Documentation of a Computer Program (FHB1) for Assignment of Transient Specified-Flow and Specified-Head Boundaries in Applications of the Modular Finite-Difference Ground-Water Flow Model (MODFLOW)

U.S. GEOLOGICAL SURVEY

Open-File Report 97-571

Prepared in cooperation with the
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FAIRBANKS INTERNATIONAL AIRPORT
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By S. A. LEAKE and MICHAEL R. LILLY

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Tucson, Arizona
1997

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Box 25286
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PREFACE

This report presents a computer program for simulating specified-flow and specified-head boundaries in the U.S. Geological Survey ground-water model, MODFLOW. The performance of this computer program has been tested in models of hypothetical ground-water flow systems; however, future applications of the programs could reveal errors that were not detected in the test simulations. Users are requested to notify the USGS if errors are found in the report or in the computer program. Correspondence regarding the report or program should be sent to

U.S. Geological Survey
Water Resources Division
520 North Park Avenue, Suite 221
Tucson, Arizona 85719-5035

The computer program documented in this report is part of the MODFLOW-96 ground-water flow model. MODFLOW-96 and other ground-water programs are available from the USGS at World Wide Web address

http://h2o.usgs.gov/software/

or by anonymous ftp file transfer from directory /pub/software/ground_water/modflow at Internet address

h2o.usgs.gov

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CONVERSION FACTORS

Multiply	By	To obtain
foot (ft)	0.3048	meter
foot squared per day (ft^2/d)	0.09290	meter squared per day
cubic foot (ft^3)	0.02832	cubic meter

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By S.A. Leake *and* Michael R. Lilly

Abstract

A computer program called the Flow and Head Boundary Package (FHB1) was developed for the U.S. Geological Survey three-dimensional finite-difference modular ground-water flow model, commonly referred to as MODFLOW. FHB1 allows MODFLOW users to specify flow or head boundary conditions that vary at times other than starting and ending times of stress periods and associated time steps. Values of flow and (or) head at each time step are calculated by linear interpolation of user-specified values. The ability to assign variable flow and head conditions defined at times not corresponding with the model stress periods allows greater flexibility in simulating natural geohydrologic systems and, at the same time, improves the efficiency of the methods used to represent these systems. The package also provides a way to apply specified-flow and specified-head boundaries in embedded, or nested, smaller-scale models using flow and (or) head values from larger-scale models. Using FHB1, the two models can have different simulation stress periods and time steps. Specification of variable-flow pumped wells in ground-water models is another example application.

INTRODUCTION

Version 1 of the Flow and Head Boundary Package (FHB1) is a computer program developed for the U.S. Geological Survey (USGS) three-dimensional finite-difference modular ground-water flow model, which is commonly referred to as MODFLOW-96 (Harbaugh and McDonald, 1996). FHB1 allows MODFLOW users to specify flow and (or) head, as functions of time, at selected model cells. Flow or head can be specified at any model cell within the active flow region. The values input do not have to be at times corresponding to starting and ending times of stress periods or time steps defined in the model applications. The package uses interpolation to compute values of head and flow at each model time step.

FHB1 is an alternative and (or) supplement to using the Well (WEL) Package or the Recharge Package for simulating specified-flow boundaries. FHB1 also is an alternative and (or) supplement to using the Block-Centered Flow (BCF) Package and the Time-Variant Specified-Head (CHD) Package (Leake and Prudic, 1991, Appendix C) for simulating specified-head boundaries. The method of specifying boundary values used by FHB1 allows for more detailed representations of variations with simulation time. Most previous MODFLOW packages keep boundary values (head or flow) constant within each stress period. The CHD Package allows boundary head to vary linearly within each stress period.

In contrast, FHB1 can simulate head and flow values independent of stress periods. Values for each time step are interpolated from data sets of simulation times and flow and head values. This approach allows for detailed representation of variations in boundary and internal flow and head values over time, without requiring many stress periods to be defined.

CONCEPTUALIZATION OF FLOW AND HEAD BOUNDARY PACKAGE (FHB1)

FHB1 uses a function, based on user-specified values, of flow and simulation time or head and simulation time to define boundary conditions for the entire simulation at each selected model cell. The function is based on linear interpolation and calculates values for each MODFLOW time step. If both head and flow are specified at any individual model cell, the specified-flow function will not be applied. Information for specifying flow and head at individual model cells is read at the start of the simulation. In addition to calculation of interpolated flow and head at each time step, FHB1 also allows calculation of interpolated values of auxiliary variables. These values are not used in simulations of flow only; however, simulation of solute transport and other processes can make use of auxiliary variables associated with specified-flow and specified-head cells.

All specified-flow and specified-head cells implemented by FHB1 use the same set of simulation times to define the function of flow or head (fig. 1). One or more times for specifying flow and head must be entered, and the initial time must be zero. If only one time is entered, flows or heads will not change during the simulation. Otherwise, the functions are used for interpolating flow and head at individual time steps. Note that a specified simulation time can be equal to an immediately preceding simulation time. This allows a single simulation time to have two values of flow or head at each cell, resulting in the ability to simulate step-type hydrologic responses in the ground-water model. Other than the initial time, times for specifying flow and head need not coincide with starting or ending times of time steps or stress periods. The final time normally coincides with the maximum simulation time; however, FHB1 will interpolate within functions or extrapolate beyond the ends of functions to compute flow and head for any time step.

Although FHB1 offers the greatest advantages for transient simulations, the package also can be used in steady-state simulations. Two options are included for computation of values of flow, head, and auxiliary variables in steady-state simulations. For the first option, FHB1 takes values at the starting point of the simulation. This option is appropriate for steady-state simulations that will be used as starting conditions for following transient simulations that use FHB1. For the second option, FHB1 interpolates values in the same way that values are interpolated in transient simulations. This option allows simulation of steady-state flow with transient solute transport or other processes.

Specified-Flow Conditions

FHB1 input includes the number of cells at which flows will be specified for the simulation. If a value of zero is specified, FHB1 will be used for specified-head conditions only. For each specified-flow cell, the program reads the layer, row, and column indices of the cell, and a flow value for each of the times used to define the functions. Flow values are specified in units of volume per unit time, using units consistent with other length and time units used in the simulation.

The values of flow and time define a function for each specified-flow location. The area on a graph between a function for a model cell and the ordinate axis from the start to the end of the simulation defines the volumes of flow into and (or) out of the aquifer for the entire simulation (fig. 2). Before each time step, the program computes area between the ordinate axis and each flow function from the start to the end of the time step. The resulting areas are the volumes of water entering or leaving the aquifer for the time step. Volumes are divided by time-step length, Δt, to get flow rates at each specified-flow cell for the time step.

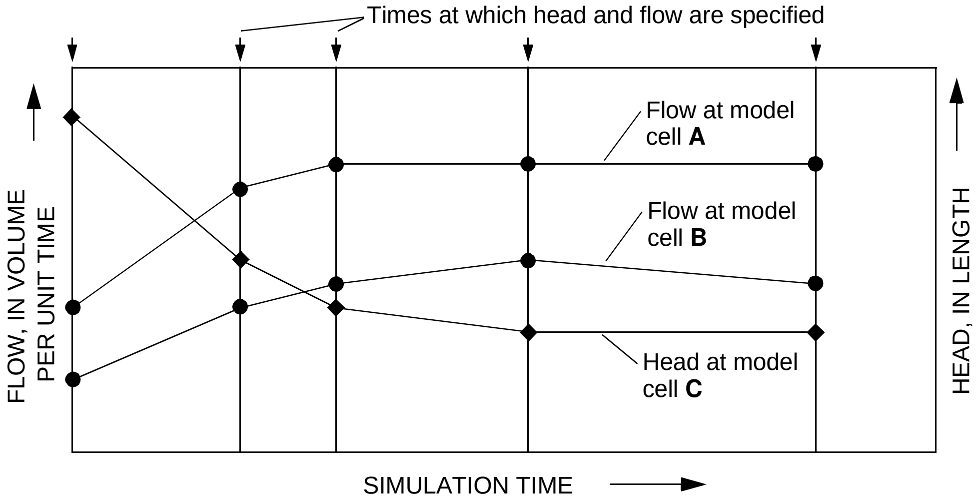


Figure 1. An example of definition of functions of flow and head for individual model cells.

With this procedure, the total volume of flow at each specified-flow cell for a simulation does not vary with number and length of time steps used in the simulation.

At the start of each time step, FHB1 computes flow for each specified-flow cell. Flow values are stored in an array and are incorporated on the right-hand side of the finite-difference equation for each specified-flow cell. The procedure of incorporating specified-flow values in the finite-difference equations is identical to the procedure used by McDonald and Harbaugh (1988) for the WEL Package. For more information on the structure of the finite-difference equations, see McDonald and Harbaugh (1988).

When a solution is reached using an iterative or direct solver, the flow values are used in calculating volumetric mass balances for the model. Cell-by-cell specified-flow values can be written or recorded in the same way that flow quantities are written or recorded for other MODFLOW packages.

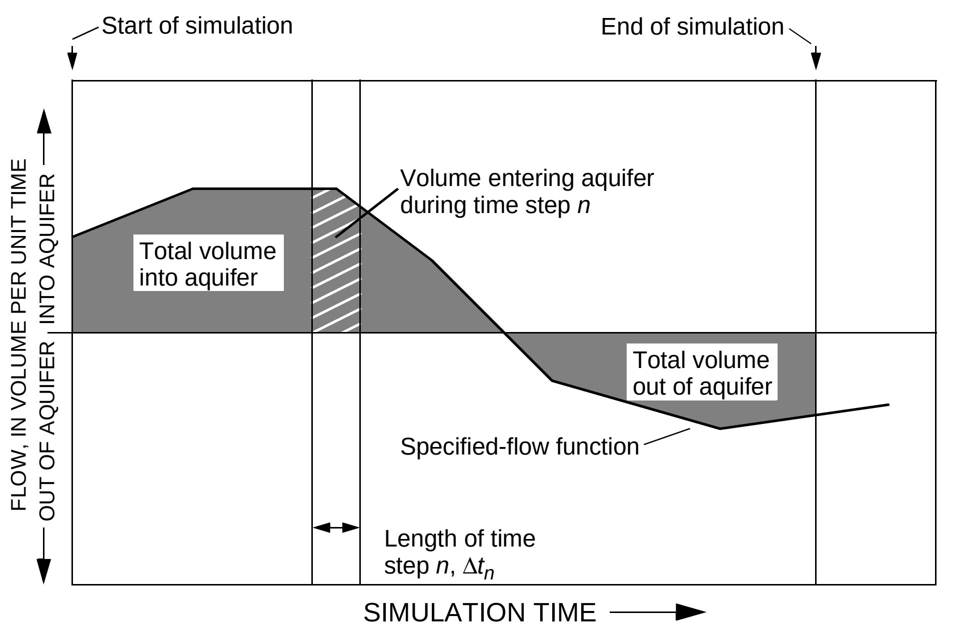


Figure 2. Volume of water entering the aquifer at a specified-flow location during a time step and during the entire simulation.

Specified-Head Conditions

FHB1 input includes the number of specified-head cells active for the simulation. If a value of zero is specified, FHB1 will be used for specified-flow conditions only. For each specified-head cell, the program reads the layer, row, and column indices of the cell, and a head value for each of the times used to define the functions. Head values are specified with a unit of length and a datum that are consistent with other head values used in the simulation.

Specified-head cells use the "constant-head" feature of the BCF Package in MODFLOW (McDonald and Harbaugh, 1988) and add the capability of changing head values over time. The incorporation of specified-head in MODFLOW is similar to that of the CHD Package (Leake and Prudic, 1991). However, FHB1 allows head variations to be specified independently of starting and ending times of stress periods.

The head values and the times in FHB1 define a function for each specified-head cell (fig. 3). The total simulation time at the end of a time step is used to interpolate head at each specified-head location. Interpolation at the end of the time step is consistent with the fully implicit finite-difference scheme of MODFLOW and is the same approach used by the CHD Package (Leake and Prudic, 1991). Note that although times used to specify variations in head do not need to correspond to starting and ending times of time steps, the lengths of time steps is an important factor in the detail to which variations in specified head is simulated. The peak in specified head in time step *n* in the example (fig. 3) is not simulated because the peak falls in the middle of a time step. If a certain level of detail is desired in representing the specified-head functions, users can carry out trial-and-error sensitivity analyses to determine the appropriate lengths for time steps.

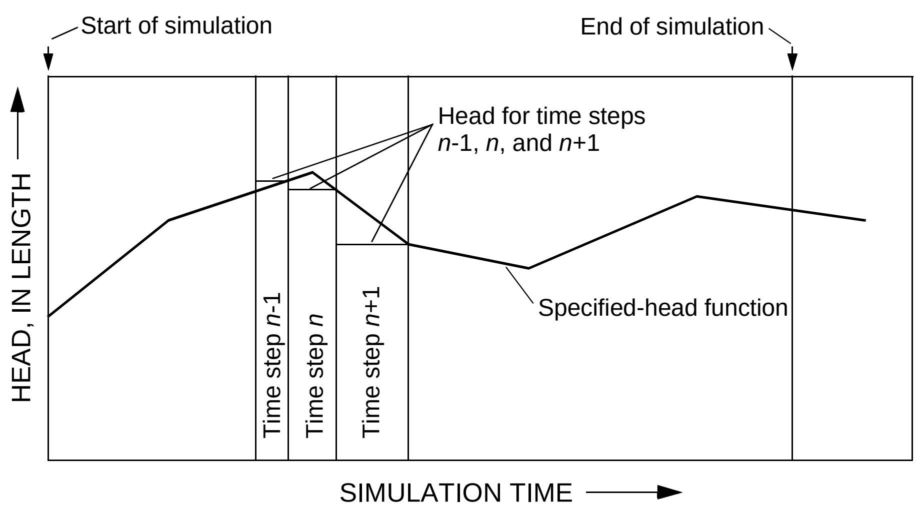


Figure 3. Interpolation of specified-head function for individual time steps.

At the start of each time step, FHB1 computes head for each specified-head cell. Head values are stored in MODFLOW arrays that contain the head for the current and previous time steps. Because FHB1 uses the constant-head feature of the BCF Package, no further operations are needed by FHB1 for formulation of finite-difference equations and calculation of an overall volumetric budget. Flow volumes and rates to or from specified-head cells are included in the overall volumetric budget in totals of "constant head" volumes and rates. Flow rates to individual specified-head cells can be saved or printed using options in the BCF Package.

Auxiliary Variables

MODFLOW can make use of boundary flow and head values defined by FHB1; however, other related programs may require additional variables to be defined for cells at which flow or head are specified. For example, the particle-tracking program MODPATH (Pollock, 1994) requires specification of an integer code that indicates which cell face a boundary flow enters or leaves a cell. Also, solute-transport model MOC3D (Konikow and others, 1996) requires that solute concentration be defined for constant-flow and constant-head cells. To allow compatibility with MODPATH, MOC3D, and perhaps other programs to be developed in the future, FHB1 allows definition of an integer auxiliary variable and up to five real auxiliary variables that are associated with specified-flow and specified-head cells. The auxiliary variables are not needed in simulations using MODFLOW-96 to solve only the flow equation.

The integer auxiliary variable is required input to the FHB1 Package and is read along with layer, row, and column indices for each specified-flow and specified-head cell. For simulations using MODFLOW-96 in which the variable is not needed, users may enter zero or any other integer value.

Definition of real auxiliary variables for specified-head and specified-flow cells is optional. The list of auxiliary variables for specified-flow cells is treated separately from the list of auxiliary variables for specified-head cells and users may define from zero to five real auxiliary variables for each of the two groups. For each variable, a character string containing the variable name and a number defining a time-weighting factor is read. Values of the variable are read for each of the times used to specify flow and head for each specified-flow and specified-head cell. With this information, FHB1 interpolates values of each variable every time step in much the same way that specified head is interpolated. The time-weighting factor, *W*, is a number ranging from 0.0 to 1.0 that specifies the relative time within each time step at which values of a variable will be computed (fig. 4). A value of 0.5 results in the values of a variable being computed at the center of each time step and a value of 1.0 results in the values of a variable being computed at the end of each time step. Interpolated values of auxiliary variables for each time step are stored in arrays that can be accessed by MOC3D or other programs.

