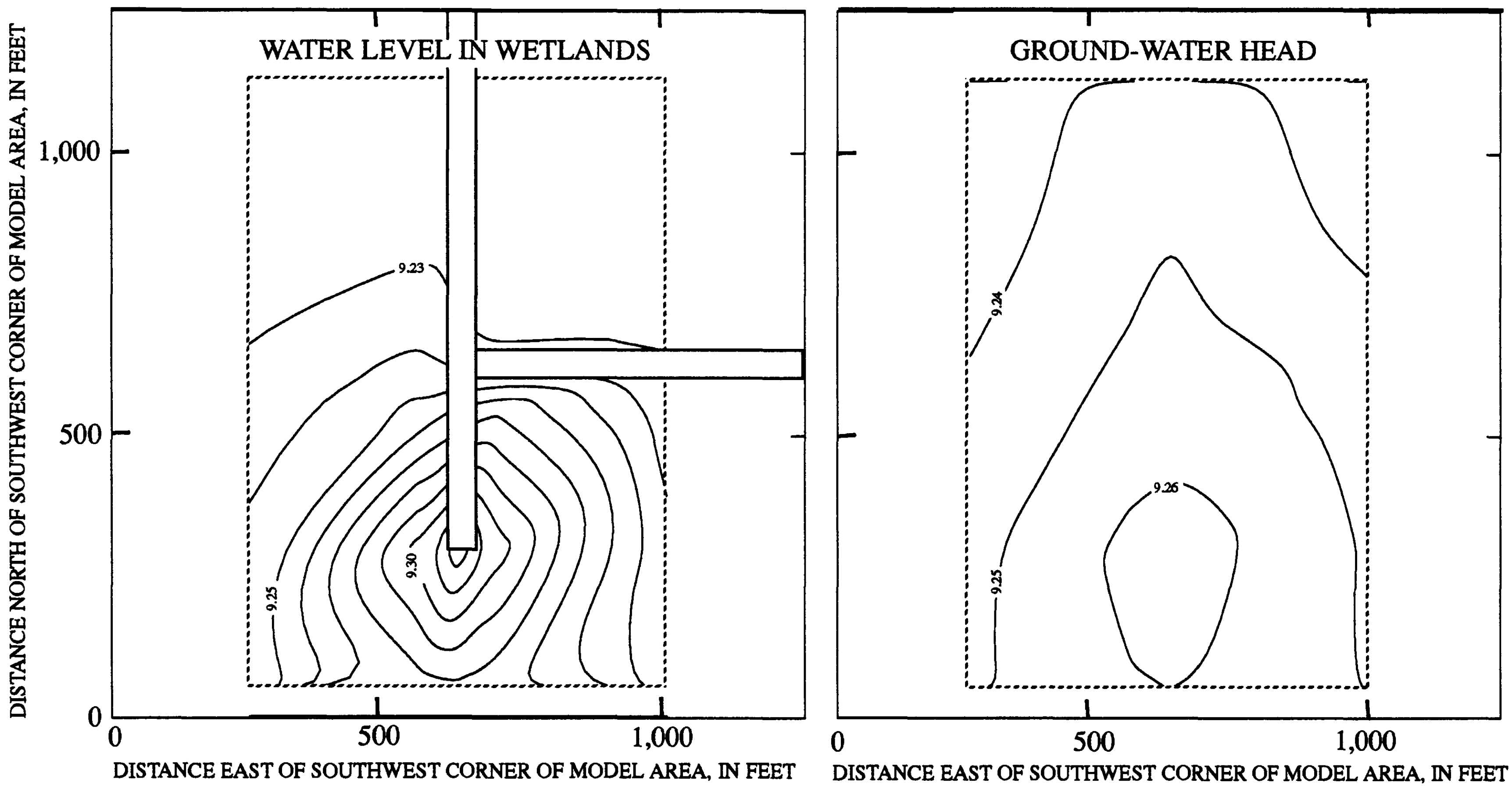


Figure 12. Water-levels in the wetlands (layer 1) and ground-water heads in the underlying aquifer at 1 hour (contour interval 0.01 foot).

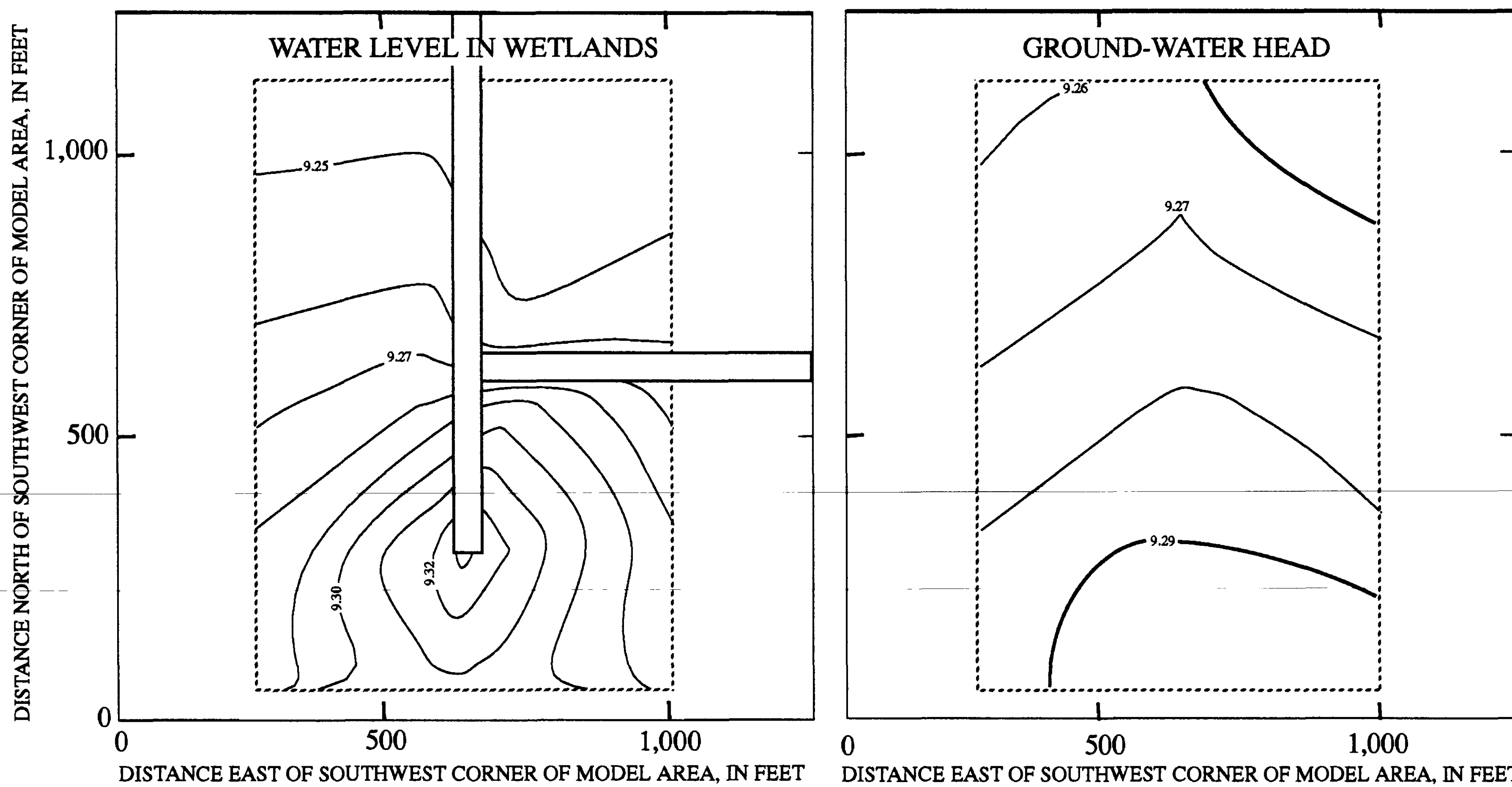


Figure 13. Water-levels in the wetlands (layer 1) and ground-water heads in the underlying aquifer at 4 hours (contour interval 0.01 foot).

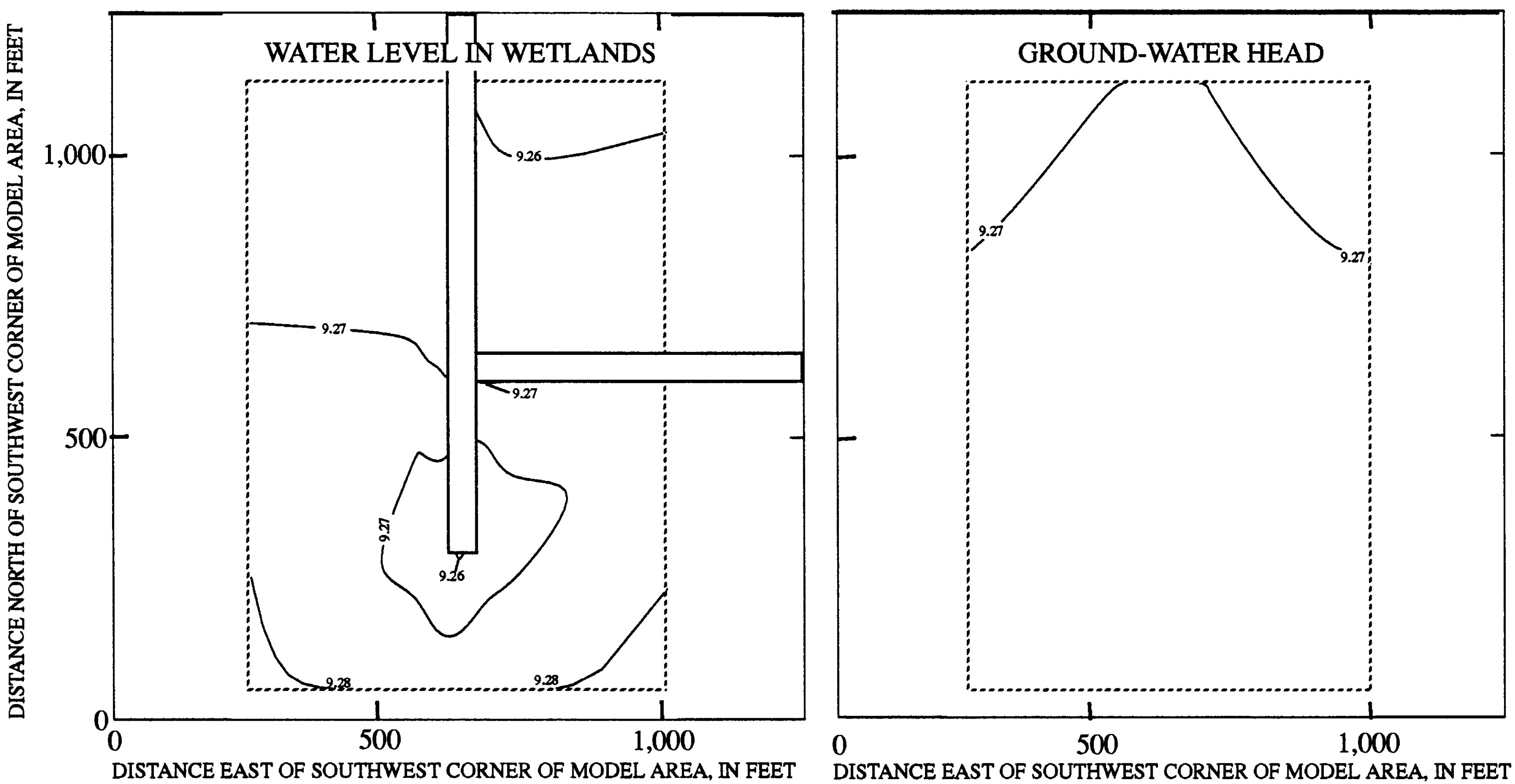


Figure 14. Water-levels in the wetlands (layer 1) and ground-water heads in the underlying aquifer at 6 hours (contour interval 0.01 foot).

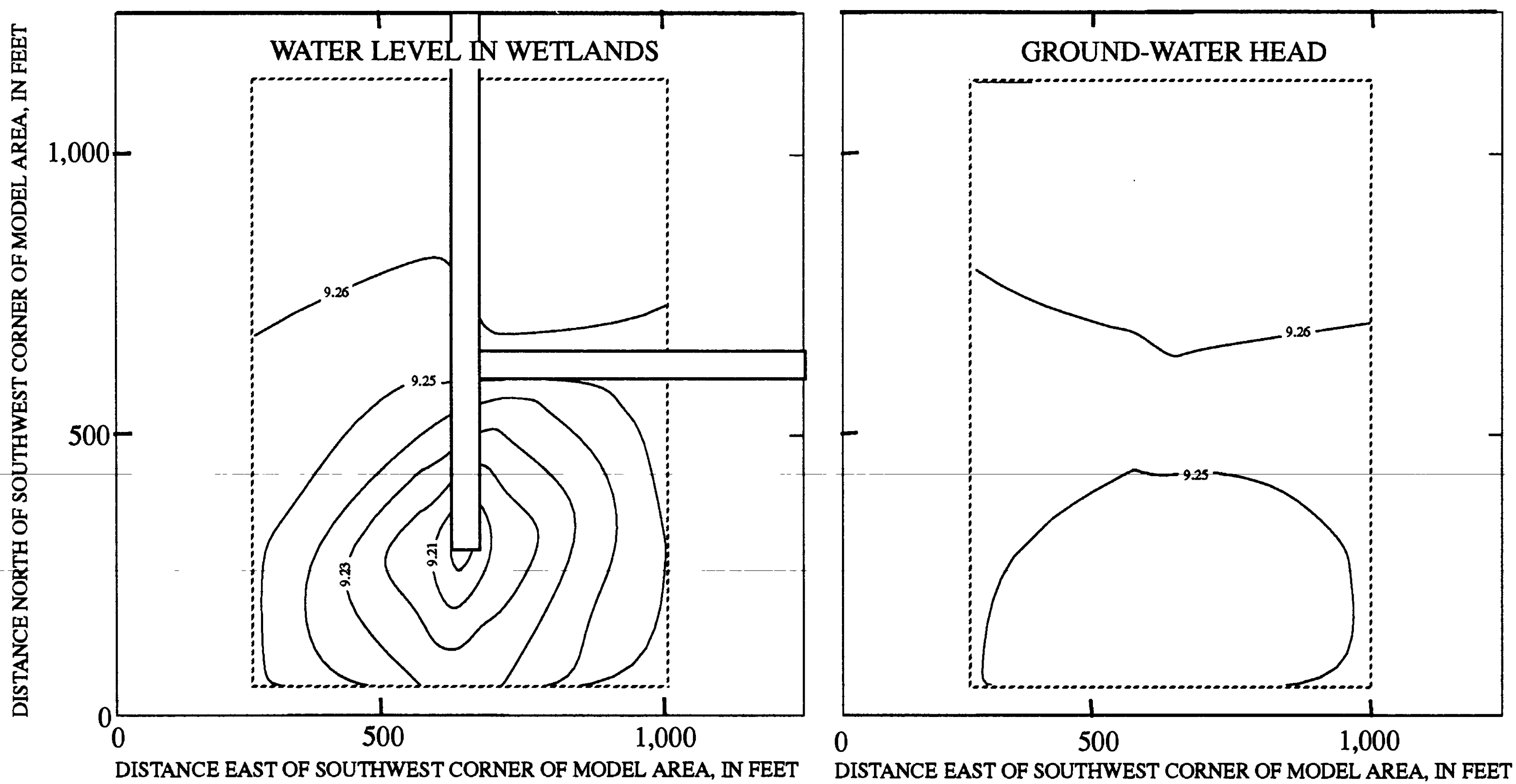


Figure 15. Water-levels in the wetlands (layer 1) and ground-water heads in the underlying aquifer at 8 hours (contour interval 0.01 foot).

