Documentation of a Computer Program (RES1) to Simulate Leakage from Reservoirs Using the Modular Finite-Difference Ground-Water Flow Model (MODFLOW)

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PREFACE

This report presents a computer program for simulating leakage resulting from the contraction and expansion of reservoir(s). The performance of this computer program has been tested in models of hypothetical and actual 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 originating office of any errors found in the report or in the computer program. Correspondence regarding the report or program should be sent to

> U.S. Geological Survey
> 375 South Euclid Avenue
> Tucson, Arizona 85719-6644

Copies of the computer program and test data sets on tape or diskette are available at cost of processing from

> U.S. Geological Survey
> National Water Information System
> 437 National Center
> Reston, Virginia 20192
> Telephone: (703) 648-5695

Reference to trade names, commercial products, manufacturers, or distributors in this manual constitutes neither endorsement by the U.S. Geological Survey nor recommendation for use.

pag V follows

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CONVERSION FACTORS

	Multiply	By	To obtain
	inch (in)	2.54	centimeter
	foot (ft)	0.3048	meter
	per foot (ft^{-1})	3.281	per meter
	foot per day (ft/d)	0.3048	meter per day
	foot squared per day (ft^2/d)	0.0329	meter squared per day
	cubic foot (ft^3)	0.0283	cubic meter

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By Jon P. Fenske[1], S.A. Leake[2], *and* David E. Prudic[3]

Abstract

A set of computer subroutines called the Reservoir Package (RES1) was developed for the U.S. Geological Survey three-dimensional finite-difference modular ground-water flow model, commonly referred to as MODFLOW. The Reservoir Package simulates leakage between a reservoir and an underlying ground-water system as the reservoir area expands and contracts in response to changes in reservoir stage. The Reservoir Package also automates the process of specifying head-dependent boundary cells during the simulation. For each time step, all cells for which the reservoir stage is above the reservoir land-surface elevation are simulated as active reservoir cells. Leakage between the reservoir and the underlying ground-water system is simulated for each active reservoir cell by multiplying the difference between the reservoir stage and the ground-water head by the hydraulic conductance of the reservoir bed. The package uses linear interpolation to calculate reservoir stage for each time step within a stress period. Other input requirements include the areal distributions of the following items: model cells subject to inundation by each reservoir, model layer number to which each active reservoir cell is connected, land-surface elevation of the reservoir bottom, and vertical hydraulic conductivity and thickness of the reservoir bed. Starting and ending reservoir stage are required input data for each model stress period.

INTRODUCTION

The Reservoir Package (RES1) is a set of computer subroutines developed for the U.S. Geological Survey (USGS) three-dimensional finite-difference modular ground-water flow model, which is commonly referred to as MODFLOW (McDonald and Harbaugh, 1988). RES1 automates the process of specifying head-dependent flow boundary cells used to simulate leakage between a reservoir and a ground-water system as the reservoir area expands and contracts in response to reservoir stage.

Numerical models can provide an efficient means of analyzing water exchange between surface water and ground water. Ground-water flow models used to quantify flow between a reservoir and a ground-water system typically use a specified head to represent the average reservoir stage. Reservoir stage, however, can have short-term changes not readily simulated with the use of specified heads. If these short-term changes are ignored, calculated ground-water fluxes may be unreliable. Transient reservoir-stage fluctuations can be simulated using a head-dependent flux boundary, such as the River Package (McDonald and Harbaugh,

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1988, chap. 6). The River Package calculates flow to or from the adjoining ground-water system as a linear function dependent on the difference in head between surface water and ground water, and a hydraulic-conductance term. As stage rises in reservoirs, however, a spreading out of the impoundment occurs. Thus, leakage to or from a reservoir is dependent on stage and area of inundation. This change in area can be accounted for in the River Package manually by determining the inundated area for selected stress periods and then specifying head-dependent boundaries for cells corresponding to the inundated area. The accuracy of this method is dependent on the number of stress periods used to simulate changes in reservoir stage. RES1 overcomes these limitations. The package also reduces the number of stress periods needed to simulate changing reservoir stage by using linear variation of reservoir stage during a stress period.

CONCEPTUALIZATION OF RESERVOIR PACKAGE (RES1)

RES1 is designed for cases where reservoirs are much greater in area than the area represented by individual model cells. More than one reservoir can be simulated using RES1. The area subject to inundation by each reservoir is specified by entering the reservoir number for selected cells in a data array (fig. 1). For reservoirs that include two or more areas of lower elevation separated by areas of higher elevation, the filling of part of the reservoir may occur before spilling over to an adjacent area. The package can simulate this process by specifying two or more reservoirs in the area of a single reservoir.