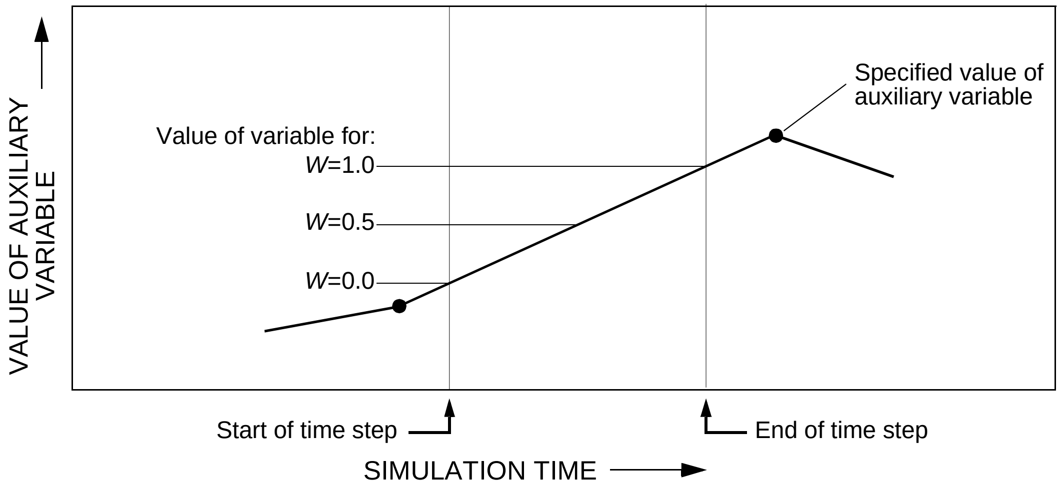


Figure 4. Effect of time-weighting factor, *W*, on interpolation of value of an auxiliary variable within a time step.

APPLICABILITY AND LIMITATIONS

The specified-flow and specified-head features of FHB1 are applicable for simulating known or estimated inflow or outflow quantities and head variations in ground-water models using MODFLOW.

Application can be made to simulate effects of features such as wells, streams, and lakes, that cause addition or removal of water from the system or cause head to vary. The package gives model users the ability to simulate transient variations in flow and head with model stress periods that may not have been designed for simulating changes of the boundary flow and head. For example, the package is useful for simulating features such as water-supply wells pumped at rates that change continually or at times other than starts and ends of model stress periods. The package also is useful for simulating continual or step changes in head of surface-water features such as streams, lakes, reservoirs, and gravel pits. The package requires that flow and head values for all cells implemented by the package be specified using a single set of simulation times.

In addition to physical boundary features, FHB1 can be used to simulate flow quantities and head variations at ground-water model boundaries that do not coincide with flow-system boundaries. This application allows boundary-flow rates and head values to be estimated or extracted from another ground-water model that simulates flow within a larger area. That application is known as “telescopic mesh refinement” (Ward and others, 1987; Anderson and Woessner, 1992, p. 61) or “embedded-mesh modeling.” This ability to use fluxes from a larger regional, or subregional, ground-water model is useful in studying relatively small parts of the larger regional or subregional flow systems. Such applications are common in studies of well fields and contaminant movement. These small-scale ground-water models seldom can incorporate physical flow-system boundaries. The ability to efficiently extract boundary fluxes out of a regional model and apply them to smaller-scale models is important in both reducing the costs and improving the confidence in the small-scale ground-water models.

Basic assumptions for FHB1 are the same as for other specified-flow and head features in MODFLOW. Formulation of finite-difference equations for specified-flow cells in FHB1 is the same as formulation for wells in the WEL Package. Formulation for specified-head cells is carried out by the BCF Package; therefore, assumptions for specified-head cells are the same as for constant-head cells. For information on specified-flow and constant-head features in MODFLOW, see McDonald and Harbaugh (1988) and Harbaugh and McDonald (1996).

An advantage in using FHB1 to simulate specified-flow and specified-head boundaries is that times for specifying changes in rates of flow and boundary head can be independent of times that model stress periods and time steps change. Users should note, however, that the lengths and numbers of model time steps will control the detail in simulating model response to the functions describing specified flow and specified head. If the specified values of flow and (or) head are changing rapidly during a part of a simulation, then to simulate the effects of the rapid changes, users must set up the model with sufficiently small time steps during those periods.

EXAMPLE PROBLEM

The example problem described in this section illustrates the use of FHB1. MODFLOW input data sets and the output listing file for the problem presented here are given in the appendix. The problem uses a model grid consisting of 1 layer, 3 rows, and 10 columns (fig. 5). Cell dimensions in the horizontal directions are 1,000 ft on each side. The ground-water system is homogeneous and isotropic, has a transmissivity of 5,000 ft^2/d, and has a storage coefficient of 0.01. The problem simulates transient flow for 1,000 days using three stress periods. The first stress period is 400 days long and is divided into 10 time steps of equal length. The second stress period is 200 days long and is divided into four time steps of equal length. The third stress period is 400 days long and is divided into six time steps with each successive time step 1.1 times longer than the previous time step. This scheme results in initial and final time-step lengths of 51.8 days and 83.5 days, respectively.

Flow is specified in the FHB1 Package at the cell in column 1 of row 2, and head is specified at all three cells in column 10. Flow and head are specified at 0, 307, 791, and 1,000 days since start of the simulation (figs. 6, 7). Of these times, the first two are in the first stress period and the second two are in the third stress period. The middle two times do not coincide with starting or ending times of stress periods. Note that all

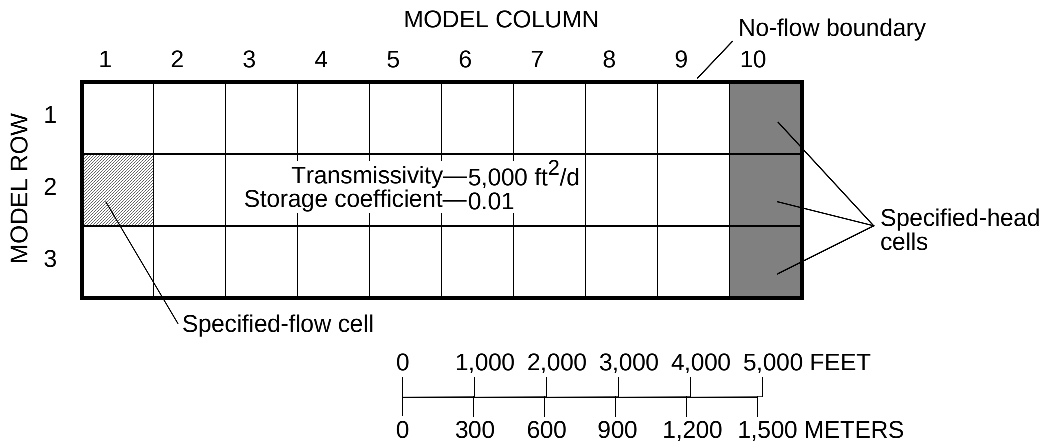


Figure 5. Model grid used in example problem.

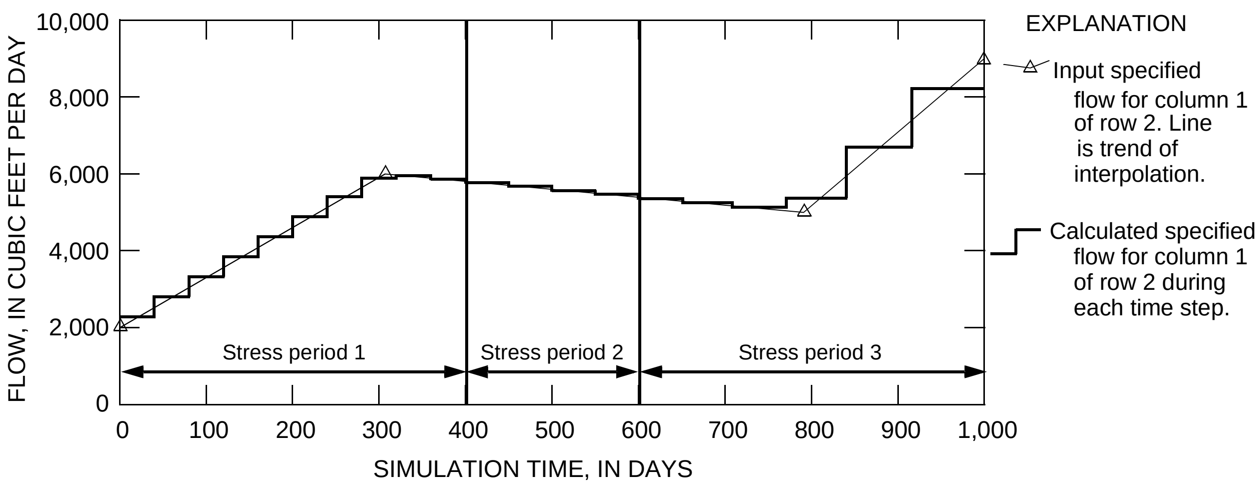


Figure 6. Input and calculated specified flow for cell in column 1 of row 2.

specified-flow and specified-head cells must have values defined at these four times. The specified flow values defined for the four times are 2,000, 6,000, 5,000, and 9,000 ft^3/d, respectively.

The total volume of inflow for the 1,000-day period, V_t, can be calculated as the area under the flow curve from the start to the end of the simulation (fig. 6). The resulting flow is

$$V_t = (307\text{-}0)\ \mathrm{d} \times \frac{(6{,}000+2{,}000)\ \mathrm{ft^3/d}}{2} + (791\text{-}307)\ \mathrm{d} \times \frac{(6{,}000+5{,}000)\ \mathrm{ft^3/d}}{2} + (1{,}000\text{-}791)\ \mathrm{d} \times \frac{(9{,}000+5{,}000)\ \mathrm{ft^3/d}}{2} = 5{,}353{,}000\ \mathrm{ft^3}.$$

When using the example, problem the FHB1 Package computed the same volume, 5,353,000 ft^3, by summing flow volumes for each of the 20 time steps (see appendix).

Specified head for rows 1–3, column 10, is calculated by FHB1 each time step using values of 0, 1, 5, and 2 ft, respectively, at simulation times of 0, 307, 791, and 1,000 d (fig. 7). The value for each time step is interpolated at the time corresponding to the end of the step. Using this procedure, local minimums or maximums may not be simulated unless the times of minimum or maximum head are the same as ends of

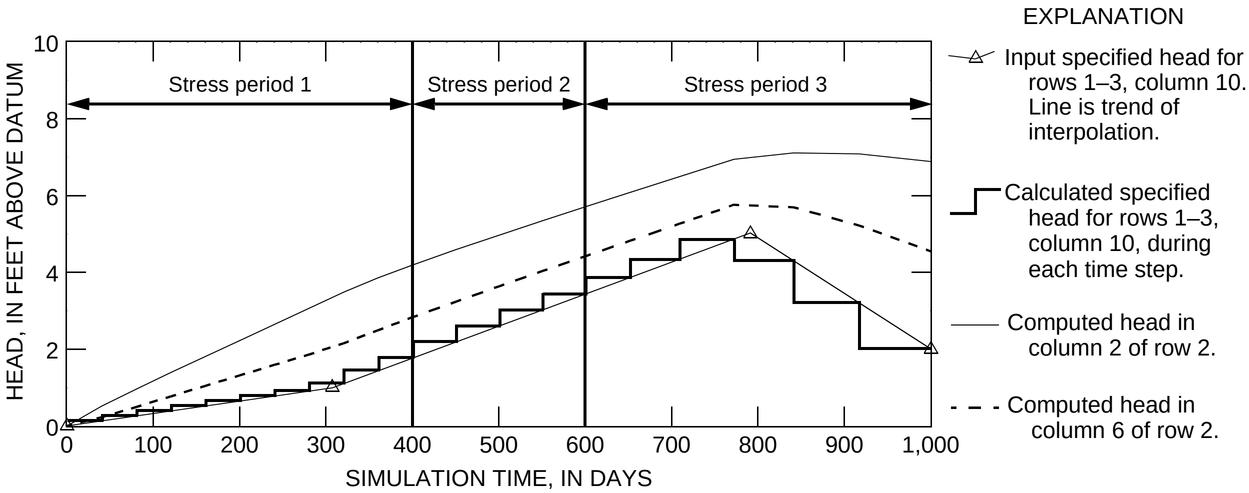


Figure 7. Input and calculated specified head in rows 1–3, column 10, and computed head in row 2, columns 2 and 6.

time steps. For example, the maximum specified head of 5 ft occurs at 791 d. This simulation time falls within a time step that starts at 771.6 d and ends at 840.6 d. A value of 4.84 ft is calculated as the specified head for this time step using linear interpolation at the simulation time 840.6 d. Smaller time steps would allow closer approximation of this maximum value.

IMPLEMENTATION OF FLOW AND HEAD BOUNDARIES IN THE GROUND-WATER MODEL

FHB1 is designed for incorporation into the USGS three-dimensional finite-difference modular ground-water flow model, MODFLOW-96 (Harbaugh and McDonald, 1996). The package is not compatible with earlier versions of MODFLOW, such as the program documented by McDonald and Harbaugh (1988).

FHB1 consists of five FORTRAN subroutines (modules)—FHB1AL, FHB1RP, FHB1AD, FHB1FM, and FHB1BD. The MAIN program of the ground-water flow model must be modified to call these modules. Call statements to the modules must be placed in sections of the MAIN program in which the particular procedure is being carried out for other packages. For example, the FHB1AL module must be called within the section of the MAIN program in which other allocation modules (for example BAS1AL) are called. In all sections of the MAIN program, the call to the Basic (BAS) Package module (subroutine) must come before any other module call statements. The authors have selected IUNIT (21) as the package file unit (McDonald and Harbaugh, 1988, p. 4–9 through 4–12). The package file unit is the FORTRAN unit number from which input data are read. The call statements to add to the MAIN program are as follows:

Add a new call statement for the FHB1AL module after comment C4 and within the group of statements that calls BCF5AL, WEL5AL, DRN5AL, and other space-allocation modules:

```
       IF(IUNIT(21).GT.0) CALL FHB1AL(ISUM,LENX,LCFLLC,LCBDTM,LCFLRT,
      1          LCBDFV,LCBDHV,LCHDLC,LCSBHD,NBDTIM,NFLW,NHED,IUNIT(21),
      2          IOUT,IFHBCB,NFHBX1,NFHBX2,IFHBD3,IFHBD4,IFHBD5,
      3          IFHBSS,ISS)
```

Add a new call statement for the FHB1RP module after comment C6 and within the group of statements that calls the BAS5RP, BCF5RP, SIP5RP, and SOR5RP:

```
       IF(IUNIT(21).GT.0) CALL FHB1RP(X(LCIBOU),NROW,NCOL,NLAY,
      &          X(LCFLLC),X(LCBDTM),NBDTIM,X(LCFLRT),NFLW,NHED,
      &          X(LCHDLC),X(LCSBHD),IUNIT(21),IOUT,
      &          NFHBX1,NFHBX2,IFHBD3,IFHBD5)
```

Add a new call statement for the FHB1AD module after the statement that calls the BAS5AD module:

```
       IF(IUNIT(21).GT.0) CALL FHB1AD(X(LCHNEW),X(LCHOLD),NCOL,NROW,NLAY,
      &          ISS,TOTIM,DELT,X(LCBDTM),NBDTIM,X(LCFLRT),
      &          X(LCBDFV),X(LCBDHV),NFLW,X(LCSBHD),X(LCHDLC),NHED,
      &          NFHBX1,NFHBX2,IFHBD3,IFHBD4,IFHBD5,IFHBSS)
```

Add a new call statement for the FHB1FM module after comment C7C2A and within the group of statements that call BCF5FM, WEL5FM, DRN5FM, and other formulation modules:

```
       IF(IUNIT(21).GT.0) CALL FHB1FM(X(LCRHS),X(LCIBOU),X(LCFLLC),
      1 X(LCBDFV),NFLW,NCOL,NROW,NLAY,IFHBD4)
```

Add a new call statement for the FHB1BD module after comment C7C4 and within the group of statements that call BCF5BD, WEL5BD, DRN5BD, and other budget modules:

```
       IF(IUNIT(21).GT.0) CALL FHB1BD(X(LCFLLC),X(LCBDFV),NFLW,
      1     VBNM,VBVL,MSUM,X(LCIBOU),DELT,NCOL,NROW,NLAY,KKSTP,KKPER,
      2     IFHBCB,ICBCFL,X(LCBUFF),IOUT,IFHBD4)
```

If desired, another IUNIT element can be used rather than 21. To do this, change all above references to IUNIT(21) to the new value.

INPUT INSTRUCTIONS FOR FLOW AND HEAD BOUNDARY PACKAGE

Input for FHB1 is read from the IUNIT(21), specified in the Basic Package input (McDonald and Harbaugh, 1988, chap. 4, p. 9–11). All input is free format, which requires each of the numbered data groups to start on a new input record. More than one record can be used for any data group and numbers within data groups must be separated by at least one space or a comma. Integer data types cannot include a decimal point. Blank spaces are not treated as zeros. For an example annotated input data set, refer to figure 8.

FOR EACH SIMULATION

1.	Data:	NBDTIM	NFLW	NHED	IFHBSS	IFHBCB	NFHBX1	NFHBX2
	Type:	Integer	Integer	Integer	Integer	Integer	Integer	Integer

Omit data item 2 if NFHBX1=0. Input item 2 consists of one record for each of NFHBX1 auxiliary variables.

2.	Data:	VarName	Weight
	Type:	Character	Real

Omit data item 3 if NFHBX2=0. Input item 3 consists of one record for each of NFHBX2 auxiliary variables.

3.	Data:	VarName	Weight
	Type:	Character	Real

Data items 4a and 4b are required for all simulations. Include NBDTIM times in data item 4b.