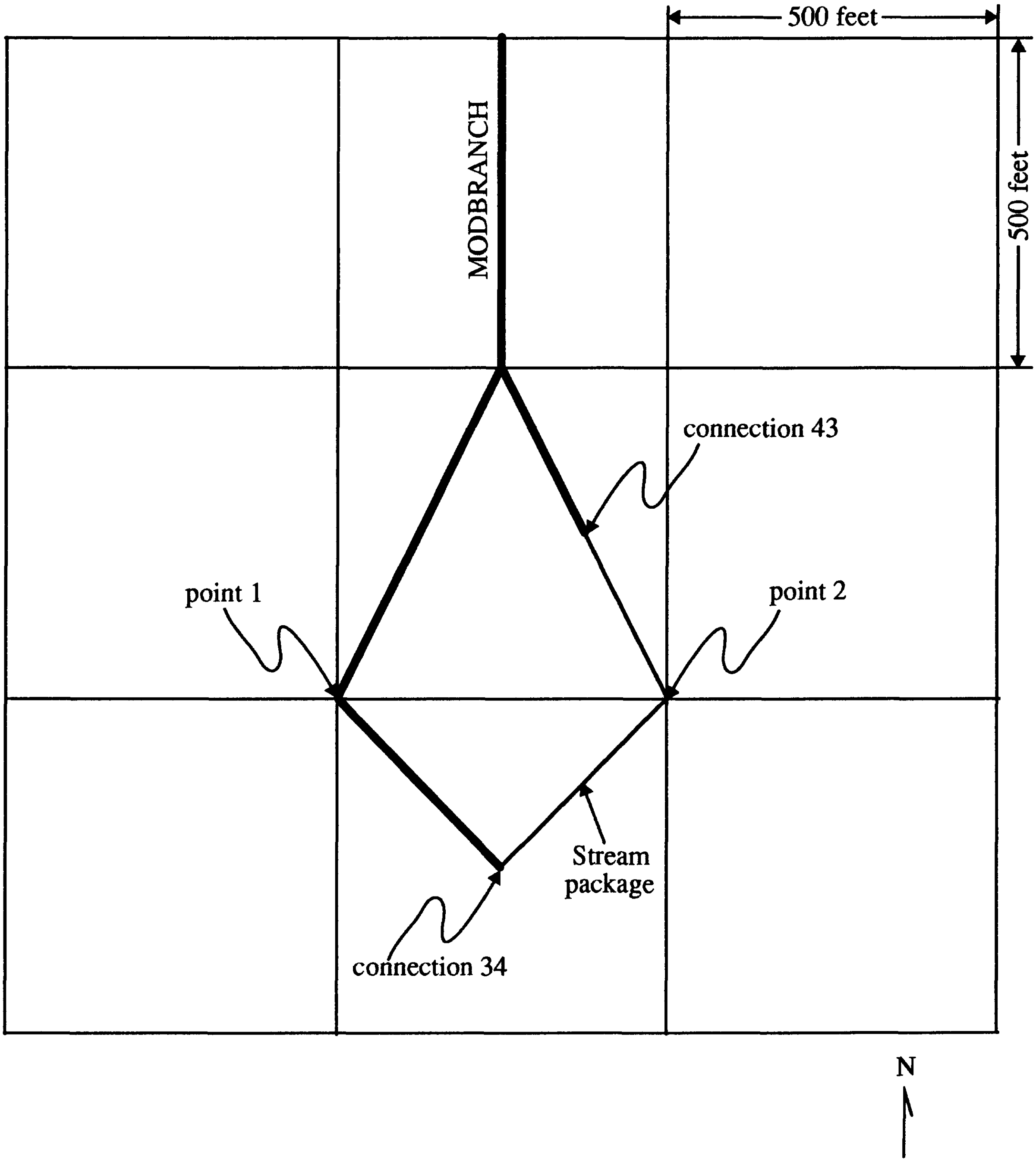


Figure 16. Channel-aquifer system for test case 2.

General Description

The model area is 1,500 ft by 1,500 ft, divided into nine 500-ft square cells, and consists of an unconfined aquifer with an incised canal system. The aquifer has a hydraulic conductivity of 6,000 ft/d, a bottom elevation of 100 ft below sea level, and a storage coefficient of 0.25. The channel is designed with an inlet at the northern end and a loop at the southern end (fig. 16). The single northern channel is rectangular and 25 ft wide. The loop channel is rectangular and 10 ft wide. The channel bottom elevations are 8.6 ft above sea level at the northern boundary, 8.4 ft above sea level where the single channel meets the loop, and 8.2 ft above sea level at the bottom of the loop. Manning's *n* is set to 0.050 for all channels, and the leakage coefficient is set to 0.864 per day.

Aquifer heads are initialized to 9.6 ft above sea level everywhere. Water levels in all the channels are initialized to a 1-ft depth (stage is 1 ft above bottom elevations). Discharge is initialized to 10 ft^3/s in the single channel and 5 ft^3/s flowing down each side of the loop (fig. 15, points 1 and 2). Discharge is maintained constant at the northern channel boundary for a 5-hour simulation. A 6-minute timestep is used in MODBRANCH, and a 1-hour timestep is used in MODFLOW.

The channels are modeled in two different ways. In the first simulation, the entire system is modeled with MODBRANCH. In the second simulation, a section of the eastern side of the loop is modeled with the Stream package (fig. 16). Flow from MODBRANCH to Stream is affected by connection 43, and flow from Stream to MODBRANCH at the southernmost point of the loop is affected by connection 34. Comparison of these two simulations indicates the differences in using the connection package.

Results

Discharge at points 1 and 2 produced when MODBRANCH is used for all channels (fig. 16) is shown in figure 17. The two discharge values plot directly on top of one another, as would be expected in this symmetric channel-aquifer system. Discharges decline initially as the southern part of the loop is filled. Discharge eventually levels off at about 1 ft^3/s. Because a constant discharge of 10 ft^3/s is entering the northern channel boundary and is not all lost by leakage to the aquifer, stages in the channel continue to rise through the simulation.

Discharge at points 1 and 2 with the Stream package used on the eastern side of the loop (fig. 16) are shown in figure 18. As evidenced, discharge differs greatly from that in figure 17. Discharge on the eastern side of the loop modeled by the Stream package becomes increasingly greater in the southward direction; on the western side of the loop (modeled by MODBRANCH), discharge becomes increasingly greater in the northward direction.

The effect is to produce a clockwise flow in the loop that steadily increases in magnitude. This effect is obviously an incorrect representation because the system should be symmetric. This effect can be explained by considering that the Stream package does not represent backwater effects (MODBRANCH does represent backwater effects). Therefore, water that flows down the eastern side of the loop is not impeded by downstream conditions because the Stream package uses Manning's equation. However, when this flow arrives on the southern tip of the loop, it causes the flow to back up northward on the western side of the loop because MODBRANCH is affected by backwater. Thus, the clockwise motion is produced.

This example illustrates dramatically what can happen if the option to connect the different channel packages is not used properly. The criteria mentioned in the "Application Criteria" section must be considered as well as an analysis of the flow system.

Test Case 3: Field Study, MODBRANCH-River Connection

As part of a USGS study to quantify leakage to the Biscayne aquifer, Dade County, Fla., a 2-mi reach of the L-31N Canal south of the Tamiami Canal (fig. 19) was studied to determine flows and stages in the canal and heads in the adjacent aquifer. The locations of observation wells and canal discharge stations are shown in figure 20. Data collected at the site included ground-water heads, canal stages and discharges, and channel cross-sectional measurements. The aquifer parameters, hydraulic conductivity, and depth are well known for the area (Fish and Stewart, 1991), and leakage coefficients for the canal were calculated in the study (Chin, 1990). These data allowed the construction of the MODBRANCH model of this 2-mi reach of L-31N Canal and the aquifer.

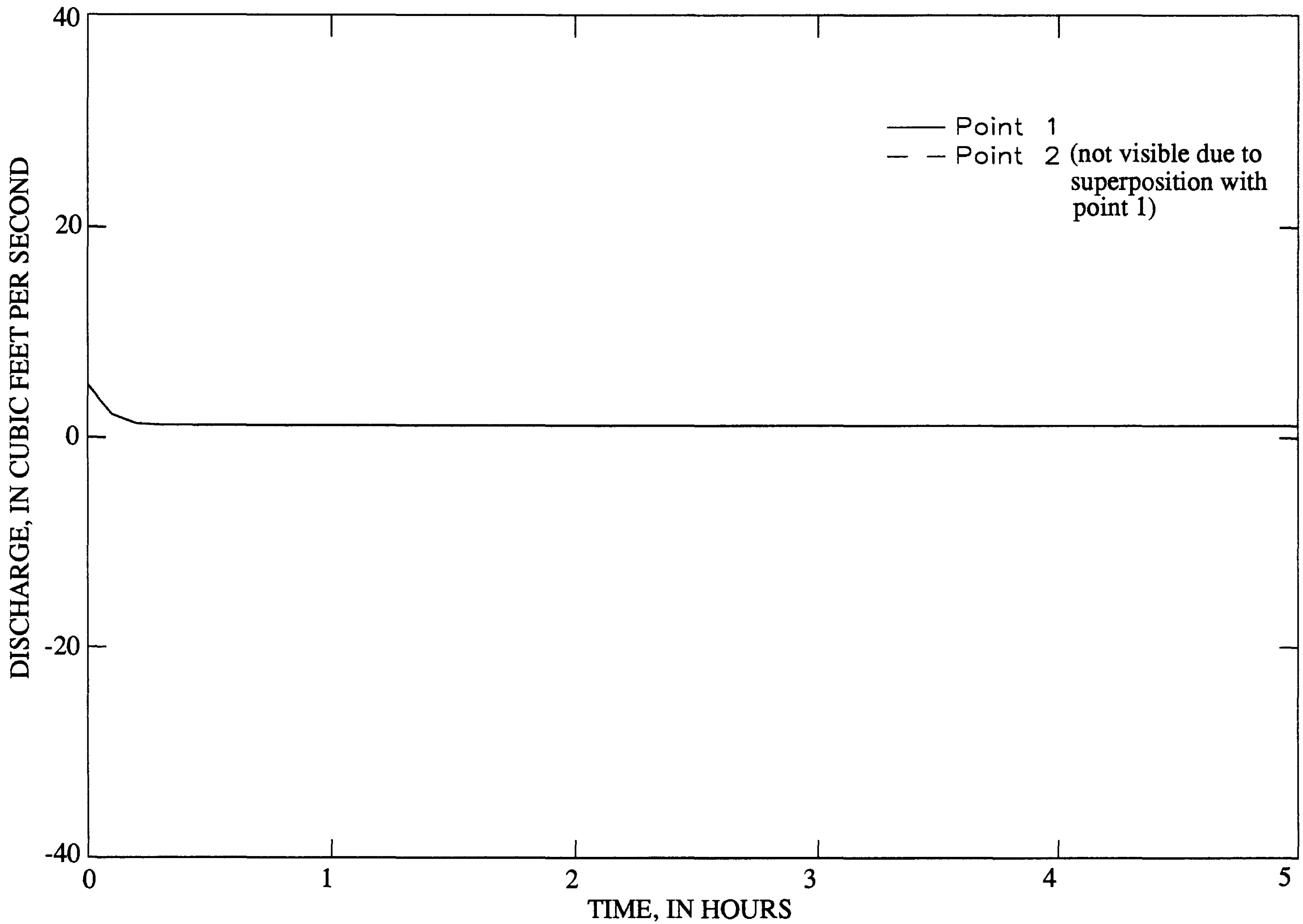


Figure 17. Hydrograph showing discharge at points 1 and 2 when MODBRANCH model is used for all channels.