EXPLANATION

▢0 MODEL CELL NOT SUBJECT TO INUNDATION FROM RESERVOIRS

■ MODEL CELL SUBJECT TO INUNDATION FROM RESERVOIRS—Number in cell is reservoir number entered in IRES array

Figure 1. Designation of maximum areal extent of reservoirs in a model grid.
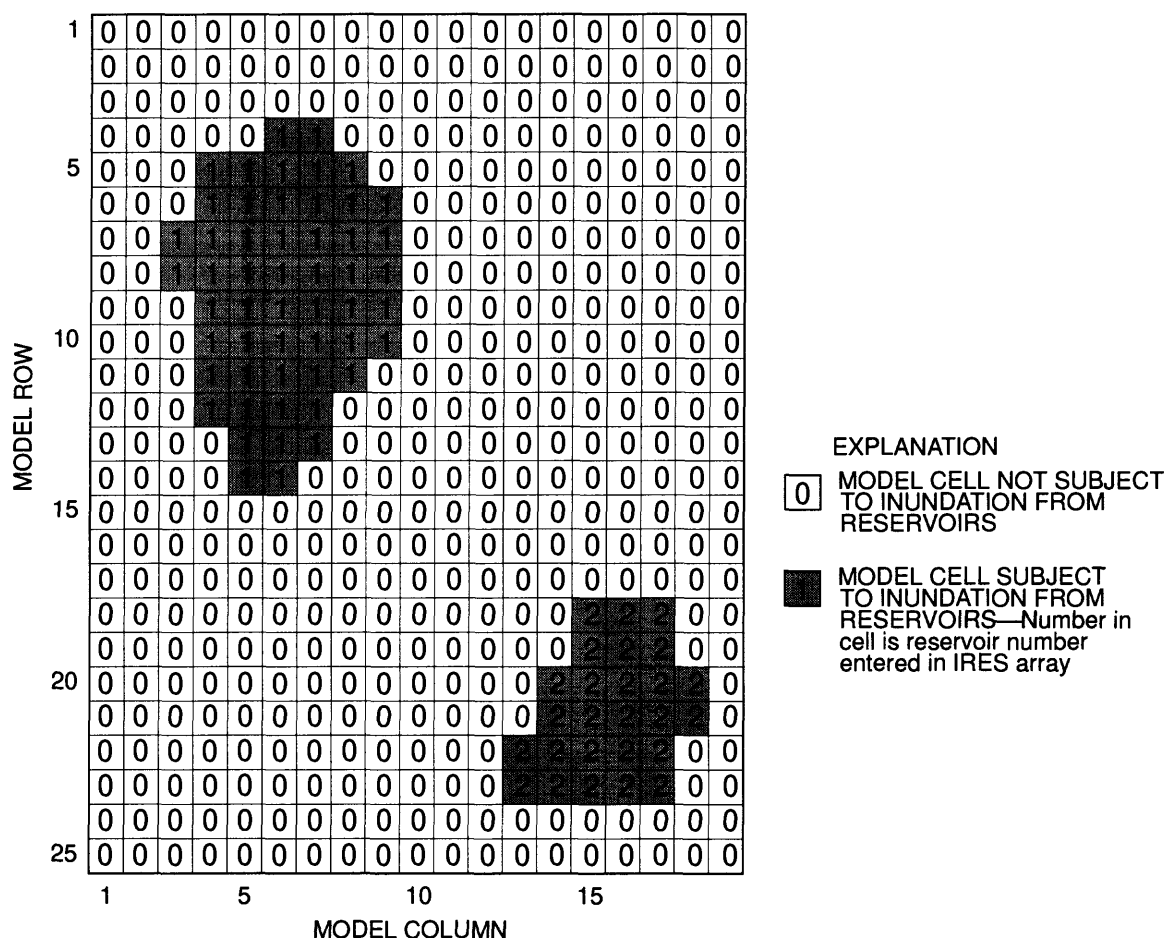
Input into RES1 includes: (1) an array representing the area of potential inundation, (2) reservoir stage at the beginning and end of each stress period, (3) land-surface elevation of the reservoir, (4) model layer, (5) hydraulic conductivity of the reservoir bed, and (6) thickness of the reservoir-bed sediments. In active cells, water exchange between surface water and ground water is computed in a manner identical to the MODFLOW River Package. RES1 is ideally suited for cases where leakage from or to reservoirs may be a significant component of flow in a ground-water system; however, if reservoir stage is unknown, then a more complex conceptualization would be needed in which reservoir stage would be computed as part of the simulation rather than having stage be specified as model input. For reservoirs where stage is unknown, a program that computes the stage in lakes based on inflows and outflows has been written by Cheng and Anderson (1993).