4a.	Data:	IFHBUN	CNSTM	IFHBPT
	Type:	Integer	Real	Integer
4b.	Data:	BDTIM(NBDTIM)		
	Type:	Real		

Omit data items 5a and 5b if NFLW=0. Input item 5b consists of one set of numbers for each of NFLW cells. Each set of numbers includes layer, row, and column indices, an integer auxiliary variable, and NBDTIM values of specified flow.

5a.	Data:	IFHBUN	CNSTM	IFHBPT		
	Type:	Integer	Real	Integer		
5b.	Data:	Layer	Row	Column	IAUX	FLWRAT(NBDTIM)
	Type:	Integer	Integer	Integer	Integer	Real

Omit data items 6a and 6b if NFHBX1=0 or if NFLW=0. Include one set of data items 6a and 6b for each of NFHBX1 auxiliary variables. Input item 6b consists of one set of numbers for each of NFLW cells. Each set includes NBDTIM values of the variable.

6a.	Data:	IFHBUN	CNSTM	IFHBPT
	Type:	Integer	Real	Integer
6b.	Data:	AuxVar(NBDTIM)		
	Type:	Real		

Table 1. Primary modules of MODFLOW organized by procedure and package

[Modified from McDonald and Harbaugh (1988, fig. 15)]

Omit data items 7a and 7b if NHED=0. Input item 7b consists of one set of numbers for each of NFLW cells. Each set of numbers includes layer, row, and column indices, an integer auxiliary variable, and NBDTIM values of specified head.

7a.	Data:	IFHBUN	CNSTM	IFHBPT		
	Type:	Integer	Real	Integer		
7b.	Data:	Layer	Row	Column	IAUX	SBHED(NBDTIM)
	Type:	Integer	Integer	Integer	Integer	Real

Omit data items 8a and 8b if NFHBX2=0 or if NHED=0. Include one set of data items 8a and 8b for each of NFHBX2 auxiliary variables. Input item 8b consists of one set of numbers for each of NHED cells. Each set includes NBDTIM values of the variable.

8a.	Data:	IFHBUN	CNSTM	IFHBPT
	Type:	Integer	Real	Integer
8b.	Data:	AuxVar(NBDTIM)		
	Type:	Real		

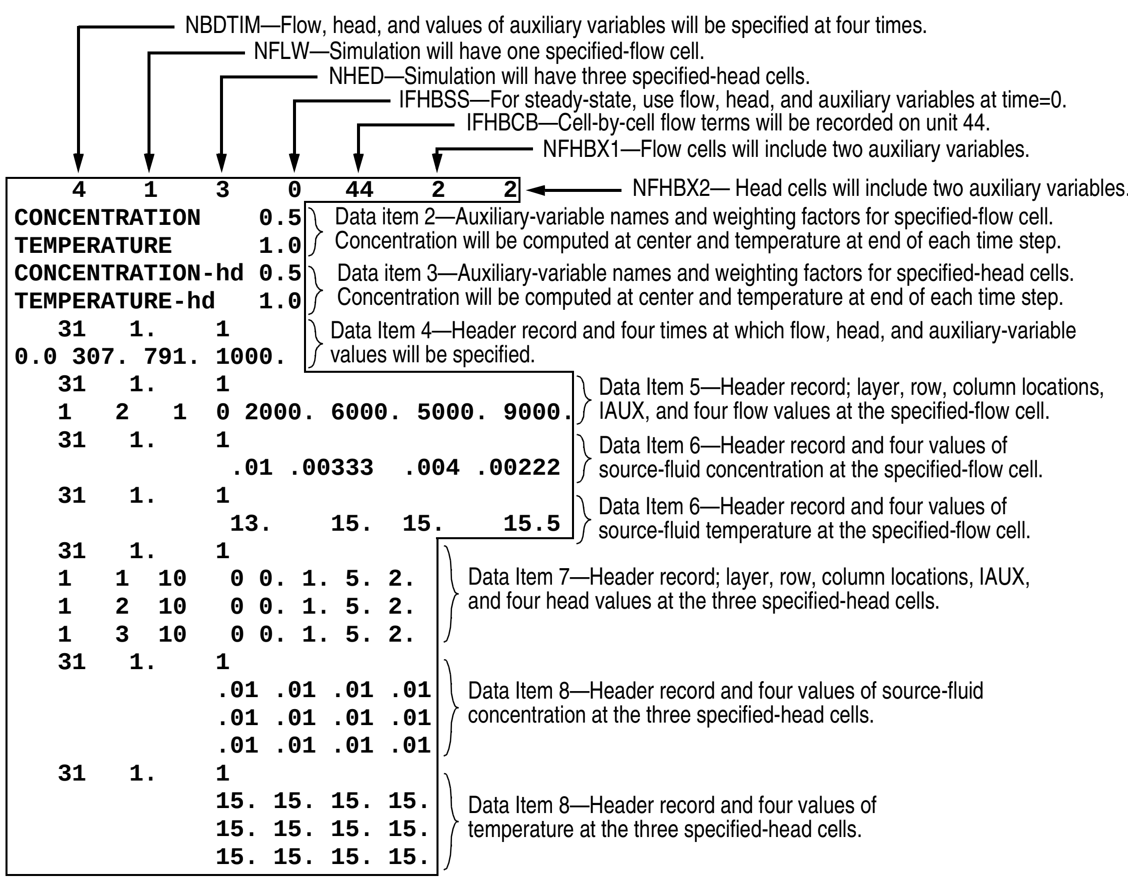


Figure 8. Annotated example input data set for FHB1. Input data are enclosed in border.

Explanation of Fields Used in Input Instructions

NBDTIM is the number of times at which flow and head will be specified for all selected cells.

If NBDTIM = 1, specified flow and head values will remain constant for the entire simulation.

If NBDTIM > 1, specified flow and head values will be computed for each time step using linear interpolation.

NFLW is the number of cells at which flows will be specified.

NHED is the number of cells at which head will be specified.

IFHBSS is the FHB steady-state option flag. If the simulation is transient, the flag is read but not used. For steady-state simulations, the flag controls how specified-flow, specified-head, and auxiliary-variable values will be computed for each steady-state solution.

If IFHBSS = 0, values of flow, head, and auxiliary variables will be taken at the starting time of the simulation. This results in use of the first value in arrays FLWRAT, SBHED, and AuxVar for each respective boundary cell.

If IFHBCB ≠ 0, values of flow, head, and auxiliary variables will be interpolated in the same way that values are computed for transient simulations.

IFHBCB is a flag and unit number.

If IFHBCB > 0, it is the unit number on which cell-by-cell flow terms will be recorded whenever ICBCFL is set (see McDonald and Harbaugh, 1988, chap. 4, p. 14–15).

If IFHBCB ≤ 0, cell-by-cell flow terms will not be recorded.

NFHBX1 is the number of auxiliary variables whose values will be computed for each time step for each specified-flow cell.

NFHBX2 is the number of auxiliary variables whose values will be computed for each time step for each specified-head cell.

VarName is the name of an auxiliary variable. Name can include up to 16 characters with no embedded blank characters.

Weight is the time-weighting factor for an auxiliary variable specifying the fraction of each time step at which the value of the variable will be interpolated. Value must be in the range from 0.0 to 1.0.

IFHBUN is the unit number on which data lists will be read. The same or different unit numbers can be used to read lists in data items 4b, 5b, 6b, 7b, and 8b.

CNSTM is a constant multiplier for data list BDTIM (data item 4b), FLWRAT (part of data item 5b), SBHED (part of data item 7b), and auxiliary variables in data items 6b and 8b.

<u>IFHBPT</u> is a flag for printing values of data lists in items 4b, 5b, 6b, 7b, and 8b.

If IFHBPT > 0 data list read at the beginning of the simulation will be printed.

If IFHBCB ≤ 0 data list read at the beginning of the simulation will not be printed.

<u>BDTIM</u> is simulation time at which values of specified flow and (or) values of specified head will be read. NBDTIM values are required.

<u>Layer</u> is the layer index of specified-flow cell (data item 5b) or specified-head cell (data item 7b).

<u>Row</u> is the row index of specified-flow cell (data item 5b) or specified-head cell (data item 7b).

<u>Column</u> is the column index of specified-flow cell (data item 5b) or specified-head cell (data item 7b).

IAUX Is an integer auxiliary variable associated with each specified-flow and specified-head boundary cell. A value is read but not used in simulations of ground-water flow with MODFLOW-96. IAUX can be used by programs such as MODPATH (Pollock, 1994) to store information such as the cell face associated with the specified-flow or specified-head boundary.

<u>FLWRAT</u> is volumetric rate of flow at specified-flow cells. A list of NBDTIM values must be specified for each of NFLW specified-flow cells.

<u>AuxVar</u> is value of real auxiliary variable at specified-flow and specified-head cells. A list of NBDTIM values must be specified for each of NFLW specified-flow cells and for each of NHED specified-head cells.

<u>SBHED</u> is an array containing NBDTIM values of the head for each specified-head cell.

PROGRAM OUTPUT

Output from FHB1 consists of printed output and information recorded to a disk or another storage device. Printed output can include any arrays read by FHB1. Furthermore, computed rates for each specified-flow cell can be printed if the rates are not being recorded to a disk or another storage device.

The printed output also includes rates and volumes of flow to or from specified-flow cells in the overall volumetric budget. The budget is printed by MODFLOW and includes flow rates and volumes for all flow-component and stress packages used in a simulation. The left side of the budget lists cumulative volumes of inflow and outflow for the entire simulation. The right side of the budget lists rates of inflow and outflow for the most recent time step. Components in the volumetric budget generated by FHB1 are denoted with the label “SPECIFIED FLOWS.” If a value greater than zero is specified for IFHBCB, FHB1 will record cell-by-cell flow terms for time steps in which a nonzero value of ICBCFL is specified (McDonald and Harbaugh, 1988, chap. 4, p. 14–15). The cell-by-cell flow terms are recorded in an unformatted file with one element for each cell in the model grid or in an unformatted file with a list containing layer, row, and column indices and computed flow for each specified-flow cell. A value of zero is recorded for cells that are not specified-flow cells. The sign convention is that positive quantities denote flow into the ground-water system and negative quantities denote flow out of the ground-water system. The header record for the unformatted arrays includes the label “SPECIFIED FLOWS.” MODFLOW computes, prints, and records flow components to or from “constant-head” cells. Specified-head cells in FHB1 are treated as constant-head cells in MODFLOW budget calculations.

MODULE DOCUMENTATION

FHB1 contains five modules (subroutines), each of which is called by the main program of MODFLOW. Required changes to the main program are given in the section of this report titled “Implementation of Flow and Head Boundaries in the Ground-Water Model” (p. 9). The modules in FHB1 are

FHB1AL Reads number of times at which flow and head will be specified, number of specified-flow and specified-head cells, flag for steady-state option, flag for cell-by-cell flow terms, numbers of auxiliary variables, and names and weights of auxiliary variables; allocates space for data arrays.

FHB1RP Reads data arrays containing times at which flow and head will be specified, locations and rates for specified-flow cells, locations and heads for specified-head cells, and values of auxiliary variables; if requested, prints array values.

FHB1AD Computes specified-flow, specified-head, and auxiliary-variable values for the current time step.

FHB1FM Subtracts specified-flow values from the right-hand-side array (RHS).

FHB1BD Incorporates specified-flow rates into the overall mass balance and writes cell-by-cell flow rates if option is selected.

The last two characters in the names of each of the modules are an abbreviation for the procedure that the module carries out. Most flow-component and stress packages in MODFLOW use four procedures—Allocate (AL), Read and Prepare (RP), Formulate (FM), and Budget (BD) (table 1). In addition to these basic procedures, FHB1 uses the Advance procedure (AD) to calculate the specified flows and heads at each time step.

Procedure	Packages										
	BAS1	BCF1	WEL1	RCH1	RIV1	DRN1	EVT1	GHB1	SIP1	SOR1	FHB1
Define (DF)	BAS1DF										
Allocate (AL)	BAS1AL	BCF1AL	WEL1AL	RCH1AL	RIV1AL	DRN1AL	EVT1AL	GHB1AL	SIP1AL	SOR1AL	FHB1AL
Read and prepare (RP)	BAS1RP	BCF1RP							SIP1RP	SOR1RP	FHB1RP
Stress (ST)	BAS1ST										
Read and prepare (RP)			WEL1RP	RCH1RP	RIV1RP	DRN1RP	EVT1RP	GHB1RP			
Advance (AD)	BAS1AD										FHB1AD
Formulate (FM)	BAS1FM	BCF1FM	WEL1FM	RCH1FM	RIV1FM	DRN1FM	EVT1FM	GHB1FM			FHB1FM
Approximate (AP)									SIP1AP	SOR1AP	
Output Control (OC)	BAS1OC										
Budget (BD)		BCF1BD	WEL1BD	RCH1BD	RIV1BD	DRN1BD	EVT1BD	GHB1BD			FHB1BD
Output (OT)	BAS1OT										

FHB1AL

Narrative for Module FHB1AL

This module reads number of times at which flow and head will be specified, number of specified-flow and specified-head cells, flag for steady-state option, flag for cell-by-cell flow terms, numbers of auxiliary variables, and names and weights of auxiliary variables; and allocates space for data arrays in the X array (McDonald and Harbaugh, 1988, chap. 3, p. 22–23). Operations are carried out in the following order:

Print a message identifying the package.

1. Read number of times at which flow and head will be specified, NBDTIM; number of specified-flow cells, NFLW; number of specified-head cells, NHED; steady-state option flag, IFHBSS; unit number for cell-by-cell flow terms, IFHBCB; number of auxiliary variables for specified-flow cells, IFHBX1; and number of auxiliary variables for specified-head cells, IFHBX2.

2. Print number of times at which flow and head will be specified. Stop if no times are specified.

3. Print number of specified-flow cells and number of specified-head cells.

4. If cell-by-cell flow terms are to be saved, print unit number.

5. Read names and time-weighting factors for auxiliary variables.

6. Allocate storage for the following arrays:

   BDTIM individual times at which values of specified flow and specified head read by package will be applied,

   IFLLOC layer, row, and column location, and integer auxiliary variable for each of NFLW specified-flow cells,

   FLWRAT specified-flow rates for each of NFLW specified-flow cells for each of NBDTIM simulation times, BDFV computed values of specified-flow cell variables for the current time step, including flow and values of auxiliary variables.

IHDLOC layer, row, and column location, and integer auxiliary variable for each of NHED specified-head cells,

SBHED specified-head values for each of NHED specified-head cells for each of NBDTIM simulation times,

BDHV computed values of specified-head cell auxiliary variables for the current time step.

7. Calculate and print the amount of space used by FHB1.

8. If space in the X array is not sufficient, print a warning message.

9. RETURN.

Flowchart for Module FHB1AL

NBDTIM is the number of times used to define functions of flow and head.

NFLW is the number of specified-flow cells.

NHED is the number of specified-head cells.

IFHBCB is a flag and a unit number:

- > 0, unit number on which cell-by-cell flow terms will be recorded whenever ICBCFL is set.
- ≤ 0, cell-by-cell flow terms will not be printed.

BDTIM is array of times at which values of specified flow and specified head will be read.

IFLLOC is array with layer, row, and column location, and integer auxiliary variable for each of NFLW specified-flow cells.

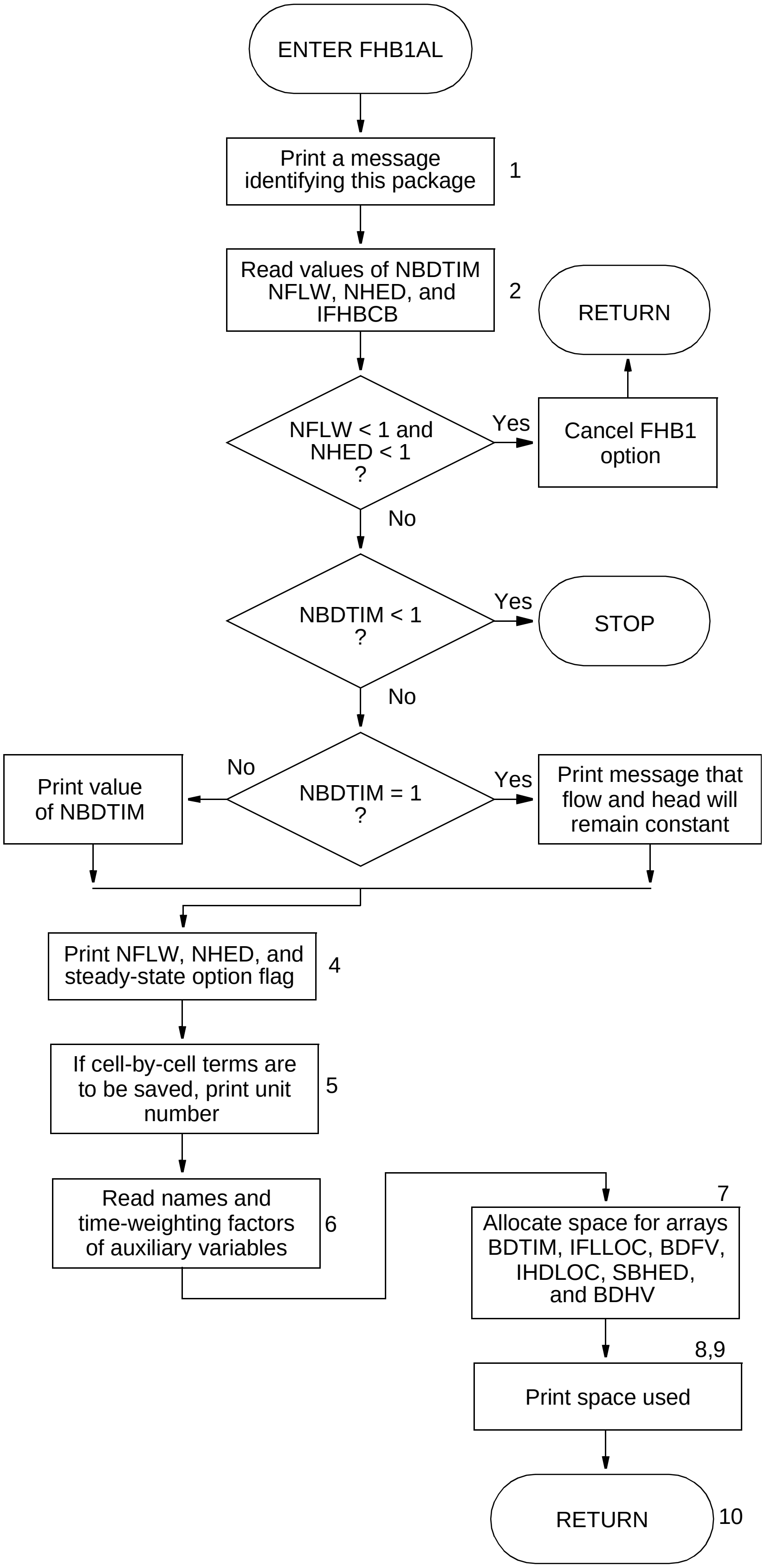
FLWRAT is array with specified-flow rates for each of NFLW specified-flow cells for each of NBDTIM simulation times.