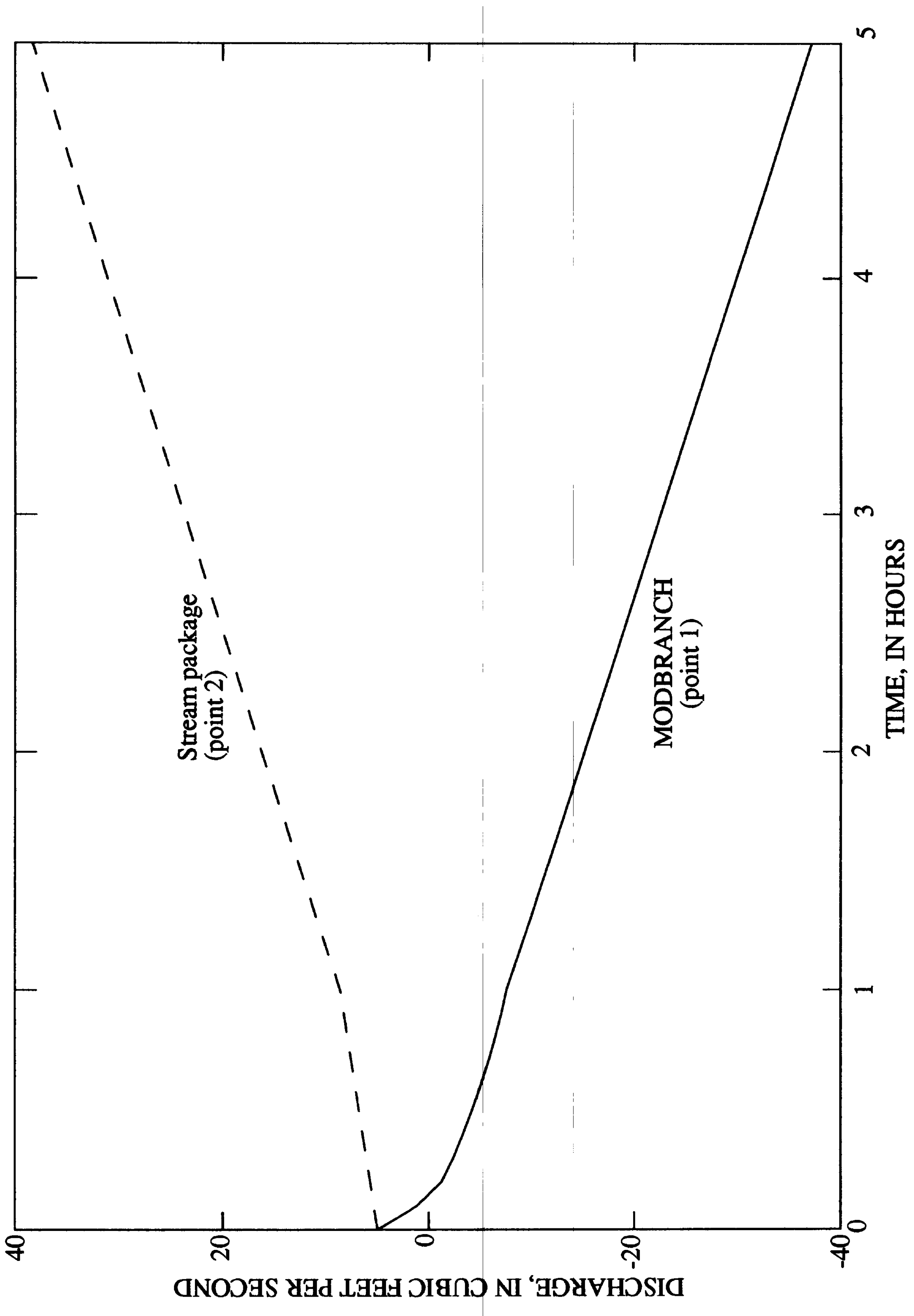


Figure 18. Hydrograph showing discharge at points 1 and 2 when Stream package is used with MODBRANCH.

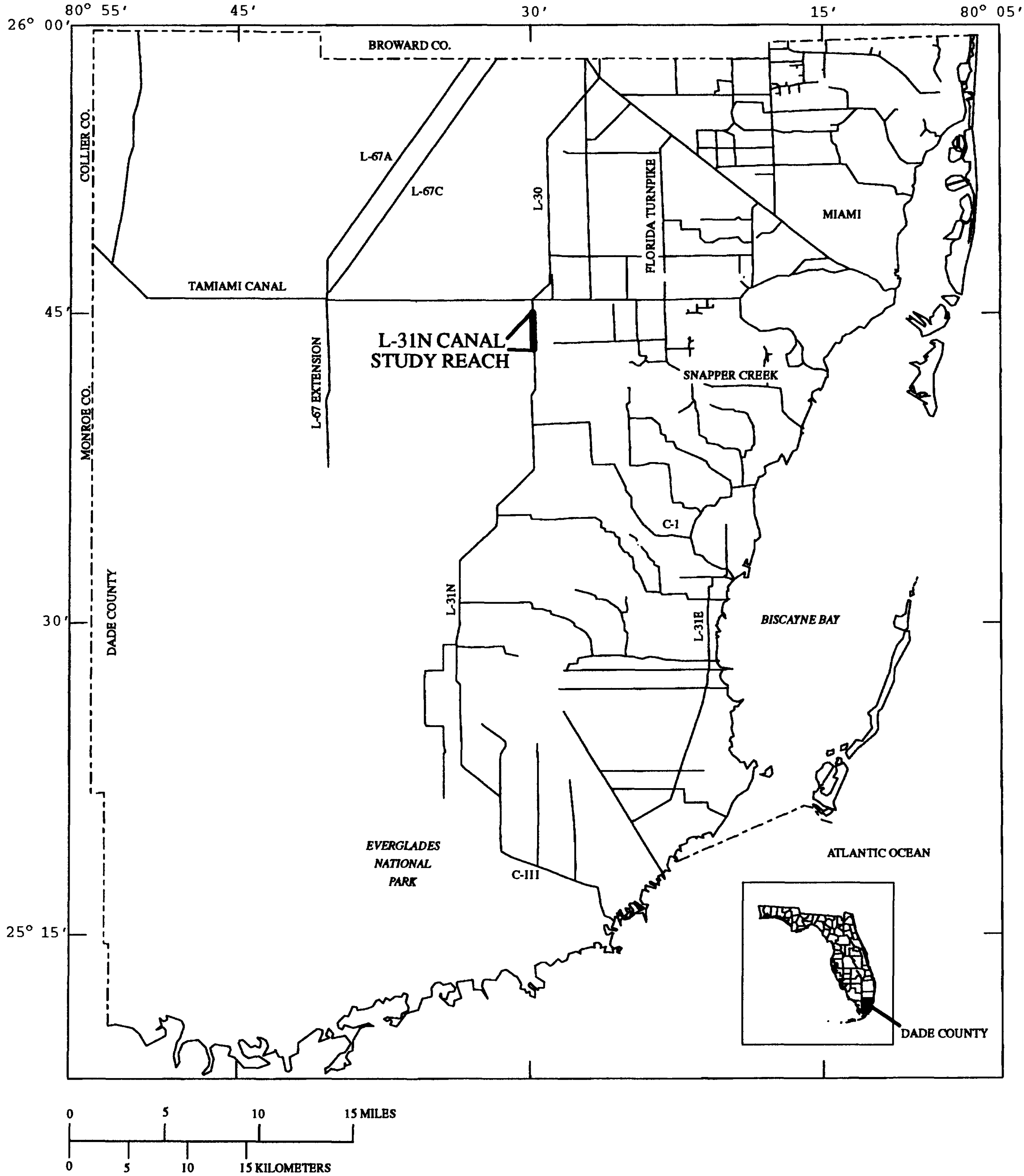


Figure 19. Location of the L-31N Canal in Dade County, Florida.

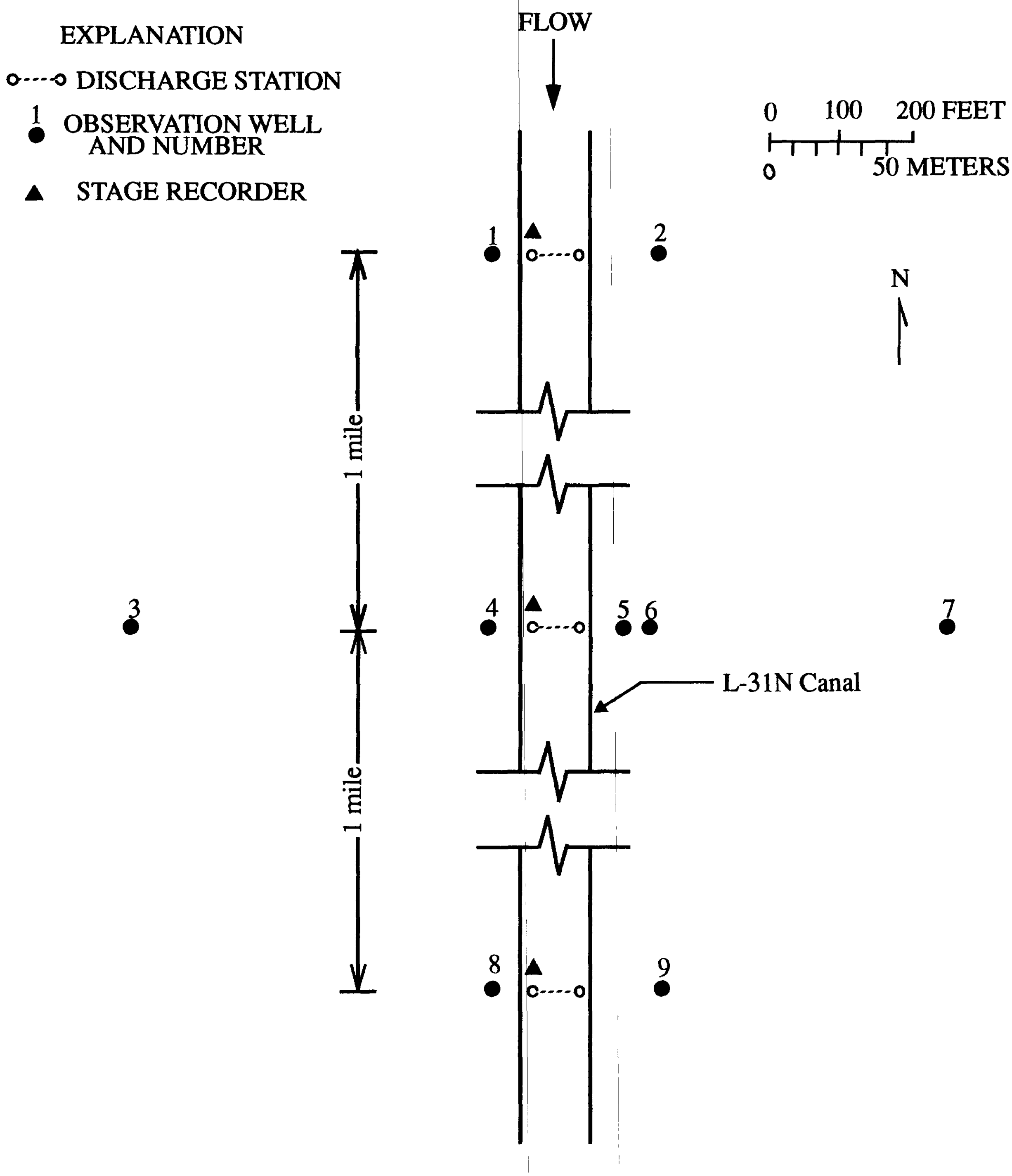


Figure 20. Field instrumentation at L-31N Canal (from Chin, 1990).

General Description

The channel is modeled in two different ways. In the first simulation, a 1,160 ft wide strip of the aquifer adjacent to L-31N Canal is modeled by MODFLOW, the canal is modeled with BRANCH, and the two models are coupled using MODBRANCH. In the second simulation using Streamlink with connection 42, the second mile of the canal was modeled using the River package. The model grid with the location of the wells in figure 20 is shown in figure 21. The water levels in the distant wells (wells 3 and 7) and those at the northern and southern boundaries (wells 1, 2, 8, and 9) are used for aquifer boundary heads.

For the MODBRANCH simulation, the upstream and downstream boundaries for the canal flow are the flows measured by site 1 and site 3 discharge installation. Verification of the model is done by comparing ground-water levels in interior wells to those calculated by MODFLOW and comparing measured stages at L-31N Canal to those calculated by MODBRANCH.

The field measurements of the channel cross section at 1-mi spacings were used to define the stage-area-topwidth relations in MODBRANCH (Schaffranek and others, 1981) as well as the channel bottom elevation. Manning's n for this type of channel (straight with minimal aquatic growth) was selected at 0.025 (Roberson and others, 1988). Chin (1990) concluded that the local reach transmissivity (and the resultant leakage) was 630 $(ft^3/s)/(mi/ft)$ (cubic feet per second per mile of canal length per foot of head difference between the canal stage and aquifer head); this is 0.1193 $(ft^3/s)/(ft/ft)$. To convert the local reach transmissivity to a leakage coefficient, as used in MODBRANCH, the transmissivity must be divided by the wetted perimeter. The wetted perimeter is about 135 ft, thus, the leakage coefficient is 0.0009 per second, which is the value used in MODBRANCH.

Based on normal values for the Biscayne aquifer in this region, the hydraulic conductivity was selected to be 40,000 ft/d, and the base of the aquifer was 52 ft below sea level (Fish and Stewart, 1991). A steady-state simulation was performed for the conditions of May 2, 1989.

Using Streamlink, the same simulation was repeated with the second mile of the canal modeled with the River package. Connection 42 is used to set the River stage in the second mile to the MODBRANCH stage at the end of the first mile. The River package is limited to rectangular cross sections, so the depth and topwidth were used to define the cross sections in the River package.

Results

The L-31N Canal water-surface profile measured in the field and produced by MODBRANCH is shown in figure 22. The close match indicates the model is functioning acceptably. Ground-water heads measured and computed at wells 4, 5, and 6 are given in table 1. Leakage from canal to aquifer is about 100 ft^3/s, and it is apparent that this situation could not have been modeled properly with only BRANCH, which could not calculate the proper leakage.

Table 1. Measured and computed ground-water heads near L-31N Canal
[Heads shown in feet]

Well No.	Measured head	Computer head (MODBRANCH)	Computer head (MODBRANCH-River)
4	4.63	4.71	4.71
5	4.65	4.68	4.68
6	4.63	4.67	4.67

The water-surface profile using the River package to model the second mile of L-31N Canal is shown in figure 23. Because of the virtually flat water surface, this is a reasonable approximation and is close to the results of MODBRANCH modeling the entire canal. The stage in the first mile is determined by MODBRANCH and is assumed to be close to the stage in the second mile. Thus, this connection of MODBRANCH and the River package combines their best features; stage is calculated by MODBRANCH (which cannot be accomplished by the River package), and the River package maintains this stage downstream without the computational effort MODBRANCH would need. The ground-water heads produced in this case are given in table 1. A contour plot of the ground-water heads produced when only MODBRANCH is used is shown in figure 24. Figure 25 shows the contours when both MODBRANCH and the River package are used. The contours are seen to be virtually identical. Differences are only 0.001