Reservoir stage is used to determine whether the reservoir boundary is activated for a model cell at the beginning of each time step. The reservoir stage for each time step is determined by linear interpolation using the starting and ending stages for the stress period (fig. 2). The interpolated reservoir stage corresponds with the simulation time at the end of a model time step. This approach is consistent with the backward-difference formulation of the finite-difference equations in MODFLOW (McDonald and Harbaugh, 1988, chap. 2, p. 16) and is consistent with the method of interpolation of head values in the Time-Variant Specified Head Package (Leake and Prudic, 1991). Because the interpolated stage corresponds to the value at the end of each time step, reservoir stage will never equal the starting stage for a stress period unless starting and ending stages are equal.
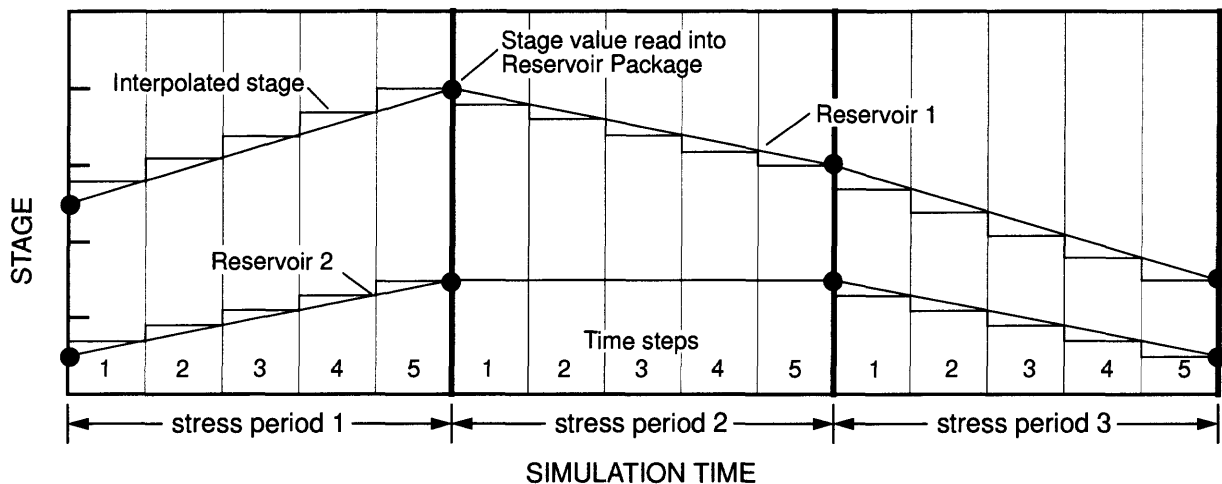
Figure 2. Interpolation of reservoir stages for individual time steps.

The land-surface elevation within the specified area of potential inundation for each reservoir typically is defined by the average land-surface elevation of individual cells within the area. At cells in which reservoir stage exceeds land-surface elevation within the specified reservoir area, the reservoir boundary is activated. Similarly, wherever reservoir stage is less than the land-surface elevation of a cell, the reservoir boundary is not activated. If reservoir stage drops below the lowest land-surface elevation for all cells within the specified reservoir area, water exchange is not simulated between the reservoir and the underlying ground-water system.

Two-dimensional arrays are read to specify areas of potential inundation of the reservoir, land-surface elevation of the reservoir, model-layer number, vertical hydraulic conductivity, and thickness of the reservoir-bed sediments. A single two-dimensional array is used to define each data item for all reservoirs. Values specified for cells that correspond to locations within areas of inundation are used, whereas values specified for cells outside areas of inundation are not used.

Three options are available for simulating leakage between a reservoir and underlying ground-water system using the same method described in the Recharge Package of MODFLOW (McDonald and Harbaugh, 1988, chap. 7). The first option simulates leakage only to layer 1; the second option simulates leakage to the uppermost active layer; and the third option simulates leakage to a specified model layer for each active reservoir-boundary cell (fig. 3). Inherent in the simulation of reservoirs is that the reservoir only partially penetrates an active model cell. If the reservoir fully penetrates a cell, it is assumed that the cell will be specified as no flow and that reservoir flow will be simulated in a lower cell. Thus, water exchange between the ground-water system and the reservoir takes place across the bottom of the reservoir and the top of the model cells.
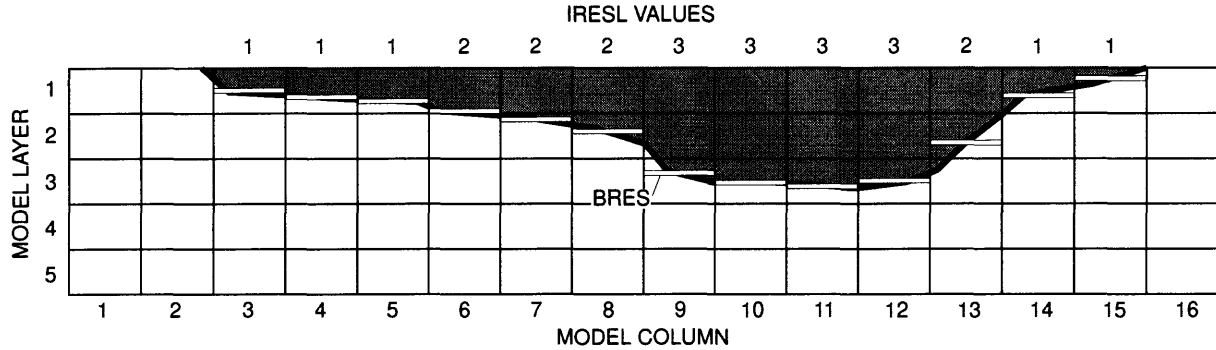
Figure 3. Specification of model layer using option (NRESOP=3) for which flow between reservoir and ground-water system occurs in selected layers. BRES is the land-surface elevation of the reservoir for each reservoir cell.

Leakage between the reservoir and the underlying ground-water system is simulated for each model cell corresponding to the inundated area by multiplying the head difference between the reservoir and the ground-water system by the hydraulic conductance of the reservoir bed. Hydraulic conductance of the reservoir bed ($CRES$) is given by:

$$CRES = \frac{HCres \times DELC(I) \times DELR(J)}{Rbthck},$$
(1)

where $HCres$ is vertical hydraulic conductivity of the reservoir bed (L/T), $DELC(I)$ is width of model row I (L), $DELR(J)$ is width of model column J (L), and $Rbthck$ is thickness of the reservoir-bed sediments (L). The calculation of hydraulic conductance of the reservoir-bed sediments for cell I, J is shown in figure 4. Values of hydraulic conductivity and thickness of the reservoir-bed sediments can be entered into RES1 as a single value to be applied to all reservoir cells or as a two-dimensional array. $CRES$ is computed in the program for each reservoir boundary cell using equation (1).