BDFV is array with computed values of specified-flow cell variables for the current time step, including flow and values of auxiliary variables.

IHDLOC is array with layer, row, and column location, and integer auxiliary variable for each of NHED specified-head cells.

SBHED is array with specified-head values for each of NHED specified-head cells for each of NBDTIM simulation times.

BDHV is array with computed values of specified-head cell auxiliary variables for the current time step.



Program Listing for Module FHB1AL

```
      SUBROUTINE FHB1AL(ISUM,LENX,LCFLLC,LCBDTM,LCFLRT,LCBDFV,LCBDHV,
     &                  LCHDLC,LCSBHD,NBDTIM,NFLW,NHED,IN,IOUT,IFHBCB,
     &                  NFHBX1,NFHBX2,IFHBD3,IFHBD4,IFHBD5,IFHBSS,ISS)
C
C-----VERSION 0000 10JAN1997 FHB1AL
C     ******************************************************************
C     ALLOCATE ARRAY STORAGE FOR FLOW AND HEAD BOUNDARY PACKAGE
C     ******************************************************************
C
C        SPECIFICATIONS:
C     ------------------------------------------------------------------
      COMMON /FHBCOM/ FHBXNM(10),FHBXWT(10)
      CHARACTER*16 FHBXNM
      CHARACTER*80 LINE
C     ------------------------------------------------------------------
C
C1------IDENTIFY PACKAGE
      WRITE(IOUT,1)IN
    1 FORMAT(1H0,'FHB1 -- SPECIFIED FLOW PACKAGE, VERSION 1,12/3/96',
     &' INPUT READ FROM',I3)
C
C2------READ NUMBER OF TIMES, NUMBER OF SPECIFIED-FLOW CELLS AND
C2------UNIT OR FLAG FOR CELL-BY-CELL FLOW TERMS, NUMBER OF
C2------AUXILIARY VARIABLES.
      READ(IN,*) NBDTIM,NFLW,NHED,IFHBSS,IFHBCB,NFHBX1,NFHBX2
C
C3------PRINT NBDTIM, STOP IF NO TIMES ARE TO BE SPECIFIED
      IF(NFLW.LT.1.AND.NHED.LT.1) THEN
         WRITE(IOUT,4)
 4       FORMAT(1X,'SPECIFIED FLOW AND HEAD BOUNDARY OPTION ',
     &   'CANCELLED.',/,1X,'NO BOUNDARY CELLS WERE SPECIFIED.')
         IN=0
         RETURN
      ENDIF
      IF(NBDTIM.LT.1) THEN
         WRITE(IOUT,6)
 6       FORMAT(1X, 'SIMULATION ABORTING.  NOT ENOUGH TIMES ',
     &   'SPECIFIED FOR FHB1 PACKAGE.')
         STOP
      ELSE IF(NBDTIM.EQ.1) THEN
         WRITE(IOUT,8)
 8       FORMAT(1X,' SPECIFIED FLOW AND HEAD VALUES WILL REMAIN ',
     &   'CONSTANT FOR ENTIRE SIMULATION.')
      ELSE
         WRITE(IOUT,10) NBDTIM
 10      FORMAT(1H ,'TOTAL OF',I5,' TIMES WILL BE USED TO DEFINE ',
     &   'VARIATIONS IN FLOW AND HEAD.')
      ENDIF
C
C4------PRINT NFLW AND NHED AND STEADY-STATE OPTION
      WRITE(IOUT,12) NFLW
 12   FORMAT(1H ,'FLOW WILL BE SPECIFIED AT A TOTAL OF',I5,' CELLS.')
      WRITE(IOUT,14) NHED
```

```
 14   FORMAT(1H ,'HEAD WILL BE SPECIFIED AT A TOTAL OF',I5,' CELLS.')
      IF(ISS.EQ.0) THEN
         WRITE(IOUT,15)
 15      FORMAT(1H ,'FHB STEADY-STATE OPTION FLAG WILL BE IGNORED,'/,
     &          1H ,'SIMULATION IS TRANSIENT.')
      ELSE
      IF(IFHBSS.EQ.0) THEN
         WRITE(IOUT,16)
 16      FORMAT(1H ,'FLOW, HEAD, AND AUX VARIABLES AT TIME=0 WILL BE ',
     &        /,1H ,'USED IN STEADY-STATE SIMULATIONS.')
      ELSE
         WRITE(IOUT,18)
 18      FORMAT(1H ,'FLOW, HEAD, AND AUX VARIABLES WILL BE ',
     &      'INTERPOLATED',/,1H ,'IN STEADY-STATE SIMULATIONS.')
      ENDIF
      ENDIF
C
C5------IF CELL-BY-CELL FLOW TERMS ARE TO BE SAVED THEN PRINT UNIT #
      IF(IFHBCB.GT.0) WRITE(IOUT,20) IFHBCB
 20   FORMAT(1X,'CELL-BY-CELL FLOWS WILL BE RECORDED ON UNIT',I3)
      IF(IFHBCB.LT.0) WRITE(IOUT,24)
 24   FORMAT(1X,'CELL-BY-CELL FLOWS WILL BE PRINTED WHEN ICBCFL NOT 0')
C
C6------READ AUXILIARY VARIABLES
      IF(NFHBX1.GT.5.OR.NFHBX2.GT.5) THEN
         WRITE(IOUT,*) ' ABORTING. A MAXIMUM OF 5 AUXILIARY VARIABLES',
     &   ' CAN BE DEFINED BY FHB.'
         STOP
      ENDIF
      WRITE(IOUT,26) NFHBX1
 26   FORMAT(1X,I2,' AUXILIARY VARIABLES FOR SPECIFIED-FLOW CELLS WILL',
     & /,'  BE DEFINED BY FHB FOR USE BY OTHER PACKAGES.')
      IF(NFHBX1.LT.1) GO TO 38
      WRITE(IOUT,28)
 28   FORMAT('       NAME      WEIGHTING FACTOR',/,1X,32('-'))
      DO 30 NX=1,NFHBX1
      READ(IN,'(A)') LINE
      LLOC=1
      CALL URWORD(LINE,LLOC,ISTART,ISTOP,1,N,R,IOUT,IN)
      FHBXNM(NX)=LINE(ISTART:ISTOP)
      CALL URWORD(LINE,LLOC,ISTART,ISTOP,3,N,FHBXWT(NX),IOUT,IN)
      WRITE(IOUT,29) FHBXNM(NX),FHBXWT(NX)
 29   FORMAT(1X,A16,F11.2)
      IF(FHBXWT(NX).LT.0.0.OR.FHBXWT(NX).GT.1.0) THEN
      WRITE(IOUT,*) ' Aborting. Weights for Auxiliary variables cannot'
      WRITE(IOUT,*) ' be less than 0.0 or greater than 1.0.'
      STOP
      ENDIF
 30   CONTINUE
 38   WRITE(IOUT,126) NFHBX2
 126  FORMAT(1X,I2,' AUXILIARY VARIABLES FOR SPECIFIED-HEAD CELLS WILL',
     & /,'  BE DEFINED BY FHB FOR USE BY OTHER PACKAGES.')
      IF(NFHBX2.LT.1) GO TO 200
      WRITE(IOUT,28)
      DO 130 NX=1,NFHBX2
```

```
      READ(IN,'(A)') LINE
      LLOC=1
      CALL URWORD(LINE,LLOC,ISTART,ISTOP,1,N,R,IOUT,IN)
      FHBXNM(5+NX)=LINE(ISTART:ISTOP)
      CALL URWORD(LINE,LLOC,ISTART,ISTOP,3,N,FHBXWT(5+NX),IOUT,IN)
      WRITE(IOUT,129) FHBXNM(5+NX),FHBXWT(5+NX)
 129  FORMAT(1X,A16,F11.2)
      IF(FHBXWT(5+NX).LT.0.0.OR.FHBXWT(5+NX).GT.1.0) THEN
      WRITE(IOUT,*) ' Aborting. Weights for Auxiliary variables cannot'
      WRITE(IOUT,*) ' be less than 0.0 or greater than 1.0.'
      STOP
      ENDIF
 130  CONTINUE
C7------ALLOCATE SPACE FOR ARRAYS BDTIM, IFLLOC, FLWRAT, BDFV,
C7------IHDLOC, SBHED, AND BDHV
 200  IFHBD3=NBDTIM*(1+NFHBX1)
      IFHBD4=2+NFHBX1
      IFHBD5=NBDTIM*(1+NFHBX2)
      LCBDTM=ISUM
      ISUM=ISUM+NBDTIM
      LCFLLC=ISUM
      ISUM=ISUM+NFLW*4
      LCFLRT=ISUM
      ISUM=ISUM+NFLW*IFHBD3
      LCBDFV=ISUM
      ISUM=ISUM+NFLW*IFHBD4
      LCHDLC=ISUM
      ISUM=ISUM+NHED*4
      LCSBHD=ISUM
      ISUM=ISUM+NHED*IFHBD5
      LCBDHV=ISUM
      ISUM=ISUM+NHED*NFHBX2
      ISP=ISUM-LCBDTM
C
C8------PRINT NUMBER OF SPACES IN X ARRAY USED BY FLOW PACKAGE.
      WRITE(IOUT,210) ISP
 210  FORMAT(1X,I8,' ELEMENTS IN X ARRAY ARE USED BY FHB1')
      ISUM1=ISUM-1
      WRITE(IOUT,220) ISUM1,LENX
 220  FORMAT(1X,I8,' ELEMENTS OF X ARRAY USED OUT OF',I8)
C
C9------IF THERE ISN'T ENOUGH SPACE IN THE X ARRAY THEN PRINT
C9------A WARNING MESSAGE.
      IF(ISUM1.GT.LENX) WRITE(IOUT,230)
 230  FORMAT(1X,'   ***X ARRAY MUST BE DIMENSIONED LARGER***')
C10-----RETURN
      RETURN
      END
```

List of Variables for Module FHB1AL

Variable	Range	Definition
FHBXNM	Package	CHARACTER*16(10), Names of auxiliary variables.
FHBXWT	Package	DIMENSION(10), Time-weighting factor for auxiliary variables.
IFHBCB	Package	Flag and a unit number: > 0 Unit number on which cell-by-cell flow terms will be recorded whenever ICBCFL is set. = 0 Cell-by-cell flow terms will not be recorded or printed. < 0 Cell-by-cell flow terms will be printed whenever ICBCFL is set.
IFHBD3	Package	Dimension for storing specified-flow values and auxiliary-variable values associated with specified-flow cells.
IFHBD4	Package	Dimension for interpolated specified-flow values and interpolated auxiliary-variable values associated with specified-flow cells.
IFHBD5	Package	Dimension for storing auxiliary-variable values associated with specified-head cells.
IFHBSS	Package	Option flag for steady-state simulations: = 0 Take flow, head, and auxiliary-variable values at starting time. ≠ 0 Interpolate flow, head, and auxiliary-variable values.
IN	Package	Primary unit number from which input from this package will be read.
IOUT	Global	Primary unit number for all printed output.
ISP	Module	Number of elements in the X array allocated by this package.
ISS	Global	Flag: = 0, simulation is transient. ≠ 0, simulation is steady state.
ISTART	Module	Index pointing to the start of a word found by module URWORD.
ISTOP	Module	Index pointing to the end of a word found by module URWORD.
ISUM	Global	Element number of the lowest element in the X array that has not yet been allocated. When space is allocated in the X array, the size of the allocation is added to ISUM.
ISUM1	Module	ISUM-1.
LCBDFV	Package	Location in the X array of the first element of array BDFV.
LCBDHV	Package	Location in the X array of the first element of array BDHV.
LCBDTM	Package	Location in the X array of the first element of array BDTIM.
LCFLLC	Package	Location in the X array of the first element of array IFLLOC.
LCFLRT	Package	Location in the X array of the first element of array FLWRAT.
LCHDLC	Package	Location in the X array of the first element of array IHDLOC.
LCSBHD	Package	Location in the X array of the first element of array SBHED.
LENX	Global	Number of elements in the X array. Value should always equal the dimension of the X array specified in the MAIN program.
LINE	Module	CHARACTER*80, contents of a record THAT HAS BEEN READ FROM THE PAGKAGE INPUT FILE. LINE is parsed by URWORD.
LLOC	Module	Index that tells URWORD where to start looking for a word within LINE.
N	Module	Argument place holder for calls to URWORD in which the argument is unused.
NBDTIM	Package	Number of times used to define functions of flow and head.
NFHBX1	Package	Number of auxiliary variables associated with specified-flow cells.
NFHBX2	Package	Number of auxiliary variables associated with specified-head cells.
NFLW	Package	Number of specified-flow cells.
NHED	Package	Number of specified-head cells.
NX	Module	Index for auxiliary variables.
R	Module	Argument place holder for calls to URWORD in which the argument is unused.

FHB1RP

Narrative for Module FHB1RP

This module reads arrays with times at which flow and head will be specified, specified-flow rates, specified-head values, and auxiliary-variable values. All information is read at the start of the simulation. Operations are carried out in the following order:

1. Read times at which flow and head values will be specified.

2. If desired, print table of times.

3. Check time values to make sure that first time is zero and that no time is less than the previous time. Stop if these conditions are not met. To allow for step increases in flow or head, two adjacent time values can be the same.

4. Read cell indices, integer auxiliary-variable values, and flow rates for all specified-flow cells. If desired, print table of specified-flow cell indices (layer, row, and column) and flow rates for each time.

5. Read values of auxiliary variables for specified-flow cells. If desired, print table of values of auxiliary variables for each time.

6. Read cell indices, integer auxiliary-variable values, and head values for all specified-head cells.

7. At specified-head cell locations, set IBOUND to a negative number. Ignore specified-head conditions at cells where IBOUND is zero.

8. If desired, print table of specified-head cell indices (layer, row, and column), integer auxiliary-variable values, and head values for each time.

9. Read values of auxiliary variables for specified-head cells. If desired, print table of values of auxiliary variables for each time.

10. RETURN.

Flowchart for Module FHB1RP

BDTIM is an array containing individual times at which values of specified flow and specified head read by package will be applied.

IFLLOC is an array containing layer, row, column location, and integer auxiliary variable for each of NFLW specified-flow cells.

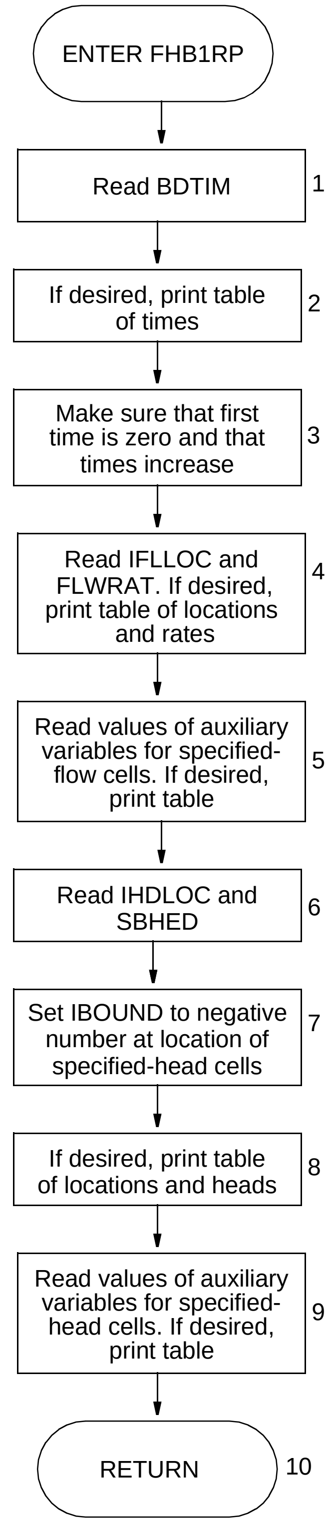
FLWRAT is an array containing specified-flow rates for each of NFLW specified-flow cells for each of NBDTIM simulation times.