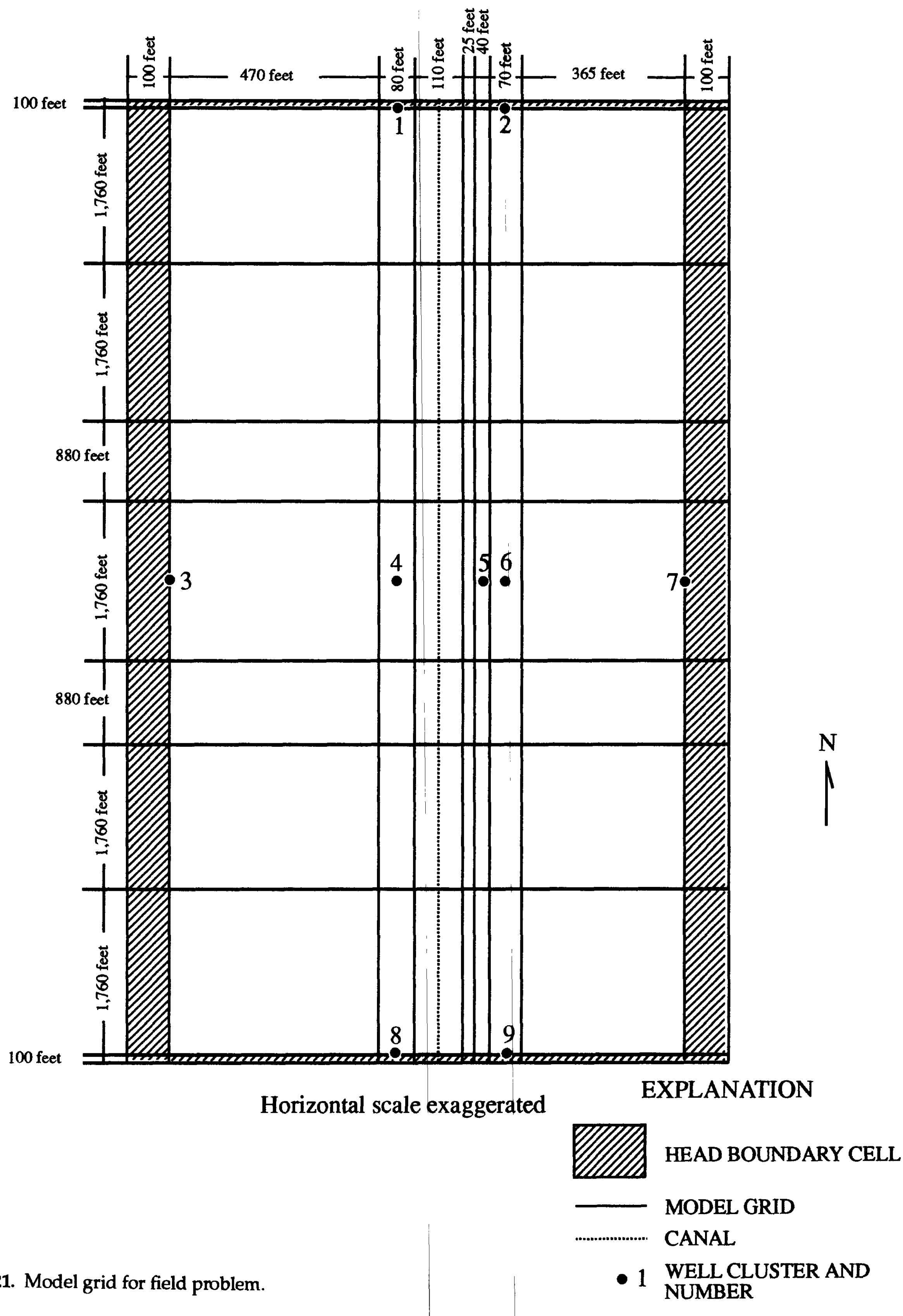


Figure 21. Model grid for field problem.

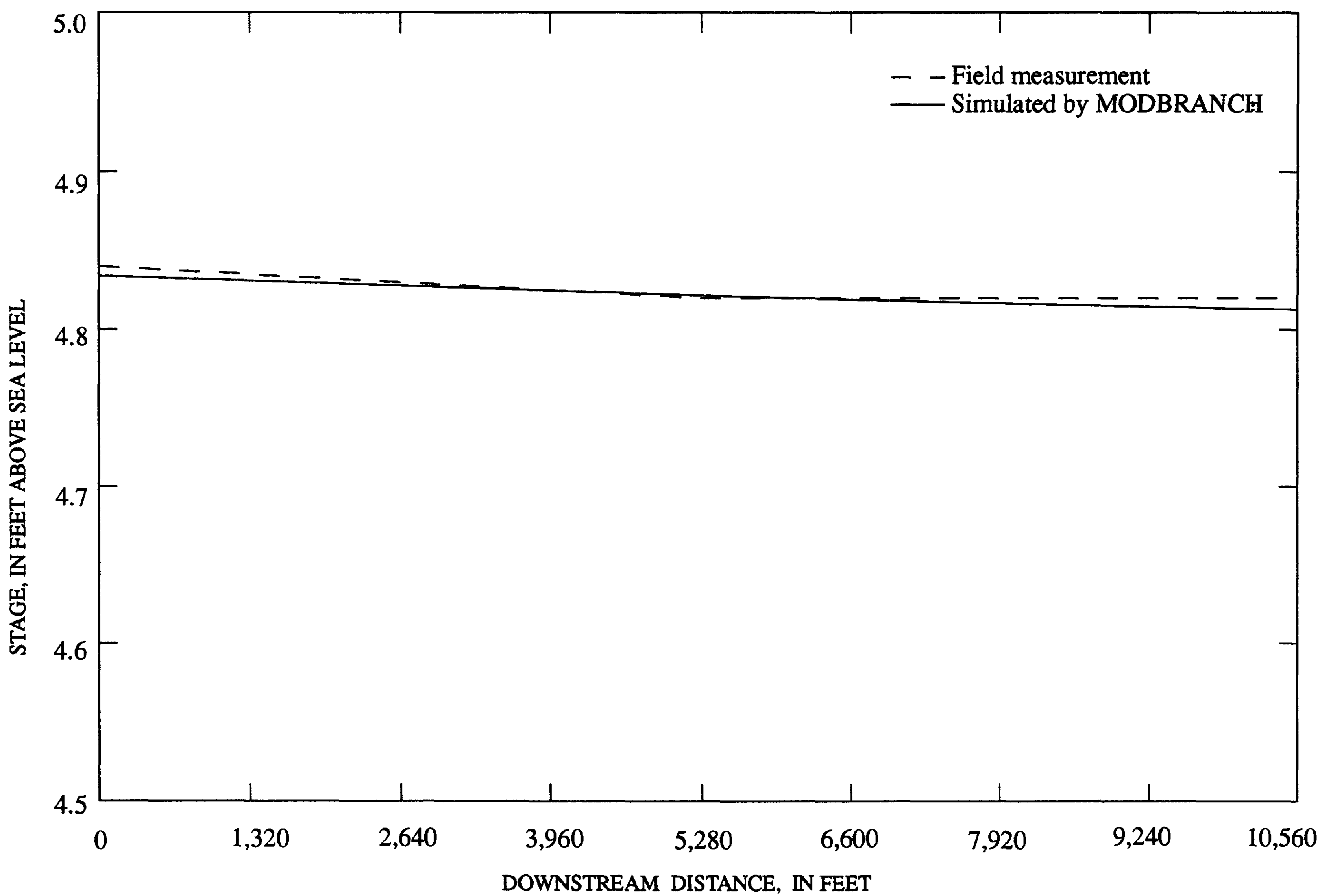


Figure 22. Simulated L-31N Canal water-surface profile produced by MODBRANCH.

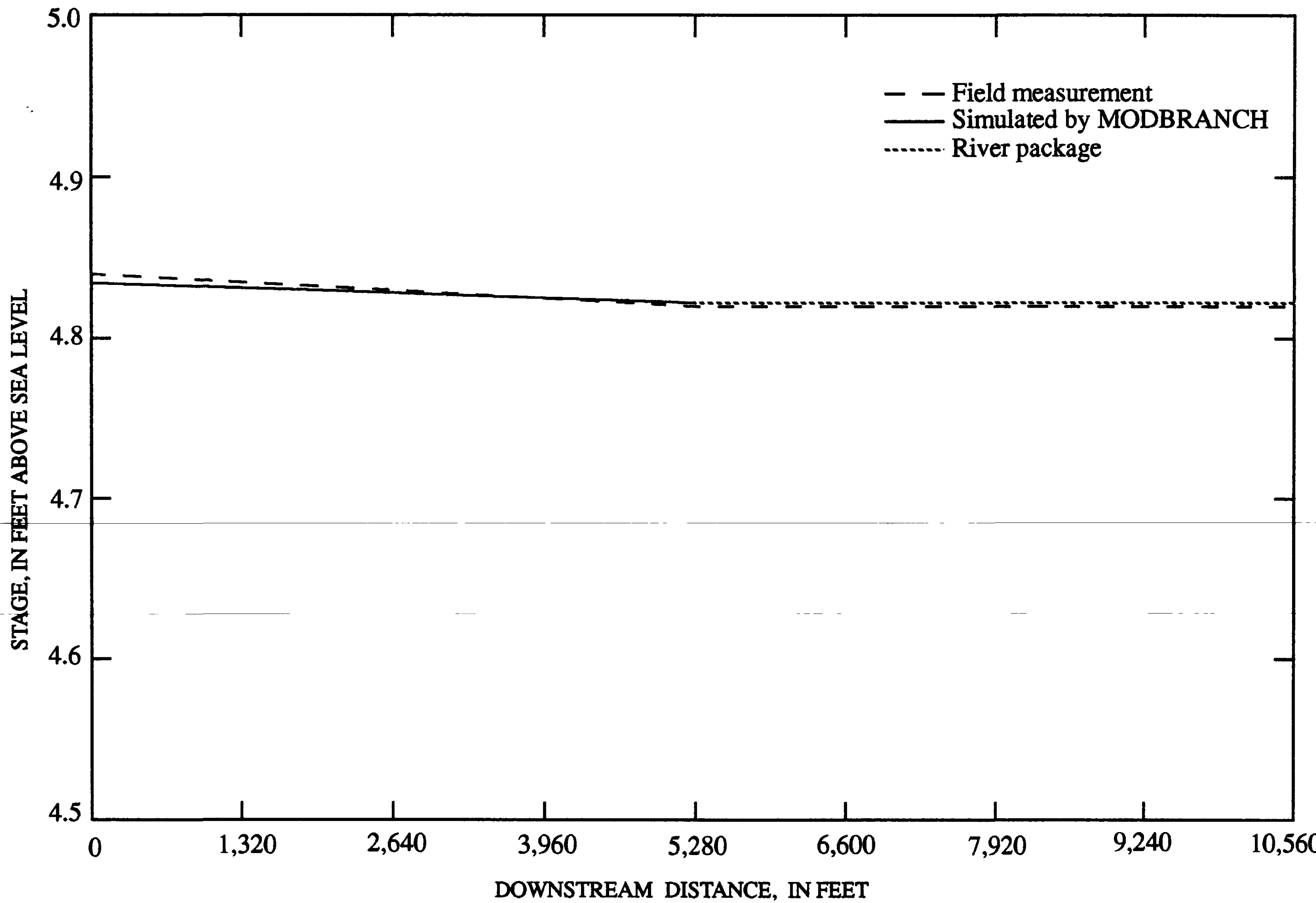


Figure 23. Simulated L-31N Canal water-surface profile produced by MODBRANCH and the River package.

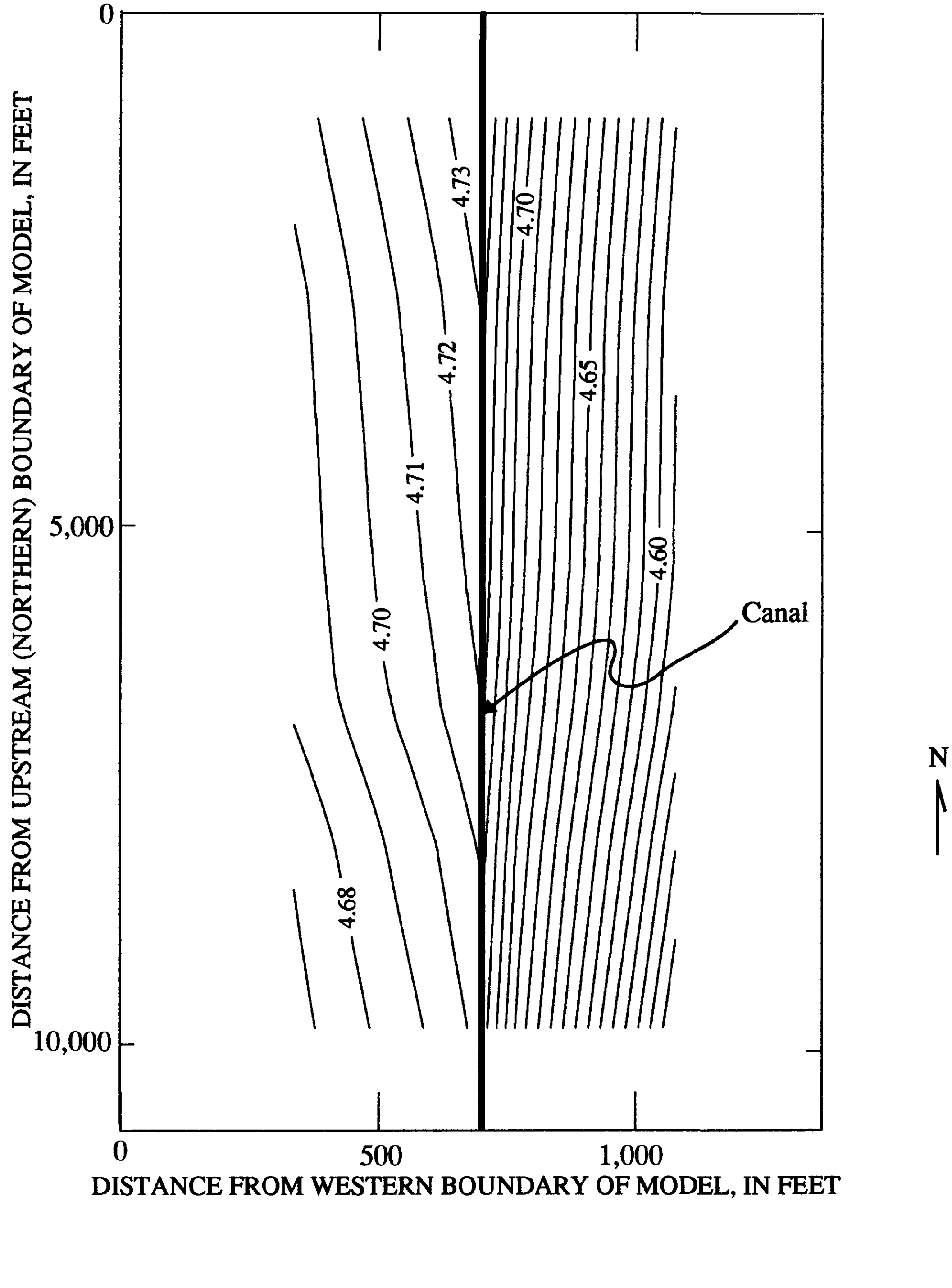


Figure 24. Water levels near L-31N Canal produced by MODBRANCH (contour interval 0.01 foot; horizontal scale exaggerated).