Reservoir-bed thickness is subtracted from the land-surface elevation of the reservoir to obtain the elevation of the base of the reservoir-bed sediments. The elevation of the base of the reservoir-bed sediments is used in computing leakage. When the head in the ground-water system is above the base of the reservoir-bed sediments, leakage from or to the ground-water system is computed by:

$$Qres = CRES(h_{res} - h_{gw}),$$
(2)

where Q_{res} is the leakage from the reservoir (L^3/T), h_{res} is reservoir stage (L), and h_{gw} is the ground-water head (L). When the head in the ground-water system is less than the elevation of the base of the reservoir-bed sediments, leakage from the reservoir to the ground-water system is computed by:

$$Qres = CRES(h_{res} - h_{resbot}),$$
(3)
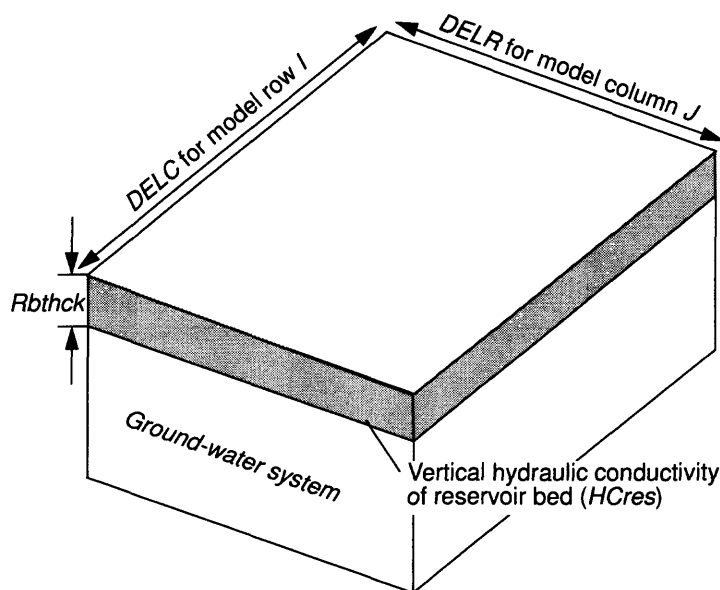
Hydraulic conductance
of reservoir bed (CRES)

$$CRES = \frac{HCres \times DELC \times DELR}{Rbthck}$$

Figure 4. Calculation of hydraulic conductance of reservoir bed (CRES) for model cell in row I and column J.

where h_{resbot} is the elevation of the base of the reservoir-bed sediments (L). Figure 5 illustrates the relation between leakage to and from a reservoir and head in the underlying ground-water system.

Formulation of equations (2) and (3) in the MODFLOW finite-difference equations for active reservoir cells is identical to formulation for river cells (McDonald and Harbaugh, 1988, chap. 6). Reservoir stage is analogous to river head, hydraulic conductance of the reservoir bed is analogous to riverbed conductance, and the elevation at the base of the reservoir-bed sediments is analogous to riverbed bottom. For details on the formulation in the MODFLOW program, see McDonald and Harbaugh (1988, chap. 6).

At the start of a simulation, RES1 calculates and prints values of surface area and volume for a selected number of reservoir stages for each reservoir. The relations of reservoir area and volume to reservoir stage are not used explicitly in the simulation; however, the relations are useful in comparison of simulated reservoir design with actual relations from reservoir design data. Reservoir stages are assigned in equal increments from lowest to highest land-surface elevations specified for a reservoir. For cells in which stage is above the land-surface elevation, the area of the cell is computed as the product of the model-cell dimensions. Areas for individual inundated cells are summed to compute total reservoir surface area. For the same cells, reservoir volume is computed as the sum of the product of cell area and depth of water (difference between reservoir stage and land-surface elevation).

APPLICABILITY AND LIMITATIONS

The conceptual design of RES1 is similar to that of the MODFLOW River Package; therefore, many of the assumptions and limitations that apply to the River Package also apply to RES1. Three major assumptions apply to both packages. First, water exchange between a river or reservoir and an underlying ground-water system is assumed to be instantaneous. Second, flow between a river or reservoir and a
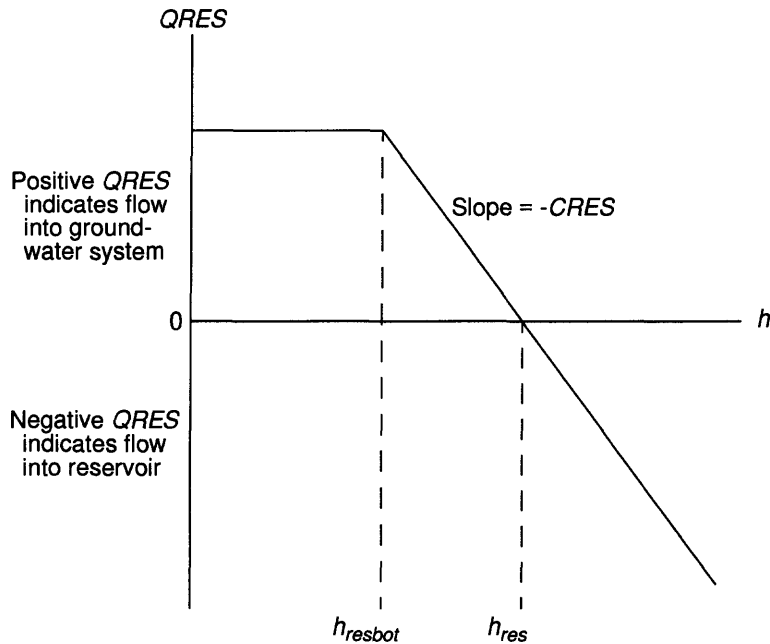
Figure 5. Relation between flow to or from reservoir ($QRES$) and head in the underlying ground-water system (h). H_{res} represents reservoir stage and h_{resbot} represents elevation at base of the reservoir-bed sediments. Modified from McDonald and Harbaugh (1988, chap. 6, p. 9).