IHDLOC is an array containing layer, row, column location, and integer auxiliary variable for each of NHED specified-head cells.

SBHED is an array containing specified-head values for each of NHED specified-head cells for each of NBDTIM simulation times.

IBOUND is an array containing the status of each cell:

< 0, cell is constant-head.
= 0, cell is no-flow.
> 0, cell is variable-head.



Program Listing for Module FHB1RP

```
      SUBROUTINE FHB1RP(IBOUND,NROW,NCOL,NLAY,IFLLOC,BDTIM,NBDTIM,
     &             FLWRAT,NFLW,NHED,IHDLOC,SBHED,IN,IOUT,
     &             NFHBX1,NFHBX2,IFHBD3,IFHBD5)
C
C
C-----VERSION 0000 10JAN1997 FHB1RP
C     ******************************************************************
C     READ TIMES, CELL LOCATIONS, RATES, AND HEADS FOR FLOW AND HEAD
C     BOUNDARY PACKAGE
C     ******************************************************************
C
C        SPECIFICATIONS:
C     ------------------------------------------------------------------
      COMMON /FHBCOM/ FHBXNM(10),FHBXWT(10)
      CHARACTER*16 FHBXNM
      CHARACTER*1 DSH1
      DIMENSION IBOUND(NCOL,NROW,NLAY),BDTIM(NBDTIM),IFLLOC(4,NFLW),
     &      FLWRAT(IFHBD3,NFLW),IHDLOC(4,NHED), SBHED(IFHBD5,NHED)
      DATA DSH1/'-'/
C     ------------------------------------------------------------------
C
C1------READ TIMES AT WHICH SPECIFIED FLOW AND HEAD VALUES WILL BE READ
      READ(IN,*) IFHBUN,CNSTM,IFHBPT
      WRITE(IOUT,10) IFHBUN,CNSTM
 10   FORMAT(1X,'TIMES FOR SPECIFIED-FLOW AND HEAD VALUES WILL BE READ',
     & ' ON UNIT',I4,' AND',/,
     &' MULTIPLIED BY',G12.4,'.')
      READ(IFHBUN,*) (BDTIM(L),L=1,NBDTIM)
      DO 12 L=1,NBDTIM
      BDTIM(L)=BDTIM(L)*CNSTM
 12   CONTINUE
C
C2------IF DESIRED, PRINT TABLE OF TIMES
      IF(IFHBPT.GT.0) THEN
         WRITE(IOUT,20) NBDTIM
 20      FORMAT(1X,I5,' TIMES FOR SPECIFYING FLOWS AND HEADS:')
         WRITE(IOUT,22) (L,L=1,NBDTIM)
 22      FORMAT(16X,I8,4I12)
         ND=MIN0(60,NBDTIM*12)
         WRITE(IOUT,24) (DSH1,M=1,ND)
 24      FORMAT(17X,60A1)
         WRITE(IOUT,26) (BDTIM(L),L=1,NBDTIM)
 26      FORMAT(17X,5G12.4)
      ENDIF
C
C3------MAKE SURE THAT FIRST TIME IS ZERO AND THAT TIMES INCREASE
      ICHK1=0
      ICHK2=0
      IF(BDTIM(1).NE.0.0) THEN
         WRITE(IOUT,30)
 30      FORMAT(1X,'STARTING TIME FOR SPECIFIED FLOWS AND HEADS MUST',
     &   ' BE ZERO. ABORTING.')
         ICHK1=1
```

```
      ENDIF
      DO 40 L=2,NBDTIM
      IF(BDTIM(L).LT.BDTIM(L-1)) THEN
         WRITE(IOUT,32)
 32      FORMAT(1X,'TIMES FOR SPECIFIED FLOWS MUST INCREASE.',
     &   '  ABORTING.')
         ICHK2=1
         GO TO 42
      ENDIF
 40   CONTINUE
 42   IF(ICHK1.EQ.1.OR.ICHK2.EQ.1) STOP
C
C4A-----READ CELL INDICIES AND SPECIFIED-FLOW RATES
      IF(NFLW.LT.1) GO TO 70
      READ(IN,*) IFHBUN,CNSTM,IFHBPT
      WRITE(IOUT,50) IFHBUN,CNSTM
 50   FORMAT(/,1X,'CELL INDICIES AND SPECIFIED-FLOW RATES ',
     & 'WILL BE READ ON UNIT',I4,'. RATES WILL',/,
     & 1X,'BE MULTIPLIED BY',G12.4,'.')
      IF(IFHBPT.GT.0) THEN
         WRITE(IOUT,52)
 52      FORMAT(1X,'LAYER  ROW  COL IAUX              FLOW RATES')
         ND=MIN0(79,19+NBDTIM*12)
         WRITE(IOUT,54) (DSH1,M=1,ND)
 54      FORMAT(1X,78A1)
      ENDIF
      DO 59 N=1,NFLW
      READ(IFHBUN,*) (IFLLOC(I,N),I=1,4),(FLWRAT(L,N),L=1,NBDTIM)
      DO 56 L=1,NBDTIM
      FLWRAT(L,N)=FLWRAT(L,N)*CNSTM
 56   CONTINUE
C
C4B-----IF DESIRED, PRINT TABLE OF SPECIFIED-FLOW CELL LOCATIONS
C4B-----AND RATES
      IF(IFHBPT.GT.0) THEN
         WRITE(IOUT,58) (IFLLOC(I,N),I=1,4),(FLWRAT(L,N),L=1,NBDTIM)
 58      FORMAT(1X,I4,3I5,5G12.4,/,(20X,5G12.4))
      ENDIF
 59   CONTINUE
C
C5A------READ VALUES OF AUXILIARY VARIABLES FOR SPECIFIED-FLOW CELLS
      IF(NFHBX1.LT.1) GO TO 70
      DO 69 NX=1,NFHBX1
      NS=NBDTIM*NX
      READ(IN,*) IFHBUN,CNSTM,IFHBPT
      WRITE(IOUT,61) FHBXNM(NX),IFHBUN,CNSTM
 61   FORMAT(/,1X,A16,
     & 'FOR SPECIFIED-FLOW CELLS WILL BE READ ON UNIT',I4,'.',/,
     &  ' VALUES WILL BE MULTIPLIED BY',G12.4,'.')
      IF(IFHBPT.GT.0) THEN
         WRITE(IOUT,62) FHBXNM(NX)
 62      FORMAT(1X,'LAYER  ROW  COL IAUX  ',A16)
         WRITE(IOUT,54) (DSH1,M=1,ND)
      ENDIF
      DO 68 N=1,NFLW
```

```
      READ(IFHBUN,*) (FLWRAT(NS+L,N),L=1,NBDTIM)
      DO 66 L=1,NBDTIM
      FLWRAT(NS+L,N)=FLWRAT(NS+L,N)*CNSTM
 66   CONTINUE
C
C5B------IF DESIRED, PRINT TABLE OF AUXILIARY VARIABLE VALUES AT
C5B------SPECIFIED-FLOW CELL LOCATIONS
      IF(IFHBPT.GT.0) THEN
         WRITE(IOUT,58) (IFLLOC(I,N),I=1,4),
     &                        (FLWRAT(NS+L,N),L=1,NBDTIM)
 67      FORMAT(1X,I4,2I6,5G12.4,/,(17X,5G12.4))
      ENDIF
 68   CONTINUE
 69   CONTINUE
C
C6------READ CELL INDICIES AND SPECIFIED-HEAD VALUES
 70   IF(NHED.LT.1) GO TO 300
      READ(IN,*) IFHBUN,CNSTM,IFHBPT
      WRITE(IOUT,71) IFHBUN,CNSTM
 71   FORMAT(/,1X,'CELL INDICIES AND SPECIFIED-HEAD VALUES ',
     & 'WILL BE READ ON UNIT',I4,'. HEAD VALUES',/,
     & 1X,'WILL BE MULTIPLIED BY',G12.4,'.')
      IF(IFHBPT.GT.0) THEN
         WRITE(IOUT,72)
 72      FORMAT(1X,'LAYER  ROW  COL IAUX             HEAD VALUES')
         ND=MIN0(79,19+NBDTIM*12)
         WRITE(IOUT,74) (DSH1,M=1,ND)
 74      FORMAT(1X,79A1)
      ENDIF
      DO 80 N=1,NHED
      READ(IFHBUN,*) (IHDLOC(I,N),I=1,4),(SBHED(L,N),L=1,NBDTIM)
      DO 75 L=1,NBDTIM
      SBHED(L,N)=SBHED(L,N)*CNSTM
 75   CONTINUE
C
C7------AT SPECIFIED-HEAD LOCATIONS, SET IBOUND TO NEGATIVE NUMBER.
C7------IGNORE SPECIFIED-HEAD CONDITIONS AT CELLS WHERE IBOUND IS ZERO
      K=IHDLOC(1,N)
      I=IHDLOC(2,N)
      J=IHDLOC(3,N)
      IF(IBOUND(J,I,K).NE.0) THEN
         IBOUND(J,I,K)=-IABS(IBOUND(J,I,K))
      ELSE
         WRITE(IOUT,76) (IHDLOC(I,N),I=1,3)
 76      FORMAT(1X,'SPECIFIED-HEAD VALUE IGNORED AT ROW',I5,', COLUMN',
     &   I5,', AND LAYER',I5,'.')
      ENDIF
C
C8------IF DESIRED, PRINT TABLE OF SPECIFIED-FLOW CELL LOCATIONS
C8------AND RATES
      IF(IFHBPT.GT.0) THEN
         IF(IBOUND(J,I,K).NE.0)
     &   WRITE(IOUT,58) (IHDLOC(I,N),I=1,4),(SBHED(L,N),L=1,NBDTIM)
      ENDIF
 80   CONTINUE
```

```
C
C9A------READ VALUES OF AUXILIARY VARIABLES FOR SPECIFIED-HEAD CELLS
      IF(NFHBX2.LT.1) GO TO 300
      DO 169 NX=1,NFHBX2
      NS=NBDTIM*NX
      READ(IN,*) IFHBUN,CNSTM,IFHBPT
      WRITE(IOUT,161) FHBXNM(5+NX),IFHBUN,CNSTM
 161  FORMAT(/,1X,A16,
     & 'FOR SPECIFIED-HEAD CELLS WILL BE READ ON UNIT',I4,'.',/,
     &  ' VALUES WILL BE MULTIPLIED BY',G12.4,'.')
      IF(IFHBPT.GT.0) THEN
         WRITE(IOUT,62) FHBXNM(5+NX)
         WRITE(IOUT,54) (DSH1,M=1,ND)
      ENDIF
      DO 168 N=1,NHED
      READ(IFHBUN,*) (SBHED(NS+L,N),L=1,NBDTIM)
      DO 166 L=1,NBDTIM
      SBHED(NS+L,N)=SBHED(NS+L,N)*CNSTM
 166  CONTINUE
C
C9B------IF DESIRED, PRINT TABLE OF AUXILIARY VARIABLE VALUES AT
C9B------SPECIFIED-HEAD CELL LOCATIONS
      IF(IFHBPT.GT.0) THEN
         WRITE(IOUT,58) (IHDLOC(I,N),I=1,4),
     &                        (SBHED(NS+L,N),L=1,NBDTIM)
      ENDIF
 168  CONTINUE
 169  CONTINUE
C
C10-----RETURN
 300  RETURN
      END
```

List of Variables for Module FHB1RP

Variable	Range	Definition
BDTIM	Package	DIMENSION(NBDTIM), Individual times at which values of specified flow and specified head read by package will be applied.
CNSTM	Module	Constant multiplier for values of time, flow, or head.
DSH1	Module	CHARACTER*1, Character string containing a single dash.
FHBXNM	Package	CHARACTER*16(10), Names of auxiliary variables.
FHBXWT	Package	DIMENSION(10), Time-weighting factor for auxiliary variables.
FLWRAT	Package	DIMENSION(NBDTIM,NFLW), Specified-flow rates for each of NFLW specified-flow cells for each of NBDTIM simulation times.
I	Module	Index for cell locations.
IBOUND	Global	DIMENSION(NCOL,NROW,NLAY), Status of each cell: < 0 Constant-head cell. = 0 No-flow cell. > 0 Variable-head cell.
ICHK1	Module	Error flag to denote proper or improper starting time: = 0 Proper starting time selected. = 1 Improper starting time selected.
ICHK2	Module	Error flag to denote relation of successive times: = 0 Each time is equal to or greater than previous time. = 1 At least one time is less than previous time.
IFHBD3	Package	Dimension for storing specified-flow values and auxiliary-variable values associated with specified-flow cells.
IFHBD5	Package	Dimension for storing auxiliary-variable values associated with specified-head cells.
IFHBPT	Module	Print flag: ≤ 0 Tables of simulation time, specified-flow values, and specified-head values will not be printed. > 0 Tables of simulation time, specified-flow values, and specified-head values will be printed.
IFHBUN	Module	Unit number on which simulation times, specified-flow values, or specified-head values will be read.
IFLLOC	Package	DIMENSION(4,NFLW), Layer, row, and column location, and integer auxiliary-variable value for each of NFLW specified-flow cells.
IHDLOC	Package	DIMENSION(4,NHED), Layer, row, and column location, and integer auxiliary-variable value for each of NHED specified-head cells.
IN	Package	Primary unit number from which input from this package will be read.
IOUT	Global	Primary unit number for all printed output.
J	Module	Index for columns.
K	Module	Index for layers.
L	Module	Index for time.
M	Module	Index for number of dash characters printed in tables of simulation time, specified-flow values, and specified-head values.
N	Module	Index for specified-flow and specified-head values.
NBDTIM	Package	Number of times used to define functions of flow and head.
NCOL	Global	Number of columns in the model grid.
ND	Module	Width of tables of simulation time, specified-flow values, and specified-head values.
NFHBX1	Package	Number of auxiliary variables associated with specified-flow cells.

List of Variables for Module FHB1RP—Continued

Variable	Range	Definition
NFHBX2	Package	Number of auxiliary variables associated with specified-head cells.
NFLW	Package	Number of specified-flow cells.
NHED	Package	Number of specified-head cells.
NLAY	Global	Number of layers in the model grid.
NROW	Global	Number of rows in the model grid.
NS	Module	Starting location of auxiliary-variable values in list that includes specified-flow values.
NX	Module	Index for auxiliary variables.
SBHED	Package	DIMENSION(NBDTIM,NHED), Specified-head values for each of NHED specified-head cells for each of NBDTIM simulation times.

FHB1AD

Narrative for Module FHB1AD

For each time step, this module computes the appropriate flow rate at each specified-flow cell and the appropriate head value at each specified-head cell. Operations are carried out in the following order:

1. If simulation is steady state or is transient with only one time specified, set flow rates and head values to constants and RETURN.

2. For calculation of flow rates at each specified-flow cell location, find array indices of times around simulation time at start of the current time step.

3. Compute factor for interpolation or extrapolation of flow at start of current time step.

4. Find array indices of times around simulation time at end of the current time step.

5. Compute factor for interpolation or extrapolation of flow at end of current time step.

6. Compute flow rates at each specified-flow cell by integrating under specified-flow functions from start to end of time step.