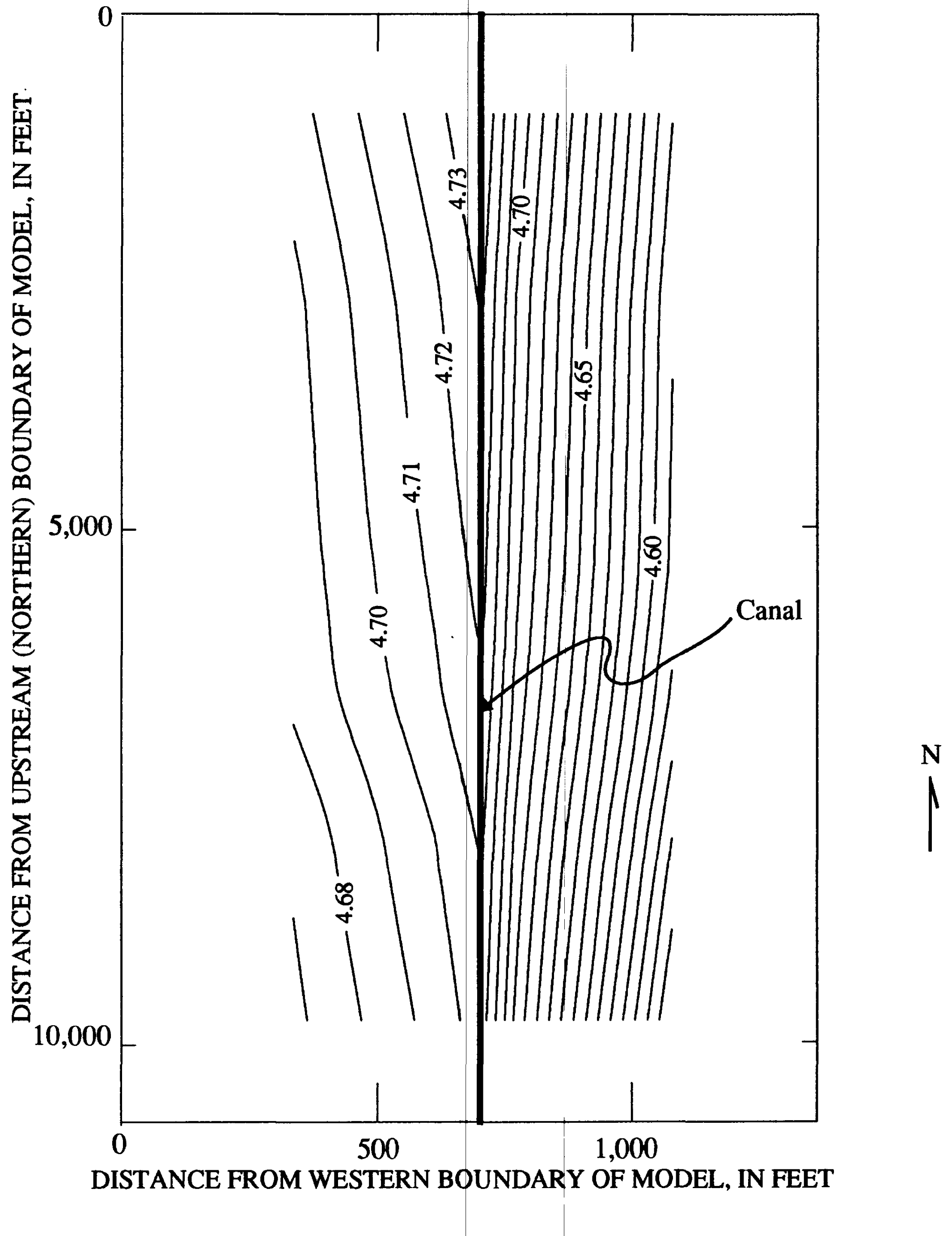


Figure 25. Water levels near L-31N Canal produced by MODBRANCH and the River package (contour interval 0.01 foot; horizontal scale exaggerated).

foot or less. Because both MODBRANCH and the River packages are calculating leakage, ground-water heads are properly modeled and closely match field conditions.

CONCLUSIONS

A computer program, Streamlink, has been developed that allows direct-flow connections to be simulated between the MODFLOW ground-water model, the channel stage River package, the flow-routing Stream package, and the unsteady, open-channel flow model BRANCH using the MODBRANCH coupling program. Two of the new connections are useful in modeling direct inlet-outlet between channels and the lakes or wetlands when the lakes or wetlands are represented by a high-conductivity aquifer block. Four other connections allow the three channel packages to connect to each other, thus, modeling different sections of channel network with various methods. Streamlink allows the modeler flexibility in deciding which method to use on each part of the modeled areas. Computation time can be reduced by using the simpler packages on some of the channel sections. Test runs indicate that the connections pass the information properly between models, and that caution and thought should be taken in selecting the appropriate package to represent channels. A field situation demonstrates that optimum schemes can be developed by combining the different channel representations with the connection package.

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(p. 41 follows)

APPENDIX

Program Listings and the Modified Stream Package Code

(The modified code is shown on the following pages with the new code in **bold**)

Program Listing for SLK1AL

```
      SUBROUTINE SLK1AL(ISUM,LENX,MAXCON,LNCODE,LNFROM,LNTO,IN,OUT)
C
C-----VERSION 1294 12JUN1991 SLK1AL
C     ****************************************************************
C     ALLOCATE ARRAY STORAGE FOR CONNECTION PACKAGE
C     ****************************************************************
C
C        SPECIFICATIONS:
C     ----------------------------------------------------------------
C     ----------------------------------------------------------------
C
C1------IDENTIFY PACKAGE AND INITIALIZE MAXCON
      WRITE(IOUT,1)IN
    1 FORMAT(1HO,'SLK1 -- STREAMLINK PACKAGE 12/6/91',
     1' INPUT READ FROM',I3)
C
C2------READ MAX NUMBER OF CONNECTIONS
      READ(IN,2) MAXCON
    2 FORMAT(I10)
      WRITE(IOUT,3) MAXCON
    3 FORMAT(1H ,'MAXIMUM OF',I5,' CONNECTION')
C
C3------SET LNCODE EQUAL TO LOCATION OF CONN LIST IN X ARRAY.
      LNCODE=ISUM
C
C4------ADD AMOUNT OF SPACE USED BY CONNECTION LIST TO ISUM.
      ISUM=ISUM+MAXCON
      LNFROM=ISUM
      ISUM=ISUM+3*MAXCON
      LNTO=ISUM
      ISUM=ISUM+3*MAXCON
C
C5------PRINT NUMBER OF SPACES IN X ARRAY USED BY CONNECTION PACKAGE.
      ISP=7*MAXCON
      WRITE(IOUT,4) ISP
    4 FORMAT(1X,I8,' ELEMENTS IN X ARRAY ARE USED FOR CONNECTION')
      ISUM1=ISUM-1
      WRITE(IOUT,5) ISUM1,LENX
    5 FORMAT(1X,I8,' ELEMENTS OF X ARRAY USED OUT OF',I8)
C
C6------IF THERE ISN'T ENOUGH SPACE IN THE X ARRAY THEN PRINT
C6------A WARNING MESSAGE.
      IF(ISUM1,GT.LENX) WRITE(IOUT,6)
    6 FORMAT(1X,'    ***X ARRAY MUST BE DIMENSIONED LARGER***')
C7------RETURN
      RETURN
      END
```

Program Listing for SLK1RP

```
      SUBROUTINE SLK1RP(MAXCON,NCON,NCODE,NFROM,NTO,IN,IOUT,IUNIT,
     2 LZQ,LIBJNC,LQLSUM,LIJF,LIJT,LZN,LXSKT,LNSEC,NBND,MAXZBD,MXTDBC,
     3 MXJN,MAXS,MXBH,NBCH,LCRIVR,MXRIVR,ICSTRM,LCSTRM,MXSTRM,LENX,LENY)
C
C-----VERSION 1320 12JUN1991 SLK1RP
C     ****************************************************************
C     READ NEW CONNECTION LOCATIONS
C     ****************************************************************
C
C        SPECIFICATIONS:
C     ----------------------------------------------------------------
      INTEGER ITMP,NCON,NCODE(MAXCON),NFROM(MAXCON,3),NTO(MAXCON,3),
     1 IUNIT(24)
C     ----------------------------------------------------------------
C
C1------READ ITMP(NUMBER OF CONNECTIONS OR FLAG SAYING TO REUSE DATA)
      READ (IN,1) ITMP
    1 FORMAT(I10)
      IF(ITMP.GE.0) GO TO 50
C
C1A-----IF ITMP LESS THAN ZERO REUSE DATA.  PRINT MESSAGE AND RETURN.
      WRITE(IOUT,6)
    6 FORMAT(1HO,'CONNECTIONS UNCHANGED SINCE LAST STRESS PERIOD')
      RETURN
C
C1B-----ITMP=>0.  SET NCON EQUAL TO ITMP.
   50 NCON=ITMP
      IF(NCON.LE.MAXCON) GO TO 100
C
C2------NCON>MAXCON.  PRINT MESSAGE.  STOP.
      WRITE(IOUT,99) NCON,MAXCON
   99 FORMAT(1HO,'NCON(',I4,') IS GREATER THAN MAXCON(',I4,')')
      STOP
C
C3------PRINT NUMBER OF CONNECTIONS IN CURRENT STRESS PERIOD.
  100 WRITE (IOUT,2) NCON
    2 FORMAT(1HO,10X,I4,' CONNECTIONS')
C
C4------IF THERE ARE NO CONNECTIONS IN THIS STRESS PERIOD THEN RETURN
      IF(NCON.EQ.0) GO TO 260
C
C5------READ AND PRINT CONNECTION TYPE AND INPUT-OUTPUT CONNECTIONS.
      WRITE(IOUT,3)
    3 FORMAT(1H ,47X,'CONNECTION  INPUT LOCATION  OUTPUT LOCATION  '/
     1,48X,45('-'))
      DO 250 II=1,NCON
      READ (IN,4) NCODE(II),(NFROM(II,JJ),JJ=1,3),(NTO(II,JJ),JJ=1,3)
    4 FORMAT(7I10)
      WRITE (IOUT,5) NCODE(II),(NFROM(II,JJ),JJ=1,3),(NTO(II,JJ),JJ=1,3)
    5 FORMAT(48X,I6,8X,3I3,8X,3I3)
```

```
C
C6     THE DUMMY VARIABLES FOR SURFACE-WATER PACKAGES NOT USED ARE SET TO
C      DUMMY VALUES.
C
       IF (IUNIT(4).LE.0) THEN
       LCRIVR=LENX-1
       MXRIVR=1
       ENDIF
       IF(IUNIT(15).LE.0) THEN
       LZQ=LENY-1
       LIBJNC=LENY-1
       LQLSUM=LENY-1
       LIJF=LENY-1
       LIJT=LENY-1
       LZN=LENY-1
       LXSKT=LENY-1
       LNSEC=LENY-1
       NBND=1
       MAXZBD=1
       MXTDBC=1
       MXJN=1
       MAXS=1
       MXBH=1
       NBCH=1
       ENDIF
       IF(IUNIT(13).LE.0) THEN
       ICSTRM=LENX-1
       LCSTRM=LENX-1
       MXSTRM=1
       ENDIF
   250 CONTINUE
C
C6------RETURN
   260 RETURN
       END
```