ground-water system does not significantly affect river or reservoir stage. The River Package and RES1 operate by specifying stage and neither package accounts for surface-water budgets. In contrast, the Stream Package (Prudic, 1989) and the Lake Package (Cheng and Anderson, 1993) account for inflow to and outflow from streams and lakes, respectively. Third, head in a model cell below a reservoir is representative of head at the base of the reservoir-bed sediments.

In addition to the three general assumptions, RES1 has six assumptions or limitations that do not necessarily apply to the River Package. First, changes in reservoir stage are transmitted instantly across the reservoir. Implied in this assumption is that the water surface in a reservoir has no slope. Second, head-dependent flow boundaries are specified for all cells having a land-surface elevation less than the reservoir stage regardless of areas of higher land-surface elevations that separate areas of lower elevations. This assumption may be unreasonable for reservoirs in which the land-surface elevation of the reservoir bottom is uneven and where parts of the reservoir fill before spilling into adjacent lower-lying areas. These reservoirs can be simulated as two or more reservoirs. Third, for any reservoir cell, the hydraulic conductance of the reservoir bed is constant. Water exchange takes place only across the horizontal faces of model cells. Model cells should be small in relation to the sizes of reservoirs so that the shape of the reservoir can be reasonably approximated by a combination of rectangular areas. Fourth, when reservoir stage drops below the lowest land-surface elevation of the reservoir, the reservoir is no longer active, and leakage from the ground-water system to the reservoir is not simulated. Furthermore, leakage from a ground-water system to a reservoir can occur only in the area inundated by the reservoir. Fifth, RES1 operates independently of other stress packages such as the River, Recharge, and Evapotranspiration Packages. If these packages are active for cells in a reservoir area, the processes will be simulated regardless of whether or not the cells are inundated by the reservoir. Finally, rivers that enter or leave a reservoir are not part of RES1. Thus, if a reservoir is completely drained during a model simulation, the reservoir will not simulate leakage between the river and the ground-water system.

EXAMPLE PROBLEM

Background

A test problem illustrates the use of RES1 and shows the comparison of results between RES1 and the River package. The test problem uses a model grid consisting of one layer, 12 rows, and 12 columns (fig. 6). Cell dimensions in the horizontal directions are 100 ft on each side. The shaded area in figure 6 represents the area of potential inundation behind a dam and is defined by nonzero values in the IRES array. For the
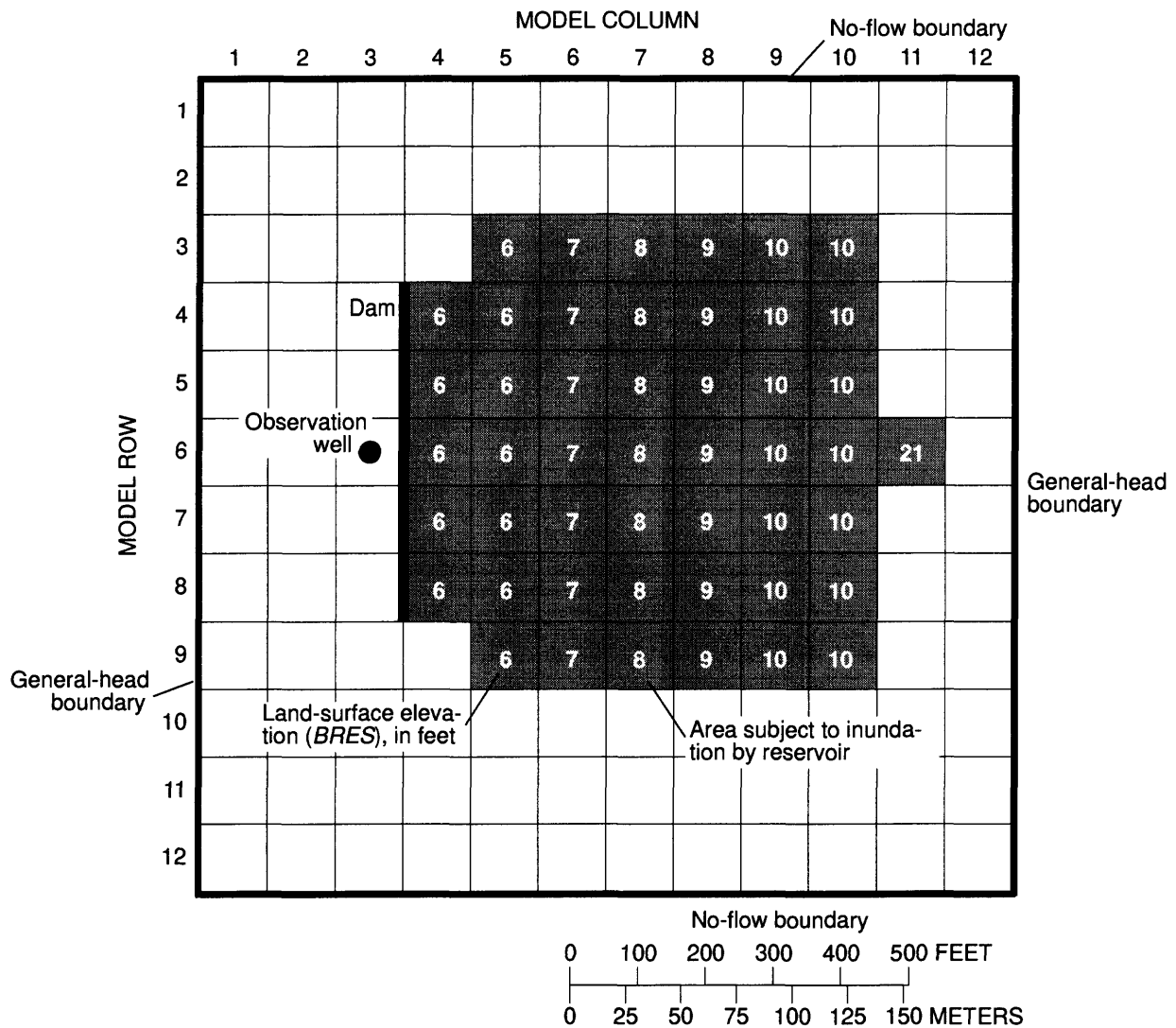
Figure 6. Model grid used in example problem.