7. Compute values of auxiliary variables for specified-flow cells for the current time step.

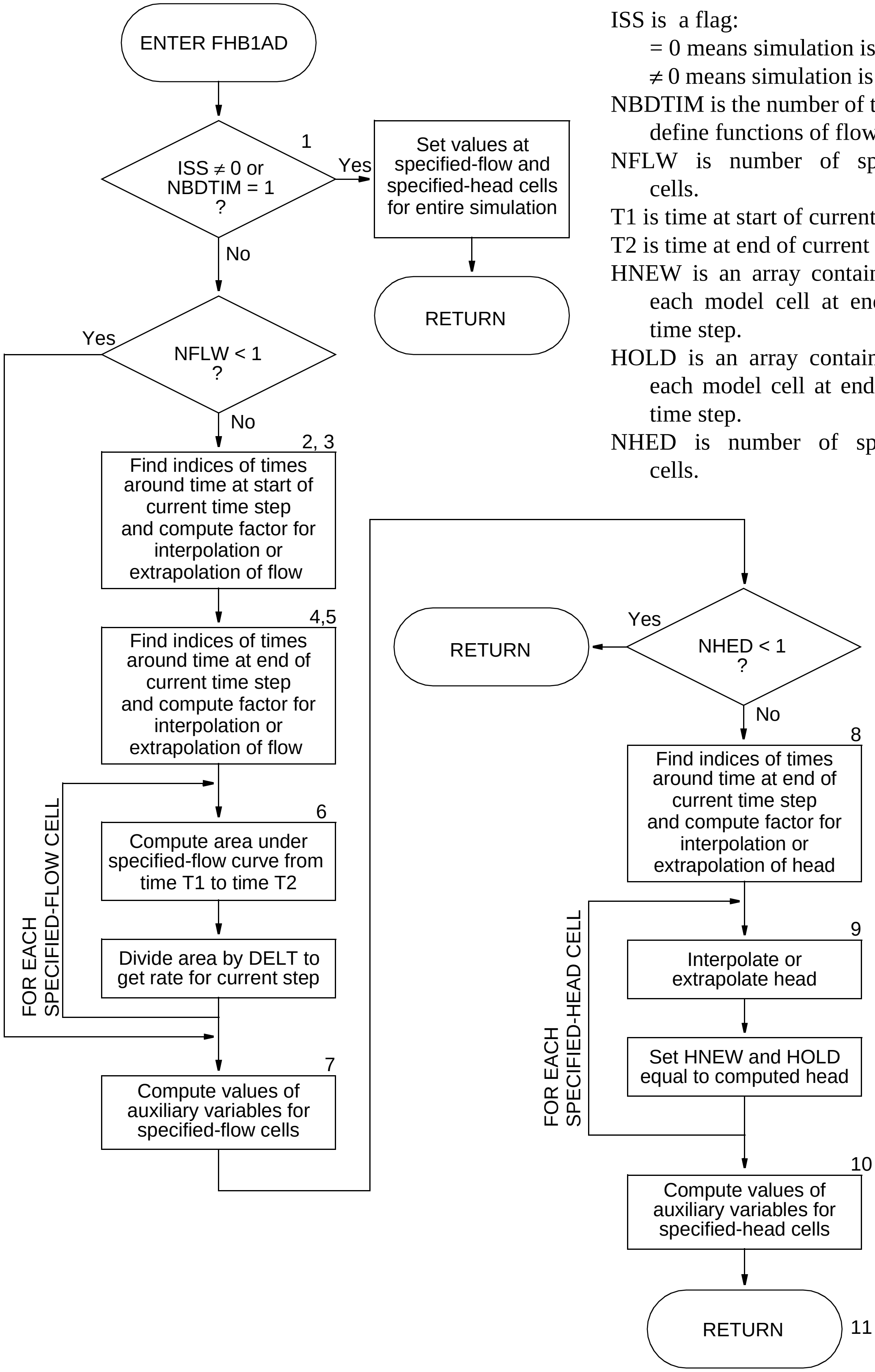
8. Find array indices of times around simulation time at end of the current time step. Compute factor for interpolation or extrapolation of head at end of current time step.

9. At each specified-head cell, interpolate or extrapolate head. Set HNEW and HOLD equal to computed head.

10. Compute values of auxiliary variables for specified-head cells for the current time step.

11. RETURN.

Flowchart for Module FHB1AD



ISS is a flag:
- = 0 means simulation is transient.
- ≠ 0 means simulation is steady state.

NBDTIM is the number of times used to define functions of flow and head.

NFLW is number of specified-flow cells.

T1 is time at start of current time step.

T2 is time at end of current time step.

HNEW is an array containing head at each model cell at end of current time step.

HOLD is an array containing head at each model cell at end of previous time step.

NHED is number of specified-head cells.

Program Listing for Module FHB1AD

```
      SUBROUTINE FHB1AD(HNEW,HOLD,NCOL,NROW,NLAY,ISS,TOTIM,DELT,BDTIM,
     & NBDTIM,FLWRAT,BDFV,BDHV,NFLW,SBHED,IHDLOC,NHED,
     & NFHBX1,NFHBX2,IFHBD3,IFHBD4,IFHBD5)
C
C------VERSION 0000 10JAN1997 FHB1AD
C     ******************************************************************
C     COMPUTE SPECIFIED FLOWS AND HEADS AT CURRENT TIME STEP
C     ******************************************************************
C
C        SPECIFICATIONS:
C     ------------------------------------------------------------------
      COMMON /FHBCOM/ FHBXNM(10),FHBXWT(10)
      CHARACTER*16 FHBXNM
      DOUBLE PRECISION HNEW
C
      DIMENSION BDTIM(NBDTIM),FLWRAT(IFHBD3,NFLW),BDFV(IFHBD4,NFLW),
     &          BDHV(NFHBX2,NHED),SBHED(IFHBD5,NHED),IHDLOC(4,NHED),
     &          HNEW(NCOL,NROW,NLAY),HOLD(NCOL,NROW,NLAY)
C     ------------------------------------------------------------------
C
C1------IF THIS IS A STEADY-STATE SIMULATION OR A TRANSIENT SIMULATION
C1------WITH CONSTANT SPECIFIED FLOWS AND HEADS, SET VALUES AND RETURN
      IF(ISS.NE.0.OR.NBDTIM.EQ.1) THEN
         IF(NFLW.LT.1) GO TO 6
         DO 5 NF=1,NFLW
         BDFV(1,NF)=FLWRAT(1,NF)
         IF(NFHBX1.LT.1) GO TO 5
         DO 4 NX=1,NFHBX1
         N1=2+NX
         N2=1+NX*NBDTIM
         BDFV(N1,NF)=FLWRAT(N2,NF)
 4       CONTINUE
 5       CONTINUE
 6       IF(NHED.LT.1) RETURN
         DO 10 NH=1,NHED
         K=IHDLOC(1,NH)
         I=IHDLOC(2,NH)
         J=IHDLOC(3,NH)
         HNEW(J,I,K)=SBHED(1,NH)
         HOLD(J,I,K)=SBHED(1,NH)
         IF(NFHBX2.LT.1) GO TO 10
         DO 8 NX=1,NFHBX2
         N2=1+NX*NBDTIM
         BDHV(NX,NF)=SBHED(N2,NF)
 8       CONTINUE
 10      CONTINUE
         RETURN
      ENDIF
C
C2------FIND ARRAY INDICES OF TIMES AROUND TIME AT START OF CURRENT
C2------TIME STEP
      IF(NFLW.LT.1) GO TO 200
      T2=TOTIM
```

```
      T1=TOTIM-DELT
      DO 20 L=2,NBDTIM
      IF(T1.LE.BDTIM(L)) THEN
         IB1=L-1
         IB2=L
         GO TO 40
      ENDIF
 20   CONTINUE
      IB1=NBDTIM-1
      IB2=NBDTIM
C
C3------COMPUTE FACTOR FOR INTERPOLATION OR EXTRAPOLATION OF FLOW AT
C3------START OF CURRENT TIME STEP
 40   QFACT1=(T1-BDTIM(IB1))/(BDTIM(IB2)-BDTIM(IB1))
C
C4------FIND ARRAY INDICES OF TIMES AROUND TIME AT END OF CURRENT
C4------TIME STEP
      DO 60 L=IB2,NBDTIM
      IF(T2.LE.BDTIM(L)) THEN
         IB3=L-1
         IB4=L
         GO TO 70
      ENDIF
 60   CONTINUE
      IB4=NBDTIM
      IB3=NBDTIM-1
C
C5------COMPUTE FACTOR FOR INTERPOLATION OR EXTRAPOLATION OF FLOW AT
C5------END OF CURRENT TIME STEP
 70   QFACT2=(T2-BDTIM(IB3))/(BDTIM(IB4)-BDTIM(IB3))
C
C6------COMPUTE SPECIFIED FLOW RATES FOR THIS TIME STEP
      NPI=IB4-IB2
      DO 90 NF=1,NFLW
      QA=FLWRAT(IB1,NF)
      QB=FLWRAT(IB2,NF)
      QC=FLWRAT(IB3,NF)
      QD=FLWRAT(IB4,NF)
      Q1=(QA+QFACT1*(QB-QA))
      Q2=(QC+QFACT2*(QD-QC))
      IF(NPI.EQ.0) THEN
         BDFV(1,NF)=0.5*(Q1+Q2)
      ELSE
         TP=T1
         QP=Q1
         SUM1=0.0
         DO 80 NI=IB2,IB3
         QN=FLWRAT(NI,NF)
         DDT=BDTIM(NI)-TP
         SUM1=SUM1+DDT*0.5*(QN+QP)
         TP=BDTIM(NI)
         QP=QN
 80      CONTINUE
         DDT=T2-TP
         SUM1=SUM1+DDT*0.5*(Q2+QP)
```

```
            BDFV(1,NF)=SUM1/DELT
         ENDIF
 90   CONTINUE
C
C7-----COMPUTE VALUES OF AUXILIARY VARIABLES FOR SPECIFIED-FLOW
C7-----CELLS FOR CURRENT TIME STEP
      IF(NFHBX1.LT.1) GO TO 200
      DO 190 NX=1,NFHBX1
      N1=2+NX
      N2=NX*NBDTIM
      TT=TOTIM-(1.-FHBXWT(NX))*DELT
      DO 120 L=2,NBDTIM
      IF(TT.LE.BDTIM(L)) THEN
         IB1=L-1
         IB2=L
         GO TO 140
      ENDIF
 120  CONTINUE
      IB1=NBDTIM-1
      IB2=NBDTIM
 140  XFACT=(TT-BDTIM(IB1))/(BDTIM(IB2)-BDTIM(IB1))
      DO 150 NF=1,NFLW
      XX=FLWRAT(N2+IB1,NF)+XFACT*(FLWRAT(N2+IB2,NF)-FLWRAT(N2+IB1,NF))
      BDFV(N1,NF)=XX
 150  CONTINUE
 190  CONTINUE
C8------FIND ARRAY INDICES OF TIMES AROUND TIME AT END OF CURRENT
C8------TIME STEP, COMPUTE FACTOR OF INTERPOLATION OR EXTRAPOLATION
C8------OF HEAD
 200  IF(NHED.LT.1) RETURN
      TT=TOTIM
      DO 220 L=2,NBDTIM
      IF(TT.LE.BDTIM(L)) THEN
         IB1=L-1
         IB2=L
         GO TO 240
      ENDIF
 220  CONTINUE
      IB1=NBDTIM-1
      IB2=NBDTIM
 240  HFACT=(TT-BDTIM(IB1))/(BDTIM(IB2)-BDTIM(IB1))
C
C9------AT EACH SPECIFIED-HEAD LOCATION, INTERPOLATE OR EXTRAPOLATE
C9------HEAD. SET HNEW AND HOLD EQUAL TO COMPUTED HEAD
      DO 250 NH=1,NHED
      K=IHDLOC(1,NH)
      I=IHDLOC(2,NH)
      J=IHDLOC(3,NH)
      HH=SBHED(IB1,NH)+HFACT*(SBHED(IB2,NH)-SBHED(IB1,NH))
      HNEW(J,I,K)=HH
      HOLD(J,I,K)=HH
 250  CONTINUE
C
C10----COMPUTE VALUES OF AUXILIARY VARIABLES FOR SPECIFIED-HEAD
C10----CELLS FOR CURRENT TIME STEP
```

```
      IF(NFHBX2.LT.1) RETURN
      DO 390 NX=1,NFHBX2
      N2=NX*NBDTIM
      TT=TOTIM-(1.-FHBXWT(5+NX))*DELT
      DO 320 L=2,NBDTIM
      IF(TT.LE.BDTIM(L)) THEN
         IB1=L-1
         IB2=L
         GO TO 340
      ENDIF
 320  CONTINUE
      IB1=NBDTIM-1
      IB2=NBDTIM
 340  XFACT=(TT-BDTIM(IB1))/(BDTIM(IB2)-BDTIM(IB1))
      DO 350 NF=1,NHED
      XX=SBHED(N2+IB1,NF)+XFACT*(SBHED(N2+IB2,NF)-SBHED(N2+IB1,NF))
      BDHV(NX,NF)=XX
 350  CONTINUE
 390  CONTINUE
C
C11------RETURN
      RETURN
      END
```

List of Variables for Module FHB1AD

Variable	Range	Definition
BDFV	Package	DIMENSION(IFHBD3,NFLW), Computed flow and values of auxiliary variables for each of NFLW specified-flow cells for current time step.
BDHV	Package	DIMENSION(IFHBD3,NFLW), Computed values of auxiliary variables for each of NHED specified-head cells for current time step.
BDTIM	Package	DIMENSION(NBDTIM), Individual times at which values of specified flow and specified head read by package will be applied.
DDT	Module	Time interval used in integrating under specified-flow function.
DELT	Global	Length of current time step.
FHBXNM	Package	CHARACTER*16(10), Names of auxiliary variables.
FHBXWT	Package	DIMENSION(10), Time-weighting factor for auxiliary variables.
FLWRAT	Package	DIMENSION(NBDTIM,NFLW), Specified-flow rates for each of NFLW specified-flow cells for each of NBDTIM simulation times.
HFACT	Module	Coefficient in equation that interpolates head at end of current time step.
HH	Module	Temporary storage of computed head at end of current time step.
HNEW	Global	DIMENSION(NCOL,NROW,NLAY), Head at each model cell at end of current time step.
HOLD	Global	DIMENSION(NCOL,NROW,NLAY), Head at each model cell at end of previous time step.
I	Module	Temporary storage of model row index for specified-flow and specified-head cells.
IB1	Module	Index of specified-flow time that immediately precedes time at start of current time step.
IB2	Module	Index of specified-flow time that immediately succeeds time at start of current time step.
IB3	Module	Index of specified-flow time that immediately precedes time at end of current time step.
IB4	Module	Index of specified-flow time that immediately succeeds time at end of current time step.
IFHBD3	Package	Dimension for storing specified-flow values and auxiliary-variable values associated with specified-flow cells.
IFHBD4	Package	Dimension for interpolated specified-flow values and interpolated auxiliary-variable values associated with specified-flow cells.
IFHBD5	Package	Dimension for storing auxiliary-variable values associated with specified-head cells.
IFHBSS	Package	Option flag for steady-state simulations: = 0 Take flow, head, and auxiliary-variable values at starting time. ≠ 0 Interpolate flow, head, and auxiliary-variable values.
IHDLOC	Package	DIMENSION(3,NHED), Layer, row, and column indices for each of NHED specified-head cells.
ISS	Global	Flag: = 0, simulation is transient ≠ 0, simulation is steady state.
J	Module	Temporary storage of model column index for specified-flow and specified-head cells.
K	Module	Temporary storage of model layer index for specified-flow and specified-head cells.
L	Module	Index for time.
N1	Module	Starting point of list of auxiliary-variable values in array BDFV.
N2	Module	Starting point of list of interpolated auxiliary-variable values in array FLWRAT.

List of Variables for Module FHB1AD—Continued

Variable	Range	Definition
NBDTIM	Package	Number of times used to define functions of flow and head.
NCOL	Global	Number of columns in the model grid.
NF	Module	Index for specified-flow cells.
NFHBX1	Package	Number of auxiliary variables associated with specified-flow cells.
NFHBX2	Package	Number of auxiliary variables associated with specified-head cells.
NFLW	Package	Number of specified-flow cells.
NH	Module	Index for specified-head cells.
NHED	Package	Number of specified-head cells.
NI	Module	Index for specified-flow times.
NLAY	Global	Number of layers in the model grid.
NPI	Package	Number of intermediate time points between T1 and T2.
NROW	Global	Number of rows in the model grid.
NX	Module	Index for auxiliary variables.
Q1	Module	Interpolated flow at start of time step.
Q2	Module	Interpolated flow at end of time step.
QA	Module	Specified-flow value at time that immediately precedes time at start of current time step.
QB	Module	Specified-flow value at time that immediately succeeds time at start of current time step.
QC	Module	Specified-flow value at time that immediately precedes time at end of current time step.
QD	Module	Specified-flow value at time that immediately succeeds time at end of current time step.
QFACT1	Module	Coefficient in equation that interpolates head at start of current time step.
QFACT2	Module	Coefficient in equation that interpolates head at end of current time step.
QN	Module	Temporary storage of flow rate at specified-flow times between T1 and T2.
QP	Module	Flow rate at the previous interpolation point.
SBHED	Package	DIMENSION(NBDTIM,NHED), Specified-head values for each of NHED specified-head cells for each of NBDTIM simulation times.
SUM1	Module	Cumulative volume of flow from time T1 to interpolation point.
T1	Module	Time at start of current time step.
T2	Module	Time at end of current time step.
TOTIM	Global	Elapsed time in the simulation.
TP	Module	Time at previous interpolation point.
TT	Module	Temporary storage of time at end of current time step.
XFACT	Module	Coefficient in equation that interpolates values of auxiliary variables for current time step.
XX	Module	Temporary storage of value of auxiliary variable for current time step.