Program Listing for SLK1FM

```
      SUBROUTINE SLK1FM (NCON,NCODE,NFROM,NTO,ZQ,IBJNC,HNEW,
     1 RHW,QLSUM,IBOUND,NCOL,NROW,NLAY,NBND,MAXZBD,MXTDBC,MXJN,MAXCON,
     2 MAXS,TFCTR,ZDATUM,HOLD,NELAP,MXBH,MXRIVR,IJF,IJT,XSKT,RIVR,ZN,
     3 NBCH,ISTRM,STRM,MXSTRM,NSEC,NSTREM,ICALC)
C
C-----VERSION 1132 12JUN1991 SLK1FM
C
C     ***********************************************************************
C     CONNECTIONS BETWEEN POINTS IN MODFLOW, THE RIVER PACKAGE,
C     THE STREAM PACKAGE, AND MODBRANCH ARE MADE
C     ***********************************************************************
C
C        SPECIFICATIONS:
C     -----------------------------------------------------------------------
      DOUBLE PRECISION HNEW
      DIMENSION RHS(NCOL,NROW,NLAY),ZQ(MAXZBD,MXTDBC),IBJNC(MXJN),
     1 HNEW(NCOL,NROW,NLAY),QLSUM(MAXS+MXJN),HOLD(NCOL,NROW,NLAY),
     2 RIVR(6,MXRIVR),ZN(MAXS),STRM(11,MXSTRM)
      INTEGER NCODE(MAXCON),NFROM(MAXCON,3),NTO(MAXCON,3),ISTRM
     1 (5,MXSTRM),IBOUND(NCOL,NROW,NLAY),IJT(MXBH),IJF(MXBH),XSKT(MXBH),
     2 NSEC(MXBH)
C     -----------------------------------------------------------------------
C1------IF NUMBER OF CONNECTIONS <= 0 THEN RETURN.
      IF(NCON.LE.0) RETURN
C
C2----IF NCODE=41, EQUATE BRANCH STAGE TO AQUIFER HEAD AND BRANCH
C     DISCHARGE TO AQUIFER INFLOW-OUTFLOW
C
      DO 1000 L=1,NCON
      IF(NCODE(L).NE.41) GO TO 100
      KJN=NFROM(L,1)
      DO 10 II=1,NBND
      IF (IBJNC(II).EQ.KNJ) THEN
      KBC=II
      GO TO 20
      ENDIF
   10 CONTINUE
   20 CONTINUE
      IC=NTO(L,1)
      IR=NTO(L,2)
      IL=NTO(L,3)
C
C2A-----IF THE CELL IS INACTIVE THEN BYPASS PROCESSING.
      IF(IBOUND(IC,IR,IL).LE.0) GO TO 100
C
C2B-----IF THE CELL IS VARIABLE HEAD THEN EQUATE STAGE TO HEAD
C
      ZQ(NELAP,KBC)=HOLD(IC,IR,IL)-ZDATUM
      ZQ(NELAP+1,KBC)=HNEW(IC,IR,IL)-ZDATUM
      ZQ(NELAP+2,KBC)=HNEW(IC,IR,IL)-ZDATUM
```

```
C
C2C-----SUBTRACT QLSUM FROM RHS ACCUMULATOR
      RHS(IC,IR,IL)=RHS(IC,IR,IL)-QLSUM(MAXS+KJN)*TFCTR
  100 CONTINUE
C
C3----IF NCODE=42, EQUATE RIVER STAGE TO BRANCH STAGE FOR ALL
C     RIVER REACHES SPECIFIED
C
      IF(NCODE(L).NE.42) GO TO 200
      DO 110 I=1,NBCH
      IJ=MAXS-XSKT(I)
      IJP1=IJ+1
      IJFI=IJF(I)
      IJTI=0
      IF(I.GT.1) IJTI=IJT(I-1)
      IF(NFROM(L,1).EQ.IJFI) KJN=IJP1
      IF(NFROM(L,1).EQ.IJTI) KJN=IJ
  110 CONTINUE
      IF(NFROM(L,1).EQ.IJT(NGCH)) KJN=IJ+NSEC(NBCH)
      DO 120 I=1,3
      IF(NTO(L,I).NE.0) RIVR(4,NTO(L,I))=ZN(KJN)+ZDATUM
  120 CONTINUE
  200 CONTINUE
C
C4 -- IF NCODE=43, SET STREAM UPSTREAM BOUNDARY DISCHARGE TO BRANCH
C     DOWNSTREAM BOUNDARY DISCHARGE.  IF HEADS ARE NOT CALCULATED BY
C     STREAM, STREAM HEADS ARE ASSIGNED FROM BRANCH
C
      IF (NCODE(L).NE.43) GO TO 300
      KJN=NFROM(L,1)
      DO 205 I=1,NBCH
      IJ=MAXS-XSKT(I)
      IJP1=IJ+1
      IJFI=IJF(I)
      IJTI=0
      IF(I.GT.1) IJTI=IJT(I-1)
      IF(NFROM(L,1).EQ.IJFI) KNN=IJP1
      IF(NFROM(L,1).EQ.IJTI) KNN=IJ
  205 CONTINUE
      IF(NFROM(L,1).EQ.IJT(NBCH)) KNN=IJ+NSEC(NBCH)
      ZPK=ZN(KNN)+ZDATUM
      QLSUMK=QLSUM(MAXS+KJN)
      IF(QLSUMK.LT.0.0.AND.ICALC.GT.0) THEN
      WRITE(IOUT,*) ' WARNING, DUE TO REVERSAL OF FLOW AT BRANCH
     1 JUNCTION',KJN,' HEADS IN STREAM SEGMENT',NTO(L,1),' CANNOT
     2 BE CALCULATED'
      STOP
      ENDIF
      DO 210 II=1,NSTREM
      IF(ISTRM(4,II).EQ.NTO(L,1)) THEN
      IF(ICALC.LE.0) STRM(2,II)=ZPK
      IF(ISTRM(5,II).EQ.1) STRM(1,II)=QLSUMK*TFCTR
```

```
      ENDIF
  210 CONTINUE
  300 CONTINUE
C
C5 -- IF NCODE=34, SET BRANCH UPSTREAM BOUNDARY DISCHARGE TO STREAM
C     DOWNSTREAM BOUNDARY DISCHARGE.
C
      IF (NCODE(L).NE.34) GO TO 400
      DO 310 II=1,NBND
      IF(IBJNC(II).EQ.NTO(L,1)) THEN
      KBC=II
      GO TO 320
      ENDIF
  310 CONTINUE
  320 CONTINUE
      DO 330 II=NSTREM,1,-1
      IF(ISTRM(4,II),EQ.NFROM(L,1)) THEN
      STROUT=STRM(9,II)
      GO TO 340
      ENDIF
  330 CONTINUE
  340 CONTINUE
      DO 350 I=1,NBCH
      IJFI=IJF(I)
      IJTI=IJT(I)
      IF(NTO(L,1).EQ.IJFI) ZQ(NELAP+1,KBC)=STROUT/TFCTR
      IF(NTO(L,1).EQ.IJTI) ZQ(NELAP+1,KBC)=-STROUT/TFCTR
      IF(NTO(L,1).EQ.IJFI) ZQ(NELAP+2,KBC)=STROUT/TFCTR
      IF(NTO(L,1).EQ.IJTI) ZQ(NELAP+2,KBC)=-STROUT/TFCTR
  350 CONTINUE
  400 CONTINUE
C
C6----IF NCODE=31, EQUATE AQUIFER INFLOW-OUTFLOW TO STREAM DISHARGE
C
      IF(NCODE(L).NE.31) GO TO 500
      IC=NTO(L,1)
      IR=NTO(L,2)
      IL=NTO(L,3)
C
C6A-----IF THE CELL IS INACTIVE THEN BYPASS PROCESSING.
      IF(IBOUND(IC,IR,IL).LE.0) GO TO 500
C
      DO 410 II=NSTREM,1,-1
      IF(ISTRM(4,II).EQ.NFROM(L,1)) THEN
      STROUT=STRM(9,II)
      GO TO 420
      ENDIF
  410 CONTINUE
  420 CONTINUE
C6B-----SUBTRACT STROUT FROM RHS ACCUMULATOR
      FHS(IC,IR,IL)=RHS(IC,IR,IL)-STROUT
  500 CONTINUE
```

```
C
C7 -- IF NCODE=32, SET RIVER STAGE TO STREAM STAGE FOR ALL RIVER
C     REACHES SPECIFIED.
C
      IF (NCODE(L).NE.32) GO TO 600
      DO 510 II=NSTREM,1,-1
      IF(ISTRM(4,II).EQ.NFROM(L,1)) THEN
      STRSTG=STRM(2,II)
      GO TO 520
      ENDIF
  510 CONTINUE
  520 CONTINUE
      DO 530 II=1,3
      IF(NTO(L,II).NE.0) RIVR(4,NTO(L,II))=STRSTG
  530 CONTIUE
  600 CONTINUE
 1000 CONTINUE
C
C3------RETURN
      RETURN
      END
```

Program Listing for SLK1BD

```
      SUBROUTINE SLK1BD(NCON,NCODE,NFROM,NTO,IBJNC,MAXCON,MAXS,QLSUM,
     1 IBOUND,NCOL,NROW,NLAY,NBND,MXJN,VBVL,VBNM,MSUM,TFCTR,DELT,NSTREM,
     2 MXSTRM,ISTRM,STRM)
C
C-----VERSION 1509 12JUN1991 SLK1BD
C     ******************************************************************
C     CALCULATE VOLUMETRIC BUDGET FOR SURFACE-WATER AND GROUND-WATER DIRECT
C     CONNECTIONS
C     ******************************************************************
C
C        SPECIFICATIONS:
C     ------------------------------------------------------------------
      CHARACTER*4 VBNM,TEXT
      DIMENSION VBNM(4,MSUM),VBVL(4,MSUM),QLSUM(MAXS+MXJN),
     1 STRM(11,MXSTRM)
      INTEGER IBJNC(MXJN),NFROM(MAXCON,3),IBOUND(NCOL,NROW,NLAY),
     1 NTO(MAXCON,3),NCODE(MAXCON),ISTRM(5,MXSTRM)
      DIMENSION TEXT(8)
C
      DATA TEXT(1),TEXT(2),TEXT(3),TEXT(4) /'  BR','ANCH',' INF','LOWS'/
      DATA TEXT(5),TEXT(6),TEXT(7),TEXT(8) /'  ST','REAM',' INF','LOWS'/
C     ------------------------------------------------------------------
C
C1------CLEAR RATIN AND RATOUT ACCUMULATORS.
      RATIN=0.
      RATOUT=0.
      RATINS=0.
      RATOUS=0
      ISETB=0
      ISETS=0
C
C2------IF THERE ARE NO CONNECTIONS DO NOT ACCUMULATE FLOW
      IF(NCON.EQ.0) GO TO 300
C
C3----ACCUMULATE FLOWS FOR AQUIFER-MODBRANCH CONNECTION
      DO 200 L=1,NCON
      IF(NCODE(L).NE.41) GO TO 100
      ISETB=1
      KJN=NFROM(L,1)
      IC=NTO(L,1)
      IR=NTO(L,2)
      IL=NTO(L,3)
C
C3A-----IF THE CELL IS EXTERNAL IGNORE IT.
      IF(IBOUND(IC,IR,IL).LE.0) GO TO 100
C
C3B-----INFLOW RATE IS POSITIVE(RECHARGE).  ADD IT TO RATIN.
      IF(QLSUM(MAXS+KJN).GT.0.0) RATIN=RATIN+QLSUM(MAXS+KJN)*TFCTR
C
C3C-----INFLOW RATE IS NEGATIVE(DISCHARGE).  ADD IT TO RATOUT.
```

```
      IF(QLSUM(MAXS+KJN).LT.0.0) RATOUT=RATOUT-QLSUM(MAXS+KJN)*TFCTR
  100 CONTINUE
C
C4-----ACCUMULATE FLOWS FOR STREAM-AQUIFER CONNECTIONS
      IF(NCODE(L).NE.31) GO TO 190
      ISETS=1
      IC=NTO(L,1)
      IR=NTO(L,2)
      IL=NTO(L,3)
C
C4A-----IF THE CELL IS INACTIVE THEN BYPASS PROCESSING.
      IF(IBOUND)IC,IR,IL).LE.0) GO TO 190
C
      DO 110 II-NSTREM,1,-1
      IF(ISTRM(4,II).EQ.NFROM(L,1)) THEN
      STROUT=STRM(9,II)
      GO TO 120
      ENDIF
  110 CONTINUE
  120 CONTINUE
C
C4B-----INFLOW RATE IS POSITIVE(RECHARGE).  ADD IT TO RATINS.
      IF(STROUT.GT.0.0) RATINS=RATINS+STROUT
C
C4C-----INFLOW RATE IS NEGATIVE(DISCHARGE).  ADD IT TO RATOUS.
      IF(STROUT.LT.0.0) RATOUS=RATOUS-STROUT
  190 CONTINUE
  200 CONTINUE
  300 CONTINUE
C
      IF(ISETB.EQ.0) GO TO 400
C5------MOVE RATES INTO VBVL FOR PRINTING BY MODULE BAS1OT
      VBVL(3,MSUM)=RATIN
      VBVL(4,MSUM)=RATOUT
C
C6------MOVE RATES TIMES TIME-STEP LENGTH INTO VBVL ACCUMULATORS.
      VBVL(1,MSUM)=VBVL(1,MSUM)+RATIN*DELT
      VBVL(2,MSUM)=VBVL(2,MSUM)+RATOUT*DELT
C
C7------MOVE BUDGET TERM LABELS INTO VBNM FOR PRINTING.
      VBNM(1,MSUM)=TEXT(1)
      VBNM(2,MSUM)=TEXT(2)
      VBNM(3,MSUM)=TEXT(3)
      VBNM(4,MSUM)=TEXT(4)
C
C8------INCREMENT BUDGET TERM COUNTER(MSUM).
      MSUM=MSUM+1
  400 CONTINUE
      IF (ISETS.EQ.0) GO TO 500
C9------MOVE RATES INTO VBVL FOR PRINTING BY MODULE BAS1OT.
      VBVL(3,MSUM)=RATINS
      VBVL(4,MSUM)=RATOUS
```

```
C
C10-----MOVE RATES TIMES TIME-STEP LENGTH INTO VBVL ACCUMULATORS.
      VBVL(1,MSUM)=VBVL(1,MSUM)+RATINS*DELT
      VBVL(2,MSUM)=VBVL(2,MSUM)+RATOUS*DELT
C
C11-----MOVE BUDGET TERM LABELS INTO VBNM FOR PRINTING.
      VBNM(1,MSUM)=TEXT(5)
      VBNM(2,MSUM)=TEXT(6)
      VBNM(3,MSUM)=TEXT(7)
      VBNM(4,MSUM)=TEXT(8)
C
C12-----INCREMENT BUDGET TERM COUNTER(MSUM).
      MSUM=MSUM+1
  500 CONTINUE
C
C13-----RETURN
      RETURN
      END
```