example problem, the ground-water system is homogeneous and isotropic and has a transmissivity of 10,000 ft²/d and a storage coefficient (specific yield) of 0.20. The thickness of reservoir-bed sediments is 2 ft. The vertical hydraulic conductivity of the reservoir-bed sediments is 1 ft/d. The combination of reservoir-bed hydraulic conductivity, thickness, and cell area results in a reservoir-bed hydraulic conductance of 5,000 ft²/d for each cell in the area subject to inundation by the reservoir. The land-surface elevation in the area subject to inundation increases along rows from a minimum of 6 ft in column 4 to a maximum

of 10 ft in column 10 (fig. 6). An additional reservoir cell in column 11 with a land-surface elevation of 21 ft was included to allow RES1 to compute design characteristics over the range from 6 to 21 ft. The cell has no effect on calculations of flow between the reservoir and the ground-water system because the maximum stage for the simulation is 14 ft. Recharge from precipitation and evapotranspiration were assumed to be negligible for this problem. The General-Head Boundary Package (McDonald and Harbaugh, 1988, chap. 11) was used to represent flow along the outside edges of columns 1 and 12 and flow was not allowed to cross the boundaries along the outside edges of rows 1 and 12 (fig. 6). Initial ground-water levels were set at zero throughout the modeled area. Initially, the impoundment area is specified to be dry and a flood results in the reservoir filling for 7 days (fig. 7). The problem simulates transient flow for a total of 9 days. Three stress periods were used to represent the flood with 1-day time steps.
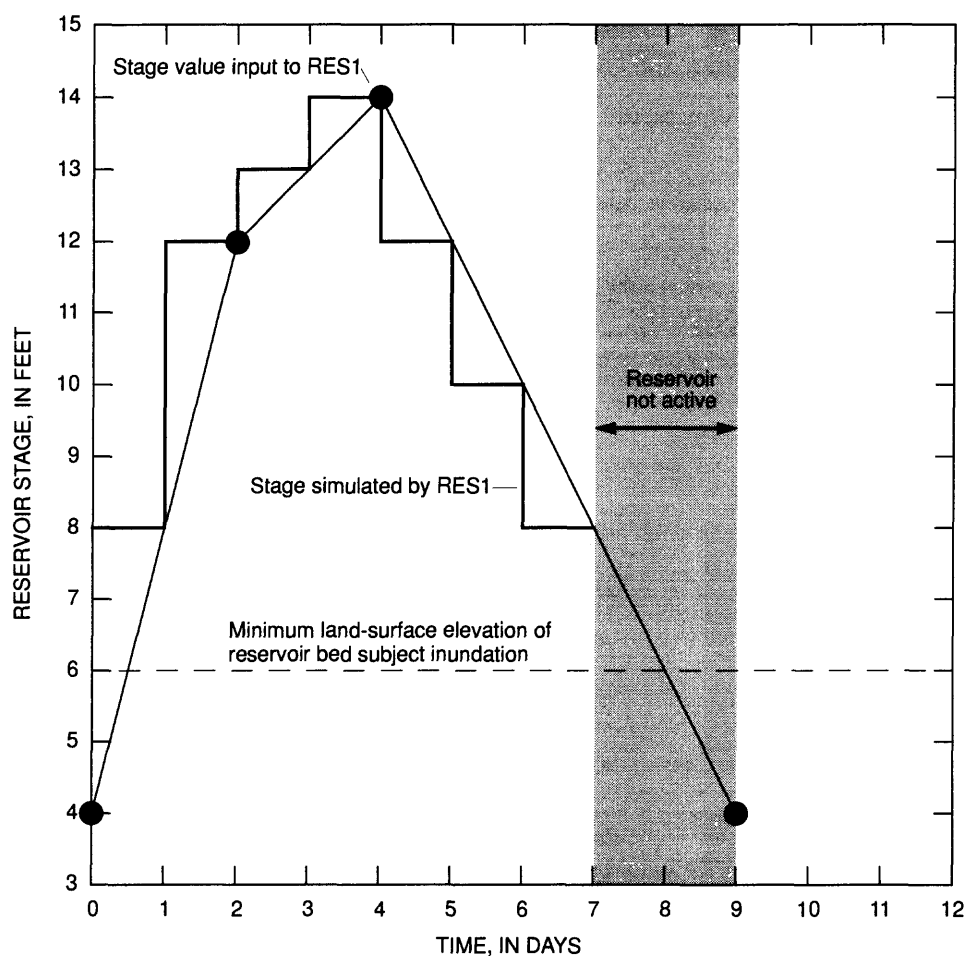
Figure 7. Reservoir stage for simulated flood. Stage was defined using three stress periods.