FHB1FM

Narrative for Module FHB1FM

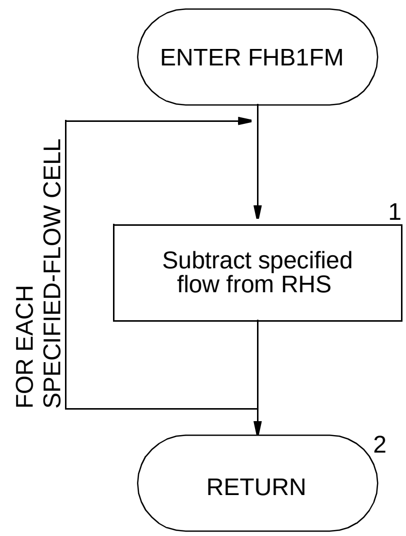
This module subtracts computed flow rates from the right-hand side of the finite-difference equations for all specified-flow cell locations. Operations are carried out in the following order:

1. For each specified-flow cell location where IBOUND is greater than zero, subtract flow rate from RHS.

2. RETURN.

Flowchart for Module FHB1FM

RHS is an array containing the right-hand side of finite-difference equations.



Program Listing for Module FHB1FM

```
       SUBROUTINE FHB1FM(RHS,IBOUND,IFLLOC,BDFV,NFLW,NCOL,NROW,NLAY,
     &                   IFHBD4)
C
C-----VERSION 0000 10JAN1997 FHB1FM
C
C     ******************************************************************
C     SUBTRACT SPECIFIED Q FROM RHS
C     ******************************************************************
C
C        SPECIFICATIONS:
C     ------------------------------------------------------------------
      DIMENSION RHS(NCOL,NROW,NLAY),IBOUND(NCOL,NROW,NLAY),
     1            IFLLOC(4,NFLW),BDFV(IFHBD4,NFLW)
C     ------------------------------------------------------------------
C
C1------PROCESS EACH SPECIFIED-FLOW LOCATION IN THE LIST.
      IF(NFLW.LE.0) RETURN
      DO 100 L=1,NFLW
      IR=IFLLOC(2,L)
      IC=IFLLOC(3,L)
      IL=IFLLOC(1,L)
      Q=BDFV(1,L)
C
C1A-----IF THE CELL IS INACTIVE THEN BYPASS PROCESSING.
      IF(IBOUND(IC,IR,IL).LE.0) GO TO 100
C
C1B-----IF THE CELL IS VARIABLE HEAD THEN SUBTRACT Q FROM
C       THE RHS ACCUMULATOR.
      RHS(IC,IR,IL)=RHS(IC,IR,IL)-Q
  100 CONTINUE
C
C2------RETURN
      RETURN
      END
```

List of Variables for Module FHB1FM

Variable	Range	Definition
BDFV	Package	DIMENSION(IFHBD3,NFLW), Computed flow and values of auxiliary variables for each of NFLW specified-flow cells for current time step.
IBOUND	Global	DIMENSION(NCOL,NROW,NLAY), Status of each cell: < 0 Constant-head cell. = 0 No-flow cell. > 0 Variable-head cell.
IC	Module	Temporary storage of model row location for specified-flow cells.
IFHBD4	Package	Dimension for interpolated specified-flow values and interpolated auxiliary-variable values associated with specified-flow cells.
IFLLOC	Package	DIMENSION(3,NFLW), Layer, row, and column location, and integer auxiliary-variable value for each of NFLW specified-flow cells.
IL	Module	Temporary storage of model-layer location for specified-flow cells.
IR	Module	Temporary storage of model-row location for specified-flow cells.
L	Module	Index for specified-flow cells.
NCOL	Global	Number of columns in the model grid.
NFLW	Package	Number of specified-flow cells.
NLAY	Global	Number of layers in the model grid.
NROW	Global	Number of rows in the model grid.
Q	Module	Temporary storage of flow at specified-flow cells.
RHS	Global	DIMENSION(NCOL,NROW,NLAY), Right-hand side of finite-difference equations.

FHB1BD

Narrative for Module FHB1BD

This module incorporates specified-flow rates into the overall mass balance and writes cell-by-cell flow rates if option is selected. Operations are carried out in the following order:

1. Initialize the cell-by-cell flow term and flag, and clear the accumulators for specified-flow rates.

2. If cell-by-cell flow terms are to be saved as a list, then write header. If cell-by-cell flow terms are to be saved as an array, clear the buffer (BUFF) in which they will be accumulated before saving.

3. Process specified-flow cells one at a time. Skip budget calculations altogether if there are no specified-flow cells. Skip processing for any no-flow or constant-head cell.

4. Get flow rate for specified-flow cell from the BDFV array. Print rate if requested (IFHBCB<0 and ICBCFL≠0). Add rate to appropriate location in buffer.

5. Add rate to appropriate inflow or outflow accumulator. If rate is positive (recharge), add rate to accumulator RATIN. If rate is negative (discharge), add rate to accumulator RATOUT.

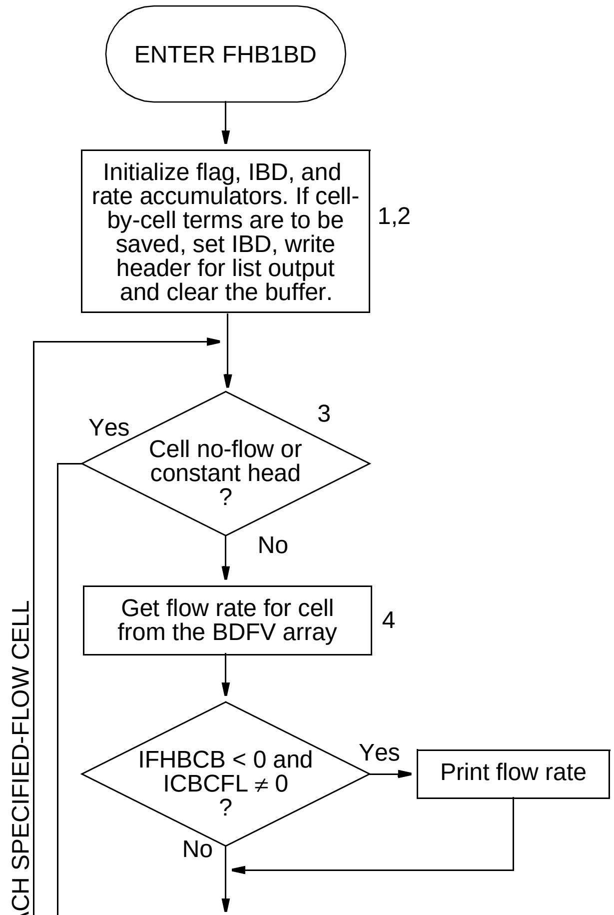
6. If cell-by-cell flow terms are to be saved as a list, write record with list information. Save the flow rate in the second column of the BDFV array. If cell-by-cell flow rates are to be saved as an array, call UBDSV to record array with rates for each cell.

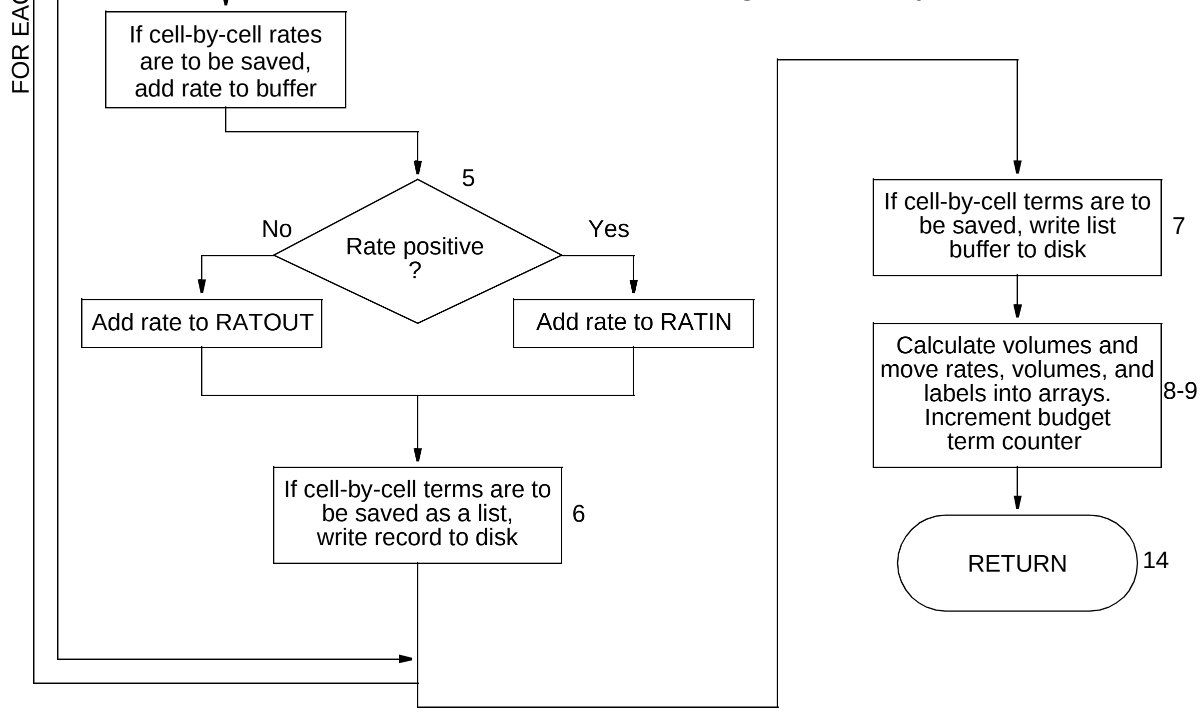
7. Move rates into VBVL for printing of overall budget by module BAS1OT. Move flow volumes (products of rates and length of current time step) into VBVL accumulators. Move budget-term labels into VBNM for printing of overall budget by module BAS1OT.

8. Increment budget-term counter, MSUM.

9. RETURN.

Flowchart for Module FHB1BD





BDFV is an array containing computed flow and values of auxiliary variables for each of NFLW specified-flow cells for current time step.

IBD is a flag:

- = 0, cell-by-cell flow terms will not be recorded.
- ≠ 0, cell-by-cell flow terms will be recorded.

IFHBCB is a flag and a unit number:

- > 0, unit number on which cell-by-cell flow terms will be recorded whenever ICBCFL is set.
- = 0, cell-by-cell flow terms will not be recorded or printed.
- < 0, cell-by-cell flow terms will be printed whenever ICBCFL is set.

ICBCFL is a flag:

- = 0, cell-by-cell flow terms will not be recorded or printed for the current time step.
- ≠ 0, cell-by-cell flow terms will be recorded or printed for the current time step.

RATOUT is an accumulator to which all flows out of the ground-water system are added.

RATIN is an accumulator to which all flows into the ground-water system are added.

Program Listing for Module FHB1BD

```
      SUBROUTINE FHB1BD(IFLLOC,BDFV,NFLW,VBNM,VBVL,MSUM,IBOUND,DELT,
     &      NCOL,NROW,NLAY,KSTP,KPER,IFHBCB,ICBCFL,BUFF,IOUT,IFHBD4)
C
C-----VERSION 0000 10JAN1997 FHB1BD
C     ******************************************************************
C     CALCULATE VOLUMETRIC BUDGET FOR SPECIFIED FLOWS
C     ******************************************************************
C
C        SPECIFICATIONS:
C     ------------------------------------------------------------------
      CHARACTER*16 VBNM(MSUM),TEXT
      DOUBLE PRECISION RATIN,RATOUT,QQ
      DIMENSION VBVL(4,MSUM),IBOUND(NCOL,NROW,NLAY),
     1          BUFF(NCOL,NROW,NLAY),IFLLOC(4,NFLW),BDFV(IFHBD4,NFLW)
C
      DATA TEXT/' SPECIFIED FLOWS'/
C     ------------------------------------------------------------------
C
C1------CLEAR RATIN AND RATOUT ACCUMULATORS.
      ZERO=0.
      RATIN=ZERO
      RATOUT=ZERO
      IBD=0
      IF(IFHBCB.LT.0 .AND. ICBCFL.NE.0) IBD=-1
      IF(IFHBCB.GT.0) IBD=ICBCFL
C
C2A----IF CELL-BY-CELL FLOWS WILL BE SAVED AS A LIST, WRITE HEADER.
      IF(IBD.EQ.2) CALL UBDSV2(KSTP,KPER,TEXT,IFHBCB,NCOL,NROW,NLAY,
     1          NFLW,IOUT,DELT,PERTIM,TOTIM,IBOUND)
C
C2B----CLEAR THE BUFFER.
      DO 50 IL=1,NLAY
      DO 50 IR=1,NROW
      DO 50 IC=1,NCOL
      BUFF(IC,IR,IL)=ZERO
   50 CONTINUE
C
C3A----IF THERE ARE NO SPECIFIED-FLOW CELLS, DO NOT ACCUMULATE FLOW
      IF(NFLW.EQ.0) GO TO 200
C
C3B-----PROCESS SPECIFIED-FLOW CELLS ONE AT A TIME.
   60 DO 100 L=1,NFLW
C
C3C-----GET LAYER, ROW, AND COLUMN NUMBERS
      IR=IFLLOC(2,L)
      IC=IFLLOC(3,L)
      IL=IFLLOC(1,L)
      Q=ZERO
C
C3D-----IF THE CELL IS NO-FLOW OR CONSTANT-HEAD, IGNORE IT.
      IF(IBOUND(IC,IR,IL).LE.0)GO TO 97
C
C4A-----GET FLOW RATE FROM SPECIFIED-FLOW LIST
```

```
      Q=BDFV(1,L)
      QQ=Q
C
C4B-----PRINT THE INDIVIDUAL RATES IF REQUESTED(IFHBCB<0).
      IF(IBD.LT.0) THEN
        WRITE(IOUT,900) TEXT,KPER,KSTP,L,IL,IR,IC,Q
  900   FORMAT(1H0,4A4,'   PERIOD',I3,'   STEP',I3,' SEQ NO',I4,
     1    '   LAYER',I3,'   ROW ',I4,'   COL',I4,'   RATE',G15.7)
      ENDIF
C
C4C-----ADD FLOW RATE TO BUFFER.
      BUFF(IC,IR,IL)=BUFF(IC,IR,IL)+Q
C
C5A-----SEE IF FLOW RATE IS NEGATIVE, ZERO, OR POSITIVE.
      IF(Q) 90,97,80
C
C5B-----FLOW RATE IS POSITIVE (RECHARGE). ADD IT TO RATIN.
   80 RATIN=RATIN+QQ
      GO TO 97
C
C5C-----FLOW RATE IS NEGATIVE(DISCHARGE). ADD IT TO RATOUT.
   90 RATOUT=RATOUT-QQ
C
C6------IF CELL-BY-CELL FLOWS ARE BEING SAVED AS A LIST, WRITE FLOW.
C6------RETURN THE ACTUAL FLOW IN THE BDFV ARRAY.
   97 IF(IBD.EQ.2) CALL UBDSVA(IFHBCB,NCOL,NROW,IC,IR,IL,Q,IBOUND,NLAY)
      BDFV(2,L)=Q
  100 CONTINUE
C
C7------IF CELL-BY-CELL FLOWS WILL BE SAVED AS A 3-D ARRAY,
C7------CALL UBUDSV TO SAVE THEM
      IF(IBD.EQ.1) CALL UBUDSV(KSTP,KPER,TEXT,IFHBCB,BUFF,NCOL,NROW,
     1                          NLAY,IOUT)
C
C8------MOVE RATES, VOLUMES & LABELS INTO ARRAYS FOR PRINTING.
 200  RIN=RATIN
      ROUT=RATOUT
      VBVL(3,MSUM)=RIN
      VBVL(4,MSUM)=ROUT
      VBVL(1,MSUM)=VBVL(1,MSUM)+RIN*DELT
      VBVL(2,MSUM)=VBVL(2,MSUM)+ROUT*DELT
      VBNM(MSUM)=TEXT
C
C9------INCREMENT BUDGET TERM COUNTER (MSUM).
      MSUM=MSUM+1
C
C10-----RETURN
      RETURN
      END
```

List of Variables for Module FHB1BD

Variable	Range	Definition
BDFV	Package	DIMENSION(NFLW), Computed flow for each of NFLW specified-flow cells for current time step.
BUFF	Global	DIMENSION(NCOL, NROW, NLAY), Buffer used for temporary storage of flow rates prior to recording cell-by-cell budgets.
DELT	Global	Length of the current time step.
IBD	Module	Flag: = 0 Cell-by-cell flow terms will not be recorded. ≠ 0 Cell-by-cell flow terms will be recorded.
IBOUND	Global	DIMENSION(NCOL,NROW,NLAY), Status of each cell: < 0 Constant-head cell. = 0 No-flow cell. > 0 Variable-head cell.
IC	Module	Index for columns.
ICBCFL	Global	Flag: = 0 Cell-by-cell flow terms will not be recorded for the current time step. ≠ 0 Cell-by-cell flow terms will be recorded for the current time step.
IFHBCB	Package	Flag and a unit number: > 0 Unit number on which cell-by-cell flow terms will be recorded whenever ICBCFL is set. = 0 Cell-by-cell flow terms will not be recorded or printed. < 0 Cell-by-cell flow terms will be printed whenever ICBCFL is set.
IFLLOC	Package	DIMENSION(3,NFLW), Layer, row, and column location, and integer auxiliary-variable value for each of NFLW specified-flow cells.
IL	Module	Index for layers.
IOUT	Global	Primary unit number for all printed output.
IR	Module	Index for rows.
KPER	Global	Stress-period counter.
KSTP	Global	Time-step counter, reset at the start of each stress period.
L	Module	Index for specified-flow cells.
MSUM	Global	Counter for budget entries in VBVL and VBNM.
N	Module	Index for text string.
NCOL	Global	Number of columns in the model grid.
NFLW	Package	Number of specified-flow cells.
NLAY	Global	Number of layers in the model grid.
NROW	Global	Number of rows in the model grid.
Q	Module	Temporary storage of flow at specified-flow cells.
RATIN	Module	Accumulator for total flow into the flow field from specified-flow cells.
RATOUT	Module	Accumulator for total flow out of the flow field into specified-flow cells.
TEXT	Module	CHARACTER*16, Label for volumetric budget and cell-by-cell budget.
VBNM	Global	CHARACTER*16(MSUM), Labels for entries in volumetric budget.
VBVL	Global	DIMENSION(4,MSUM), Entries for the volumetric budget. For flow component N, the values in VBVL are: (1,N), Rate for current time step into the flow field. (2,N), Rate for current time step out of the flow field. (3,N), Volume into the flow field during the simulation. (4,N), Volume out of the flow field during the simulation.