Modified Stream Package Code

```
      SUBROUTINE STR1AL(ISUM,LENX,LCSTRM,ICSTRM,MXSTRM,NSTREM,IN,
     1                  IOUT,ISTCB1,ISTCB2,NSS,NTRIB,NDIV,ICALC,CONST,
     2                  LCTBAR,LCTRIB,LCIVAR)
C                                                                      C
C-----VERSION 219APR1992 STR1AL                                        C
C     ******************************************************************C
C     ALLOCATE ARRAY STORAGE FOR STREAMS                               C
C     ******************************************************************C
C                                                                      C
C     SPECIFICATIONS:                                                  C
C     -----------------------------------------------------------------C
C     -----------------------------------------------------------------C
C                                                                      C
C1------IDENTIFY PACKAGE AND INITIALIZENSTREM.                         C
      WRITE(IOUT,1) IN
    1 FORMAT(1H0,'STRM -- STREAM PACKAGE, VERSION 1, 10/23/87',
     1'INPUT READ FROM UNIT',I3)
      NSTREM=0
C                                                                      C
C2------READ MXSTRM, NSS, NTRIB, ISTCB1, AND ISTCB2.                   C
  100 READ(IN,3)MXSTRM,NSS,NTRIB,NDIV,ICALC,CONST,ISTCB1,ISTCB2
    3 FORMAT(5I10,F10.0,2I10)
      IF(MXSTRM.LT.0)MXSTRM=0
      IF(NSS.LT.0)NSS=0
      WRITE(IOUT,4)MXSTRM,NSS,NTRIB
    4 FORMAT(1H ,'MAXIMUM OF',I5,' STREAM NODES'//1X,'NUMBER OF STREAM S
     1EGMENTS IS ',I5//1X,'NUMBER OF STREAM TRIBUTARIES IS ',I5//)
      IF(NDIV.GT.0) WRITE(IOUT,5)
    5 FORMAT(1H ,'DIVERSIONS FROM STREAMS HAVE BEEN SPECIFIED')
      IF(ICALC.GT.0) WRITE(IOUT,6) CONST
    6 FORMAT(1H ,'STREAM STAGES WILL BE CALCULATED USING A CONSTANT OF
     1',F12.5)
      IF(ISTCB1.GT.0) WRITE(IOUT,7) ISTCB1,ISTCB2
    7 FORMAT(1X,'CELL BUDGETS WILL BE SAVED ON UNITS',I3,'AND',I3)
C                                                                      C
C3------SET LCSTRM EQUAL TO ADDRESS OF FIRST UNUSED SPACE IN X.        C
  200 LCSTRM=ISUM
C                                                                      C
C4------CALCULATE AMOUNT OF SPACE NEEDED FOR STRM LIST.                C
      ISPA=11*MXSTRM
      ISUM=ISUM+ISPA
C                                                                      C
C5------CALCULATE AMOUNT OF SPACE NEEDED FOR ISTRM LIST.               C
      ICSTRM=ISUM
      ISPB=5*MXSTRM
      ISUM=ISUM+ISPB
C                                                                      C
C6------CALCULATE AMOUNT OF SPACE NEEEDED FOR ITRBAR LIST.             C
      LCTBAR=ISUM
```

```
      ISPC=NSS*NTRIB
      ISUM=ISUM+ISPC
C                                                                       C
C7------CALCULATE AMOUNT OF SPACE NEEDED FOR ARTRIB LIST.               C
      LCTRIB=ISUM
      ISPD=NSS
      ISUM=ISUM+ISPD
C                                                                       C
C8------CALCULATE AMOUNT OF SPACE NEEDED FOR IDIVAR LIST.               C
      LCIVAR=ISUM
      ISPE=NSS
      ISUM=ISUM+ISPE
      ISP=ISPA+ISPB+ISPC+ISPD+ISPE
C                                                                       C
C9------PRINT AMOUNT OF SPACE USED BY STREAM PACKAGE.                   C
      WRITE (IOUT,8)ISP
    8 FORMAT(1X,I8,' ELEMENTS IN X ARRAY ARE USED FOR STREAMS')
      ISUM1=ISUM-1
      WRITE(IOUT,9)ISUM1,LENX
    9 FORMAT(1X,I8,' ELEMENTS OF X ARRAY USED OUT OF',I7)
      IF(ISUM1.GT.LENX) WRITE(IOUT,10)
   10 FORMAT(1X,'    ***X ARRAY MUST BE DIMENSIONED LARGER***')
C                                                                       C
C10-----RETURN.                                                         C
      RETURN
      END
      SUBROUTINE STR1RP(STRM,ISTRM,NSTREM,MXSTRM,IN,IOUT,ITRBAR,NDIV,
     1                   NSS,NTRIB,IDIVAR,ICALC,IPTFLG)
C                                                                       C
C                                                                       C
C-----VERSION 2 19APR1992 STR1RPC                                       C
C     ******************************************************************C
C     READ STREAM DATA:  INCLUDES SEGMENT AND REACH NUMBERS, CELL       C
C         SEQUENCE OF SEGMENT AND REACH, FLOW INTO MODEL AT BOUNDARY,   C
C         STREAM STAGE, STREAMBED CONDUCTANCE, AND STREAMBED TOP AND    C
C         BOTTOM ELEVATIONS                                             C
C     ******************************************************************C
C                                                                       C
C    SPECIFICATIONS:                                                    C
C     ------------------------------------------------------------------C
     DIMENSION STRM(11,MXSTRM),ISTRM(5,MXSTRM),ITRBAR(NSS,NTRIB),
    1          IDIVAR(NSS)
C     ------------------------------------------------------------------C
C                                                                       C
C1A-----IF MXSTREAM IS LESS THAN 1 THEN STREAM IS INACTIVE. RETURN.     C
      IF(MXSTRM.LT.1) RETURN
C                                                                       C
C1B-----READ ITMP(NUMBER OF STREAM CELLS OR FLAG TO REUSE DATA).        C
      READ(IN,1)ITMP,IRDFLG,IPTFLG
    1 FORMAT(3I10)
C                                                                       C
C2A-----IF ITMP <0 THEN REUSE DATA FROM LAST STRESSPERIOD.              C
```

```
      IF(ITMP.GE.0)GO TO 50
      WRITE(IOUT,2)
    2 FORMAT(1H0,'REUSING STREAM NODES FROM LAST STRESS PERIOD')
      RETURN
C                                                                       C
C2B-----IF ITMP=> ZERO THEN IT IS THE NUMBER OF STREAM REACHES.         C
   50 NSTREM=ITMP
C                                                                       C
C3A-----IF NSTREM>MXSTRM THEN STOP.                                     C
      IF(NSTREM.LE.MXSTRM)GO TO 100
      WRITE(IOUT,99)NSTREM,MXSTRM
   99 FORMAT(1H0,'NSTREM(',I4,') IS GREATER THAN MXSTRM(',I4,')')
      STOP
C                                                                       C
C3B-----PRINT NUMBER OF STREAM CELLS IN THIS STRESS PERIOD.             C
  100 IF(IRDFLG.EQ.0) WRITE(IOUT,3)NSTREM
    3 FORMAT(1H0,//1X,I5,' STREAM NODES')
C                                                                       C
C4------IF THERE ARE NO STREAM CELLS THEN RETURN.                       C
      IF(NSTREM.EQ.0) RETURN
C                                                                       C
C5------READ AND PRINT DATA FOR EACH STREAM CELL.                       C
      IF(IRDFLG.EQ.0) WRITE(IOUT,4)
    4 FORMAT(1H ,3X,'LAYER   ROW    COL     SEGMENT   REACH   STREAMFLOW
     1     STREAM    STREAMBED     STREAMBED BOT  STREAMBED TOP',/27X,
     2'NUMBER   NUMBER                  STAGE   CONDUCTANCE       ELEVAT
     3ION      ELEVATION',/3X,110('-'))
      DO 250 II=1,NSTREM
      READ(IN,5)K,I,J,ISTRM(4,II),ISTRM(5,II),STRM(1,II),STRM(2,II),
     1STRM(3,II),STRM(4,II),STRM(5,II)
    5 FORMAT(5I5,F15.0,4F10.0)
      IF(IRDFLG.EQ.0) WRITE(IOUT,6)K,I,J,ISTRM(4,II),ISTRM(5,II),
     1STRM(1,II),STRM(2,II),STRM(3,II),STRM(4,II),STRM(5,II)
    6 FORMAT(1X,3X,I4,2I7,2I9,7X,G11.4,G12.4,G11.4,4X,2G13.4)
      ISTRM(1,II)=K
      ISTRM(2,II)=I
      ISTRM(3,II)=J
  250 CONTINUE
C                                                                       C
C6----READ AND PRINT DATA IF STREAM STAGE IS CALCULATED.                C
      IF(ICALC.LE.0) GO TO 300
      IF(IRDFLG.EQ.0) WRITE(IOUT,7)
    7 FORMAT(1H0,3X,'LAYER',3X,'ROW',4X,'COL    ',' SEGMENT',3X,
     1'REACH',8X,'STREAM',13X,'STREAM',10X,'ROUGH',/27X,'NUMBER',3X,
     2 'NUMBER',8X,'WIDTH',14X,'SLOPE',10X,'COEF.',/3X,110('-'))
      DO 280 II=1,NSTREM
      READ(IN,8) STRM(6,II),STRM(7,II),STRM(8,II)
    8 FORMAT(3F10.0)
      IF(IRDFLG.EQ.0) WRITE(IOUT,9)ISTRM(1,II),ISTRM(2,II),ISTRM(3,II),
     1ISTRM(4,II),ISTRM(5,II),STRM(6,II),STRM(7,II),STRM(8,II)
    9 FORMAT(4X,I4,2I7,2I9,7X,G12.4,4X,G13.4,4X,G12.4)
  280 CONTINUE
```

```
C                                                                         C
C7------INITIALIZE ALL TRIBUTARY SEGMENTS TO ZERO.                        C
  300 DO 320 IK=1,NSS
      DO 320 JK=1,NTRIB
      ITRBAR(IK,JK)=0
  320 CONTINUE
C                                                                         C
C8-----INITIALIZE DIVERSION SEGMENT ARRAY TO ZERO.                        C
      DO 325 IK=1,NSS
      IDIVAR(IK)=0
  325 CONTINUE
C                                                                         C
C9-----READ AND PRINT TRIBUTARY SEGMENTS.                                 C
      IF(NTRIB.LE.0) GO TO 343
      IF(IRDFLG.EQ.0) WRITE(IOUT,10)NTRIB
   10 FORMAT(1H0,30X,'MAXIMUM NUMBER OF TRIBUTARY STREAMS IS ',I5,//1X,
     1 20X,'STREAM SEGMENT',15X,'TRIBUTARY STREAM SEGMENT NUMBERS')
      DO 340 IK=1,NSS
      READ(IN,11) (ITRBAR(IK,JK),JK=1,NTRIB)
   11 FORMAT(10I5)
      IF(IRDFLG.EQ.0) WRITE(IOUT,12)IK,(ITRBAR(IK,JK),JK=1,NTRIB)
   12 FORMAT(20X,I5,20X,10I5)
  340 CONTINUE
C                                                                         C
C10----READ AND PRINT DIVERSION SEGMENTS NUMBERS.                         C
  343 IF(NDIV.LE.0) GO TO 350
      IF(IRDFLG.EQ.0) WRITE(IOUT,13)
   13 FORMAT(1H0,10X,'DIVERSION SEGMENT NUMBER',10X,
     1        'UPSTREAM SEGMENT NUMBER')
      DO 345 IK=1,NSS
      READ(IN,14) IDIVAR(IK)
   14 FORMAT(I10)
      IF(IRDFLG.EQ.0) WRITE(IOUT,15) IK,IDIVAR(IK)
   15 FORMAT(20X,I5,28X,I5)
  345 CONTINUE
C                                                                         C
C11----SET FLOW OUT OF REACH, FLOW INTO REACH, AND FLOW THROUGH           C
C       STREAM BED TO ZERO.                                               C
  350 DO 360 II =1,NSTREM
      STRM(9,II)=0.0
      STRM(10,II)=0.0
      STRM(11,II)=0.0
  360 CONTINUE
C                                                                         C
C12------RETURN                                                           C
      RETURN
      END
      SUBROUTINE STR1FM(NSTREM,STRM,ISTRM,HNEW,HCOF,RHS,IBOUND,MXSTRM,
     1             NCOL,NROW,NLAY,IOUT,NSS,ITRBAR,NTRIB,ARTRIB,
     2                  IDIVAR,ICALC,CONST)
C                                                                         C
C-----VERSION 2 19APR1992 STR1FM                                          C
```

```
C*****************************************************************************C
C     ADD STREAM TERMS TO RHS AND HCOF IF FLOW OCCURS IN MODEL CELL          C
C*****************************************************************************C
C                                                                             C
C     SPECIFICATIONS:                                                         C
C     ------------------------------------------------------------------------C
C                                                                             C
      DOUBLE PRECISION HNEW
      DIMENSION STRM(11,MXSTRM),ISTRM(5,MXSTRM),HNEW(NCOL,NROW,NLAY),
     1          HCOF(NCOL,NROW,NLAY),RHS(NCOL,NROW,NLAY),
     2          IBOUND(NCOL,NROW,NLAY),ITRBAR(NSS,NTRIB),ARTRIB(NSS),
     3          IDIVAR(NSS)
C     ------------------------------------------------------------------------C
C                                                                             C
C1------IF NSTREM<=0 THERE ARE NO STREAMS. RETURN.                            C
      IF(NSTREM.LE.0)RETURN
C                                                                             C
C2------PROCESS EACH CELL IN THE STREAM LIST.                                 C
C                                                                             C
C3------DETERMINE LAYER, ROW, COLUMN OF EACH REACH.                           C
      DO 500 L=1,NSTREM
      LL=L-1
      IL=ISTRM(1,L)
      IR=ISTRM(2,L)
      IC=ISTRM(3,L)
C                                                                             C
C4------DETERMINE IF CELL IS OUTSIDE OF MODEL BOUNDARIES.                     C
      IF(IBOUND(IC,IR,IL).LE.0)GO TO 500
C                                                                             C
C5------DETERMINE STREAM SEGMENT AND REACH NUMBER.                            C
      ISTSG=ISTRM(4,L)
      NREACH=ISTRM(5,L)
C                                                                             C
C6------SET FLOWIN EQUAL TO STREAM SEGMENT INFLOW IF FIRST REACH.             C
      IF(NREACH.GT.1) GO TO 200
      FLOWIN=STRM(1,L)
C                                                                             C
C7------STORE OUTFLOW FROM PREVIOUS SEGMENT IN ARTRIB IF SEGMENT >1.          C
      IF(ISTSG.GT.1) IFLG = ISTRM(4,LL)
      IF(ISTSG.GT.1)  ARTRIB(IFLG)=STRM(9,LL)
C                                                                             C
C8------IF SEGMENT IS A DIVERSION, COMPUTE FLOW OUT OF UPSTREAM REACH.        C
      IF(IDIVAR(ISTSG).LE.0) GO TO 50
      NDFLG=IDIVAR(ISTSG)
      DUM=ARTRIB(NDFLG)-FLOWIN
      IF(DUM.GE.0.0.AND.ICALC.GT.0) ARTRIB(NDFLG)=DUM
      IF(DUM.GE.0.0.AND.ICALC.GT.0) GO TO 50
      IF(ICALC.LE.0) GO TO 50
      FLOWIN=0.
   50 IF(FLOWIN.LT.5.0E14) GO TO 300
C                                                                             C
C9-----SUM TRIBUTARY OUTFLOW AND USE AS INFLOW INTO DOWNSTREAM SEGMENT.       C
```

```
      FLOWIN =0.
      DO 100 ITRIB=1,NTRIB
      INODE=ITRBAR(ISTSG,ITRIB)