Results

The relations between reservoir stage and reservoir surface area and volume are shown in figure 8. Such information is useful for comparison with the design characteristics of a reservoir. In the simulation, head in the observation well, which is shown in figure 6, increases for 5 days with a peak water level occurring 1 day after the peak reservoir stage (fig. 9A). Net leakage from the reservoir to the ground-water system increases for 2 days in response to the rapid increase in reservoir stage in relation to initial ground-water

levels (fig. 9B). Net leakage decreases after 2 days as ground-water levels rise beneath the reservoir. A small quantity of leakage to the reservoir is simulated during day 7. No leakage to the reservoir is simulated during the last 2 days because all reservoir-boundary cells are inactive. Ground-water levels beneath the reservoir, however, are above land surface in columns 4 through 6 (see fig. 6) during the last 2 days. The input data sets and output listing for the problem are given in the Appendix.
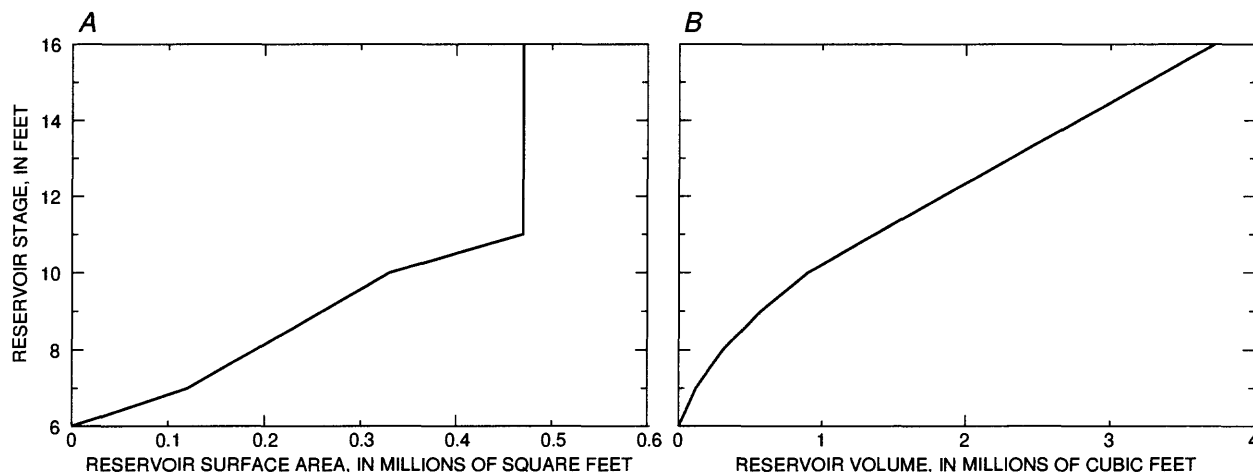
Figure 8. Surface area and volume of reservoir computed by the Reservoir Package (RES1). *A*, Relation between reservoir stage and surface area. *B*, Relation between reservoir stage and volume.

In addition to providing an example of the use of RES1, the example problem was used to test that results from RES1 are the same as results from the River Package for equivalent conditions. To simulate the same problem with the River Package, seven 1-day stress periods and one 2-day stress period were used. With riverbed conductances set at 5,000 ft²/d and appropriate river cells activated for each stress period, the simulation gave the same results as the simulation using RES1 (fig. 9). The example problem demonstrates that RES1 duplicates results obtained from the River Package. In addition, RES1 simplifies the simulation of water-exchange between ground-water systems and reservoirs that expand and (or) contract in response to reservoir stage. RES1 required only three stress periods to represent the flood depicted in figure 7, whereas the River Package required seven 1-day stress periods and one 2-day stress period. Furthermore, RES1 automatically activates and deactivates head-dependent reservoir flows at model cells. The River Package requires the manual activation and deactivation of the river reaches that represent reservoir leakage for each stress period. Additionally, RES1 allows for one value, or one array of values, to represent vertical hydraulic conductivity and thickness of the reservoir-bed sediments. The River Package requires that these values be entered for each active cell for each stress period.