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APPENDIX—Input Data Sets and Printed Results for Example Problem

Listing of MODFLOW Name file

The contents of the MODFLOW name file is given below. The input consists of 8 records (lines).

```
LIST  6 test7.lst
BAS   5 test7.bas
BCF  11 test7.bcf
SIP  19 test7.sip
OC   22 test7.oc
FHB  31 test7.fhb
DATA(BINARY) 41 test7.head
DATA(BINARY) 44 test7.cbc
```

Listing of Input Data for Basic Package

Input for the Basic Package is given below. The input consists of 14 records (lines), read from FORTRAN unit number 5, as specified in the MAIN program.

```
Example problem for Flow and Head Boundary Package, Version 1 (FHB1)
From USGS Open-File Report 97–571
         1         3        10         3         4
 11  0  0  0  0  0  0  0 19  0  0 22  0  0  0  0  0  0  0  0 31
         0         1
         5         1(10I3)                       3
  1  1  1  1  1  1  1  1  1  1
  1  1  1  1  1  1  1  1  1  1
  1  1  1  1  1  1  1  1  1  1
       0.0
         0       0.0                                  Starting head
      400.        10       1.0                        Stress Period 1
      200.         4       1.0                        Stress Period 2
      400.         6       1.1                        Stress Period 3
```

Listing of Input Data for Block-Centered Flow Package

Input for the Block-Centered Flow Package is given below. The input consists of 7 records (lines), read from FORTRAN unit number 11.

```
         0         0
 0
         0       1.0                                     TRPY
         0     1000.                                     DELR
         0     1000.                                     DELC
         0      0.01                                     Sf1
         0     5000.                                     Tran
```

Listing of Input Data for Strongly-Implicit Procedure Package

Input for the Strongly-Implicit Procedure Package is given below. The input consists of 2 records (lines), read from FORTRAN unit number 19.

```
       120         5   MXITER  NPARM
        1.    .00100         1         0         5
```

Listing of Input Data for Output Control Package

Input for the Output Control Package is given below. The input consists of 22 records (lines), read from FORTRAN unit number 22.

```
         4         4        41        42
         0         1         0         1         Time Step 1
         0         0         1         1         Layer 1
        -2         1         0         1         Time Step 2
        -3         1         0         1         Time Step 3
        -4         1         0         1         Time Step 4
        -5         1         0         1         Time Step 5
        -6         1         0         1         Time Step 6
        -7         1         0         1         Time Step 7
        -8         1         0         1         Time Step 8
        -9         1         0         1         Time Step 9
       -10         1         0         1         Time Step 10
       -11         1         0         1         Time Step 11
       -12         1         0         1         Time Step 12
       -13         1         0         1         Time Step 13
       -14         1         0         1         Time Step 14
       -15         1         0         1         Time Step 15
       -16         1         0         1         Time Step 16
       -17         1         0         1         Time Step 17
       -18         1         0         1         Time Step 18
       -19         1         0         1         Time Step 19
        20         1         0         1         Time Step 20
         1         0         1         0
```

Listing of Input Data for Flow and Head Boundary Package

Input for the General-Head Boundary Package is given below. The input consists of 34 records (lines), read from FORTRAN unit number 31.

```
        4         1         3    0   44         0      0
        31        1.        1
   0.0  307. 791. 1000.
        31        1.        1
    1    2    1    0      2000. 6000. 5000. 9000.
        31        1.        1
    1    1   10    0   0. 1. 5. 2.
    1    2   10    0   0. 1. 5. 2.
    1    3   10    0   0. 1. 5. 2.
```

Selected Parts of Printed Results for Example Problem

```
LISTING FILE: test7.lst
                        UNIT   6
OPENING test7.bas
FILE TYPE:BAS   UNIT   5
OPENING test7.bcf
FILE TYPE:BCF   UNIT  11
OPENING test7.sip
FILE TYPE:SIP   UNIT  19
OPENING test7.oc
FILE TYPE:OC   UNIT  22
OPENING test7.fhb
FILE TYPE:FHB   UNIT  31
OPENING test7.head
FILE TYPE:DATA(BINARY)   UNIT  41
OPENING test7.cbc
FILE TYPE:DATA(BINARY)   UNIT  44
                                 MODFLOW
     U.S. GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUND-WATER FLOW MODEL

Example problem for Flow and Head Boundary Package, Version 1 (FHB1)
From USGS Open-File Report 97–571
   1 LAYERS         3 ROWS        10 COLUMNS
  3 STRESS PERIOD(S) IN SIMULATION
MODEL TIME UNIT IS DAYS

BAS5 -- BASIC MODEL PACKAGE, VERSION 5, 1/1/95 INPUT READ FROM UNIT 5
ARRAYS RHS AND BUFF WILL SHARE MEMORY
INITIAL HEAD WILL BE KEPT THROUGHOUT THE SIMULATION
       287 ELEMENTS IN X ARRAY ARE USED BY BAS
       287 ELEMENTS OF X ARRAY USED OUT OF    1500000

BCF5 -- BLOCK-CENTERED FLOW PACKAGE, VERSION 5, 9/1/93 INPUT READ FROM UNIT 11
TRANSIENT SIMULATION
HEAD AT CELLS THAT CONVERT TO DRY=  0.00000E+00
WETTING CAPABILITY IS NOT ACTIVE
     LAYER  LAYER-TYPE CODE     INTERBLOCK T
     --------------------------------------------
        1            0          0 -- HARMONIC
        31 ELEMENTS IN X ARRAY ARE USED BY BCF
       318 ELEMENTS OF X ARRAY USED OUT OF    1500000

SIP5 -- STRONGLY IMPLICIT PROCEDURE SOLUTION PACKAGE
                   VERSION 5, 9/1/93 INPUT READ FROM UNIT 19
MAXIMUM OF 120 ITERATIONS ALLOWED FOR CLOSURE
 5 ITERATION PARAMETERS
       605 ELEMENTS IN X ARRAY ARE USED BY SIP
       923 ELEMENTS OF X ARRAY USED OUT OF    1500000
FHB1 -- SPECIFIED FLOW PACKAGE, VERSION 1,12/3/96 INPUT READ FROM 31
TOTAL OF    4 TIMES WILL BE USED TO DEFINE VARIATIONS IN FLOW AND HEAD.
FLOW WILL BE SPECIFIED AT A TOTAL OF    1 CELLS.
HEAD WILL BE SPECIFIED AT A TOTAL OF    3 CELLS.
FHB STEADY-STATE OPTION FLAG WILL BE IGNORED,
SIMULATION IS TRANSIENT.
CELL-BY-CELL FLOWS WILL BE RECORDED ON UNIT 44
 0 AUXILIARY VARIABLES FOR SPECIFIED-FLOW CELLS WILL
 BE DEFINED BY FHB FOR USE BY OTHER PACKAGES.
 0 AUXILIARY VARIABLES FOR SPECIFIED-HEAD CELLS WILL
 BE DEFINED BY FHB FOR USE BY OTHER PACKAGES.
      38 ELEMENTS IN X ARRAY ARE USED BY FHB1
     961 ELEMENTS OF X ARRAY USED OUT OF 1500000


                    BOUNDARY ARRAY FOR LAYER   1
READING ON UNIT   5 WITH FORMAT: (10I3)

       1   2   3   4   5   6   7   8   9  10
............................................
  1    1   1   1   1   1   1   1   1   1   1
  2    1   1   1   1   1   1   1   1   1   1
  3    1   1   1   1   1   1   1   1   1   1

AQUIFER HEAD WILL BE SET TO 0.00000E+00 AT ALL NO-FLOW NODES (IBOUND=0).

            INITIAL HEAD =  0.0000000E+00 FOR LAYER   1

OUTPUT CONTROL IS SPECIFIED EVERY TIME STEP
HEAD PRINT FORMAT CODE IS 9      DRAWDOWN PRINT FORMAT CODE IS 9
HEADS WILL BE SAVED ON UNIT 41   DRAWDOWNS WILL BE SAVED ON UNIT 42
```

```
COLUMN TO ROW ANISOTROPY =   1.000000
                    DELR =   1000.000
                    DELC =   1000.000
    PRIMARY STORAGE COEF =  0.1000000E-01 FOR LAYER   1
    TRANSMIS. ALONG ROWS =   5000.000     FOR LAYER   1

         SOLUTION BY THE STRONGLY IMPLICIT PROCEDURE
         -------------------------------------------
MAXIMUM ITERATIONS ALLOWED FOR CLOSURE =      120
                ACCELERATION PARAMETER =     1.0000
     HEAD CHANGE CRITERION FOR CLOSURE =    0.10000E-02
     SIP HEAD CHANGE PRINTOUT INTERVAL =        5

    CALCULATE ITERATION PARAMETERS FROM MODEL CALCULATED WSEED
TIMES FOR SPECIFIED-FLOW AND HEAD VALUES WILL BE READ ON UNIT 31 AND
MULTIPLIED BY 1.000.
    4 TIMES FOR SPECIFYING FLOWS AND HEADS:
                      1           2           3           4
                ------------------------------------------------
                  0.0000E+00   307.0       791.0       1000.

CELL INDICIES AND SPECIFIED-FLOW RATES WILL BE READ ON UNIT 31. RATES WILL
BE MULTIPLIED BY 1.000.
LAYER  ROW  COL IAUX              FLOW RATES
-------------------------------------------------------------------
   1    2    1    0   2000.       6000.       5000.       9000.

CELL INDICIES AND SPECIFIED-HEAD VALUES WILL BE READ ON UNIT 31. HEAD VALUES
WILL BE MULTIPLIED BY 1.000.
LAYER  ROW  COL IAUX             HEAD VALUES
-------------------------------------------------------------------
   1    1   10    0  0.0000E+00   1.000       5.000       2.000
   1    2   10    0  0.0000E+00   1.000       5.000       2.000
   1    3   10    0  0.0000E+00   1.000       5.000       2.000

                           STRESS PERIOD NO.   1, LENGTH =   400.0000
                           ----------------------------------------------
                             NUMBER OF TIME STEPS =    10
                              MULTIPLIER FOR DELT =     1.000
                           INITIAL TIME STEP SIZE =   40.00000

AVERAGE SEED = 0.02467401
MINIMUM SEED = 0.02467401
    5 ITERATION PARAMETERS CALCULATED FROM AVERAGE SEED:
 0.000000E+00 0.603667E+00 0.842920E+00 0.937744E+00 0.975326E+00

 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 10 IN STRESS PERIOD 1
 -----------------------------------------------------------------------------
    CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
    ------------------                 ------------------------
          IN:                                       IN:
          ---                                       ---
             STORAGE =           0.0000               STORAGE =           0.0000
       CONSTANT HEAD =           0.0000         CONSTANT HEAD =           0.0000
    SPECIFIED FLOWS =     1777065.2500       SPECIFIED FLOWS =        5849.1738

            TOTAL IN =     1777065.2500              TOTAL IN =        5849.1738

         OUT:                                      OUT:
         ----                                      ----
             STORAGE =      860090.3125               STORAGE =        2264.6077
       CONSTANT HEAD =      916104.8750         CONSTANT HEAD =        3582.3159
    SPECIFIED FLOWS =           0.0000       SPECIFIED FLOWS =           0.0000

           TOTAL OUT =     1776195.2500             TOTAL OUT =        5846.9238

            IN - OUT =         870.0000              IN - OUT =           2.2500

PERCENT DISCREPANCY =           0.05     PERCENT DISCREPANCY =          0.04

         TIME SUMMARY AT END OF TIME STEP 10 IN STRESS PERIOD 1
                   SECONDS     MINUTES      HOURS       DAYS        YEARS
                   -----------------------------------------------------------
  TIME STEP LENGTH 3.45600E+06  57600.      960.00      40.000     0.10951
STRESS PERIOD TIME 3.45600E+07 5.76000E+05  9600.0      400.00      1.0951
        TOTAL TIME 3.45600E+07 5.76000E+05  9600.0      400.00      1.0951

                           STRESS PERIOD NO.   2, LENGTH =   200.0000
                           ----------------------------------------------
                             NUMBER OF TIME STEPS =     4
                              MULTIPLIER FOR DELT =     1.000
                           INITIAL TIME STEP SIZE =   50.00000
```

```
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 4 IN STRESS PERIOD 2
 ---------------------------------------------------------------------------
    CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
    ------------------                 ------------------------
          IN:                                   IN:
          ---                                   ---
            STORAGE =           0.0000            STORAGE =           0.0000
      CONSTANT HEAD =           0.0000      CONSTANT HEAD =           0.0000
    SPECIFIED FLOWS =     2897313.0000    SPECIFIED FLOWS =        5446.2812

           TOTAL IN =     2897313.0000           TOTAL IN =        5446.2812

         OUT:                                  OUT:
         ----                                  ----
            STORAGE =     1284297.3750            STORAGE =        2075.0769
      CONSTANT HEAD =     1611474.1250      CONSTANT HEAD =        3367.9297
    SPECIFIED FLOWS =           0.0000    SPECIFIED FLOWS =           0.0000

          TOTAL OUT =     2895771.5000          TOTAL OUT =        5443.0068

           IN - OUT =        1541.5000           IN - OUT =           3.2744

PERCENT DISCREPANCY =           0.05     PERCENT DISCREPANCY =          0.06

         TIME SUMMARY AT END OF TIME STEP 4 IN STRESS PERIOD 2
                   SECONDS     MINUTES      HOURS       DAYS        YEARS
                   -----------------------------------------------------------
  TIME STEP LENGTH 4.32000E+06  72000.      1200.0      50.000     0.13689
STRESS PERIOD TIME 1.72800E+07 2.88000E+05  4800.0      200.00     0.54757
        TOTAL TIME 5.18400E+07 8.64000E+05  14400.      600.00      1.6427

                           STRESS PERIOD NO.   3, LENGTH =   400.0000
                           ----------------------------------------------
                             NUMBER OF TIME STEPS =     6
                              MULTIPLIER FOR DELT =     1.100
                           INITIAL TIME STEP SIZE =   51.84295

             HEAD IN LAYER 1 AT END OF TIME STEP 6 IN STRESS PERIOD 3
 -----------------------------------------------------------------------
        1     2     3     4     5     6     7     8     9    10
...............................................................
  1   7.22  6.78  6.25  5.70  5.12  4.54  3.94  3.31  2.67  2.00
  2   7.65  6.87  6.27  5.70  5.13  4.54  3.94  3.31  2.67  2.00
  3   7.22  6.78  6.25  5.70  5.12  4.54  3.94  3.31  2.67  2.00

 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 6 IN STRESS PERIOD 3
 ---------------------------------------------------------------------------

    CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
    ------------------                 ------------------------

          IN:                                   IN:
          ---                                   ---
            STORAGE =      284414.1875            STORAGE =        1836.9204
      CONSTANT HEAD =           0.0000      CONSTANT HEAD =           0.0000
    SPECIFIED FLOWS =     5352999.5000    SPECIFIED FLOWS =        8201.0176

           TOTAL IN =     5637413.5000           TOTAL IN =       10037.9375

         OUT:                                  OUT:
         ----                                  ----
            STORAGE =     1656061.7500            STORAGE =           0.0000
      CONSTANT HEAD =     3979498.7500      CONSTANT HEAD =       10050.3262
    SPECIFIED FLOWS =           0.0000    SPECIFIED FLOWS =           0.0000

          TOTAL OUT =     5635560.5000          TOTAL OUT =       10050.3262

           IN - OUT =        1853.0000           IN - OUT =         -12.3887

PERCENT DISCREPANCY =           0.03     PERCENT DISCREPANCY =         -0.12

         TIME SUMMARY AT END OF TIME STEP 6 IN STRESS PERIOD 3
                   SECONDS     MINUTES      HOURS       DAYS        YEARS
                   -----------------------------------------------------------
  TIME STEP LENGTH 7.21385E+06 1.20231E+05  2003.8      83.494     0.22859
STRESS PERIOD TIME 3.45600E+07 5.76000E+05  9600.0      400.00      1.0951
        TOTAL TIME 8.64000E+07 1.44000E+06  24000.      1000.0      2.7379
```