      IF(INODE.LE.0) GO TO 100
      FLOWIN=FLOWIN+ARTRIB(INODE)
  100 CONTINUE
C                                                                       C
C10-----IF REACH >1, SET INFLOW EQUAL TO OUTFLOW FROM UPSTREAM REACH.   C
  200 IF(NREACH.GT.1) FLOWIN=STRM(9,LL)
C                                                                       C
C11----COMPUTE STREAM STAGE IN REACH IF ICALC IS GREATER THAN 1.        C
  300 IF(ICALC.LE.0) GO TO 310
      XNUM=((FLOWIN+STRM(9,L))/2.0)*STRM(8,L)
      DNOM=CONST*STRM(6,L)*(SQRT(STRM(7,L)))
      DEPTH=(XNUM/DNOM)**0.6
      IF(DEPTH.LE.0.) DEPTH=0.
      STRM(2,L)=DEPTH+STRM(5,L)
  310 HSTR=STRM(2,L)
C                                                                       C
C12----DETERMINE LEAKAGE THROUGH STREAMBED.                             C
      IF(FLOWIN.LE.0.AND.ICALC.GT.0) HSTR=STRM(5,L)
      CSTR=STRM(3,L)
      SBOT=STRM(4,L)
      H=HNEW(IC,IR,IL)
      T=HSTR-SBOT
C                                                                       C
C13----COMPUTE LEAKAGE AS A FUNCTION OF STREAM STAGE AND HEAD IN CELL.  C
      FLOBOT=CSTR*(HSTR-H)
C                                                                       C
C14----RECOMPUTE LEAKAGE IF HEAD IN CELL IS BELOW STREAMBED BOTTOM.     C
      IQFLG=0
      IF(H.GT.SBOT) GO TO 312
      IQFLG=1
      FLOBOT=CSTR*T
C                                                                       C
C15----SET LEAKAGE EQUAL TO STREAM INFLOW IF LEAKAGE MORE THAN INFLOW.  C
  312 IF(FLOBOT.LE.FLOWIN.OR.ICALC.LE.0) GO TO 320
      IQFLG=1
      FLOBOT=FLOWIN
C                                                                       C
C16-----STREAMFLOW OUT EQUALS STREAMFLOW IN MINUS LEAKAGE.              C
 320  FLOWOT=FLOWIN-FLOBOT
      IF((ISTSG.GT.1).AND.(NREACH.EQ.1)) STRM(9,LL)=ARTRIB(IFLG)
C                                                                       C
C17----STORE STREAM INFLOW, OUTFLOW AND LEAKAGE FOR EACH REACH.         C
      STRM(9,L)=FLOWOT
      STRM(10,L)=FLOWIN
      STRM(11,L)=FLOBOT
C                                                                       C
C18----RETURN TO STEP 3 IF STREAM INFLOW IS LESS THAN OR EQUAL TO ZERO  C
C       AND LEAKAGE IS GREATER THAN OR EQUAL TO ZERO.                   C
      IF((FLOWIN.LE.0.0).AND.(FLOBOT.GE.0.0).AND.(ICALC.GT.0)) GO TO 500
```

```
C                                                                      C
C19------IF HEAD > BOTTOM THEN ADD TERMS TO RHS AND HCOF.              C
      IF(IQFLG.GT.0) GO TO 400
      RHS(IC,IR,IL)=RHS(IC,IR,IL)-CSTR*HSTR
      HCOF(IC,IR,IL)=HCOF(IC,IR,IL)-CSTR
      GO TO 500
C                                                                      C
C20------IF HEAD < BOTTOM THEN ADD TERM ONLY TO RHS.                   C
  400 RHS(IC,IR,IL)=RHS(IC,IR,IL)-FLOBOT
  500 CONTINUE
C                                                                      C
C22-----RETURN.                                                        C
      RETURN
      END
      SUBROUTINE STR1BD(NSTREM,STRM,ISTRM,IBOUND,MXSTRM,HNEW,NCOL,NROW,
     1    NLAY,DELT,VBVL,VBNM,MSUM,KSTP,KPER,ISTCB1,ISTCB2,ICBCFL,
     2    BUFF,IOUT,NTRIB,NSS,ARTRIB,ITRBAR,IDIVAR,ICALC,CONST,IPTFLG)
C-----VERSION 2 19APR1992 STR1BD                                       C
C     *****************************************************************C
C     CALCULATE VOLUMETRIC BUDGET FOR STREAMS                          C
C     *****************************************************************C
C                                                                      C
C     SPECIFICATIONS:                                                  C
C     -----------------------------------------------------------------C
      CHARACTER*4 VBNM,TEXT,STRTXT
      DOUBLE PRECISION HNEW
      DIMENSION STRM(11,MXSTRM),ISTRM(5,MXSTRM),IBOUND(NCOL,NROW,NLAY),
     1          HNEW(NCOL,NROW,NLAY),VBVL(4,20),VBNM(4,20),
     2          BUFF(NCOL,NROW,NLAY),ARTRIB(NSS),ITRBAR(NSS,NTRIB),
     3             IDIVAR(NSS)
      DIMENSION TEXT(4),STRTXT(4)
      DATA TEXT(1),TEXT(2),TEXT(3),TEXT(4) /'  ST','REAM',' LEA','KAGE'/
      DATA STRTXT(1),STRTXT(2),STRTXT(3),STRTXT(4) /'STRE','AM F',
     1                                              'LOW ','OUT '/
C     -----------------------------------------------------------------C
C                                                                      C
C1------SET IBD=1 IF BUDGET TERMS SHOULD BE SAVED ON DISK.              C
      IBD=0
      RATIN = 0.
      RATOUT = 0.
C                                                                      C
C2------IF NO REACHES, KEEP ZEROS IN ACCUMULATORS.                      C
      IF(NSTREM.EQ.0) GO TO 600
C                                                                      C
C3A-----TEST TO SEE IF CELL-BY-CELL TERMS ARE NEEDED.                  C
      IF((ICBCFL.EQ.0).OR.(ISTCB1.LE.0)) GO TO 10
C                                                                      C
C3B-----CELL-BY-CELL TERMS ARE NEEDED, SET IBD AND CLEAR BUFFER.       C
      IBD = 1
      DO 5 IL=1,NLAY
      DO 5 IR=1,NROW
      DO 5 IC=1,NCOL
```

```
      BUFF(IC,IR,IL)=0.
    5 CONTINUE
C                                                                       C
C4------IF THERE ARE STREAMS THEN ACCUMULATE LEAKAGE TO OR FROM THEM.    C
   10 DO 500 L=1,NSTREM
      LL=L-1
C                                                                       C
C5---DETERMINE REACH LOCATION.                                          C
      IL=ISTRM(1,L)
      IR=ISTRM(2,L)
      IC=ISTRM(3,L)
C                                                                       C
C6---IF CELL IS EXTERNAL SKIP CALCULATIONS.                             C
      IF(IBOUND(IC,IR,IL).LE.0)GO TO 500
C                                                                       C
C7------DETERMINE SEGMENT AND REACH NUMBER.                             C
      ISTSG=ISTRM(4,L)
      NREACH=ISTRM(5,L)
      IF(NREACH.GT.1) GO TO 200
C                                                                       C
C8------SET FLOWIN EQUAL TO SEGMENT INFLOW IF FIRST REACH.              C
      FLOWIN=STRM(1,L)
      IF(ISTSG.GT.1) IFLG = ISTRM(4,LL)
C                                                                       C
C9------STORE OUTFLOW FROM PREVIOUS SEGMENT IN ARTRIB IF SEGMENT >1.    C
      IF(ISTSG.GT.1)  ARTRIB(IFLG)=STRM(9,LL)
C                                                                       C
C10--IF SEGMENT IS A DIVERSION, COMPUTE FLOW OUT OF UPSTREAM SEGMENT.   C
      IF(IDIVAR(ISTSG).LE.0) GO TO 50
      NDFLG=IDIVAR(ISTSG)
      DUM=ARTRIB(NDFLG)-FLOWIN
      IF(DUM.GE.0.0.AND.ICALC.GT.0) ARTRIB(NDFLG)=DUM
      IF(DUM.GE.0.0.AND.ICALC.GT.0) GO TO 50
      IF(ICALC.LE.0) GO TO 50
      FLOWIN=0.
   50 IF(FLOWIN.LT.5.0E14) GO TO 300
C                                                                       C
C11--SUM TRIBUTARY OUTFLOW AND USE AS INFLOW INTO DOWNSTREAM SEGMENT.   C
      FLOWIN =0.
      DO 100 ITRIB=1,NTRIB
      INODE=ITRBAR(ISTSG,ITRIB)
      IF(INODE.LE.0) GO TO 100
      FLOWIN=FLOWIN+ARTRIB(INODE)
  100 CONTINUE
C                                                                       C
C12-----IF REACH >1, SET INFLOW EQUAL TO OUTFLOW FROM UPSTREAM REACH.   C
  200 IF(NREACH.GT.1) FLOWIN=STRM(9,LL)
C                                                                       C
C13----COMPUTE STREAM STAGE IN REACH IF ICALC > 1.                      C
  300 IF(ICALC.LE.0) GO TO 310
      XNUM=((FLOWIN+STRM(9,L))/2.0)*STRM(8,L)
      DNOM=CONST*STRM(6,L)*(SQRT(STRM(7,L)))
```

```
      DEPTH=(XNUM/DNOM)**0.6
      IF((DEPTH).LE.0) DEPTH=0.
      STRM(2,L)=DEPTH+STRM(5,L)
  310 HSTR=STRM(2,L)
C                                                                       C
C14----DETERMINE LEAKAGE THROUGH STREAMBED.                             C
      IF(FLOWIN.LE.0.0.AND.ICALC.GT.0) HSTR=STRM(5,L)
      CSTR=STRM(3,L)
      SBOT=STRM(4,L)
      H=HNEW(IC,IR,IL)
      T=HSTR-SBOT
C                                                                       C
C15----COMPUTE LEAKAGE AS A FUNCTION OF STREAM STAGE AND HEAD IN CELL.  C
      FLOBOT=CSTR*(HSTR-H)
C                                                                       C
C16----RECOMPUTE LEAKAGE IF HEAD IN CELL IS BELOW STREAMBED BOTTOM.     C
      IF(H.GT.SBOT) GO TO 312
      FLOBOT=CSTR*T
C                                                                       C
C17----SET LEAKAGE EQUAL TO STREAM INFLOW IF LEAKAGE MORE THAN INFLOW.  C
  312 IF(FLOBOT.LE.FLOWIN.OR.ICALC.LE.0) GO TO 320
      FLOBOT=FLOWIN
C                                                                       C
C18----STREAMFLOW OUT EQUALS STREAMFLOW IN MINUS LEAKAGE.               C
 320  FLOWOT=FLOWIN-FLOBOT
      IF((ISTSG.GT.1).AND.(NREACH.EQ.1)) STRM(9,LL)=ARTRIB(IFLG)
C                                                                       C
C19----STORE STREAM INFLOW, OUTFLOW AND LEAKAGE FOR EACH REACH.         C
      STRM(9,L)=FLOWOT
      STRM(10,L)=FLOWIN
      STRM(11,L)=FLOBOT
C                                                                       C
C20----IF LEAKAGE FROM STREAMS IS TO BE SAVED THEN ADD RATE TO BUFFER.  C
      IF(IBD.EQ.1) BUFF(IC,IR,IL)=BUFF(IC,IR,IL)+FLOBOT
C                                                                       C
C21----DETERMINE IF FLOW IS INTO OR OUT OF MODEL CELL.                  C
C        SKIP ESTIMATE OF LEAKAGE FROM STREAM IF LEAKAGE IS ZERO.        C
      IF(FLOBOT)494,500,496
C                                                                       C
C22-----SUBTRACT FLOW RATE FROM RATOUT IF AQUIFER DISCHARGES TO STREAM. C
  494 RATOUT=RATOUT-FLOBOT
      GO TO 500
C                                                                       C
C23-----ADD FLOW RATE TO RATIN IF STREAM DISCHARGES TO AQUIFER.         C
  496 RATIN=RATIN+FLOBOT
  500 CONTINUE
C                                                                       C
C24-----IF BUDGET TERMS WILL BE SAVED THEN WRITE TO DISK.               C
      IF(IBD.EQ.1) CALL UBUDSV(KSTP,KPER,TEXT,ISTCB1,BUFF,NCOL,NROW,
     1                          NLAY,IOUT)
C                                                                       C
C25A-----MOVE RATES INTO VBVL FOR PRINTING BY MODULE BAS_OT.            C
```

```
  600 VBVL(3,MSUM)=RATIN
      VBVL(4,MSUM)=RATOUT
C                                                                        C
C25B-----MOVE PRODUCT OF RATE AND TIME STEP INTO VBVL ACCUMULATORS.       C
      VBVL(1,MSUM)=VBVL(1,MSUM)+RATIN*DELT
      VBVL(2,MSUM)=VBVL(2,MSUM)+RATOUT*DELT
C                                                                        C
C25C-----MOVE BUDGET TERM LABELS INTO VBNM FOR PRINTING BY BAS_OT.        C
      VBNM(1,MSUM)=TEXT(1)
      VBNM(2,MSUM)=TEXT(2)
      VBNM(3,MSUM)=TEXT(3)
      VBNM(4,MSUM)=TEXT(4)
C                                                                        C
C26-----INCREASE BUDGET TERM COUNTER BY ONE.                              C
      MSUM=MSUM+1
C                                                                        C
C27-----RESET IBD COUNTER TO ZERO.                                        C
      IBD=0
C28----IF STREAM OUTFLOW FROM EACH REACH IS TO BE STORED ON DISK          C
C         THEN STORE OUTFLOW RATES TO BUFFER.                             C
      IF((ICBCFL.EQ.0).OR.(ISTCB2.LE.0)) GO TO 625
      IBD = 1
      DO 605 IL=1,NLAY
      DO 605 IR=1,NROW
      DO 605 IC=1,NCOL
  605 BUFF(IC,IR,IL)=0.
C                                                                        C
C29-----SAVE STREAMFLOWS OUT OF EACH REACH ON DISK.                       C
      DO 615 L=1,NSTREM
      IC=ISTRM(3,L)
      IR=ISTRM(2,L)
      IL=ISTRM(1,L)
      IF(IBOUND(IC,IR,IL).LE.0) GO TO 615
      BUFF(IC,IR,IL)=BUFF(IC,IR,IL)+STRM(9,L)
  615 CONTINUE
      CALL UBUDSV(KSTP,KPER,STRTXT,ISTCB2,BUFF,NCOL,NROW,NLAY,IOUT)
C                                                                        C
C30-----PRINT STREAMFLOW RATES AND LEAKAGE FOR EACH REACH.                C
  625 IF((ISTCB1.GE.0).OR.(ICBCFL.LE.0)) GO TO 800
      IF(IPTFLG.GT.0) GO TO 800
      IF(ICALC.GT.0) GO TO 700
      WRITE(IOUT,650)
  650 FORMAT(1H0,12X,'LAYER',6X,'ROW',5X,'COLUMN',5X,'STREAM',4X,
     1'REACH',6X,'FLOW INTO',4X,'FLOW INTO',6X,'FLOW OUT OF'/43X,
     2       'NUMBER',3X,'NUMBER',4X,'STREAM REACH',4X,'AQUIFER',
     3       6X,'STREAM REACH'//)
      DO 690 L=1,NSTREM
      IL=ISTRM(1,L)
      IR=ISTRM(2,L)
      IC=ISTRM(3,L)
      WRITE(IOUT,675)IL,IR,IC,ISTRM(4,L),ISTRM(5,L),
     1     STRM(10,L),STRM(11,L),STRM(9,L)
```

```
  675 FORMAT(1X,5X,5I10,8X,G9.3,5X,G9.3,8X,G9.3)
  690 CONTINUE
      GO TO 800
  700 WRITE(IOUT,710)
  710 FORMAT(1H0,7X,'LAYER',6X,'ROW',5X,'COLUMN',5X,'STREAM',4X,
     1'REACH',6X,'FLOW INTO',4X,'FLOW INTO',6X,'FLOW OUT OF',5X,
     A'HEAD IN',4X,'DEPTH OF'
     2          /38X,       'NUMBER',3X,'NUMBER',4X,'STREAM REACH',
     3 4X,'AQUIFER',6X,'STREAM REACH',5X,'STREAM'5X,'FLOW'//)
      DO 750 L=1,NSTREM
      IL=ISTRM(1,L)
      IR=ISTRM(2,L)
      IC=ISTRM(3,L)
      DEPTH=STRM(2,L)-STRM(5,L)
      WRITE(IOUT,775)IL,IR,IC,ISTRM(4,L),ISTRM(5,L),
     1      STRM(10,L),STRM(11,L),STRM(9,L),STRM(2,L),DEPTH
  775 FORMAT(1X,5I10,8X,G9.3,5X,G9.3,7X,G9.3,4X,F9.4,2X,F9.4)
  750 CONTINUE
  800 CONTINUE
C                                                                      C
C31-----RETURN.                                                        C
      RETURN
      END
```


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