IMPLEMENTATION OF RESERVOIR LEAKAGE IN THE GROUND-WATER MODEL

RES1 is designed for incorporation into the USGS three-dimensional finite-difference modular ground-water flow model (MODFLOW). The package consists of five FORTRAN subroutines (modules)—RES1AL, RES1RP, RES1AD, RES1FM, and RES1BD. The first three characters identify the modules as being part of RES1; the next character identifies the version number of the package; the last two characters identify the procedures performed in the module. The procedures used by RES1 are consistent with procedures used by existing packages in the ground-water flow model (table 1). RES1AL allocates
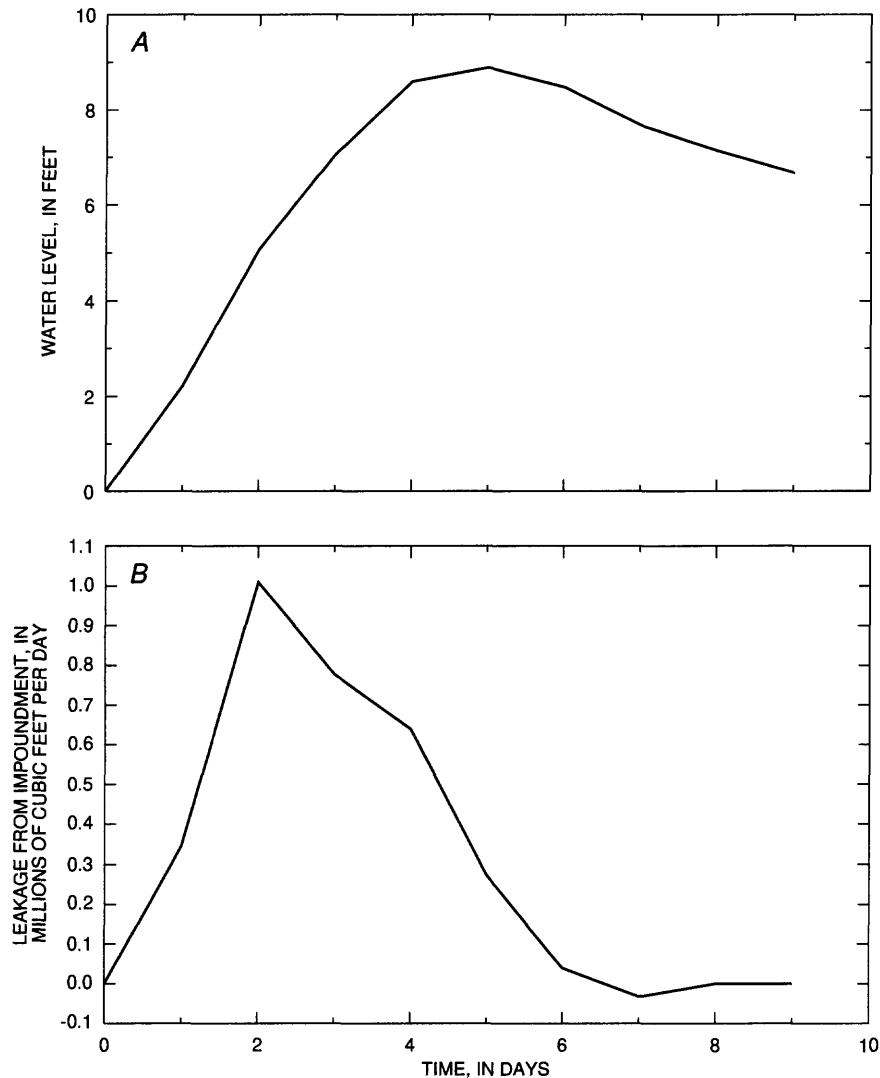
Figure 9. Results from example problem. *A*, Computed water level at location of observation well. *B*, Leakage from reservoir.

memory; RES1RP reads data and computes areas of inundation and impoundment volumes for a specified number of reservoir stages for each reservoir; RES1AD computes reservoir stage for the current time step; RES1FM formulates the finite-difference equations; and RES1BD computes a volumetric budget for each reservoir and prints results.

The MAIN program of the ground-water flow model must be modified to call the five modules of RES1. Call statements to the modules of RES1 must be placed in sections of the MAIN program in which the particular procedure is being carried out for other packages. For example, the RES1AL module must be called within the section of the MAIN program in which other allocate modules (for example BAS1AL, RIV1AL) are called. In all sections of the MAIN program, the call to the Basic (BAS1) Package module (subroutine) must come before any other module call statements. The authors have selected IUNIT (17) 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 RES1AL module after comment C4 and within the group of statements that calls BCF1AL, WEL1AL, DRN1AL, and other space-allocation modules:

```
      IF(IUNIT(17).GT.0) CALL RES1AL(ISUM,LENX,LCIRES,LCIRSL,LCBRES,
     1  LCCRES,LCBBRE,LCHRES,LCHRSE,IUNIT(17),IOUT,NRES,IRESCB,
     2  NRESOP,IRESPT,NPTS,NCOL,NROW)
```

Add a new call statement for the RES1RP module after comment C7B and within the group of statements that calls the WEL1RP, DRN1RP, RCH1RP, and other read and prepare modules:

```
      IF(IUNIT(17).GT.0) CALL RES1RP(X(LCIRES),X(LCIRSL),X(LCBRES),
     1    X(LCCRES),X(LCBBRE),X(LCHRSE),X(LCIBOU),X(LCDELR),X(LCDELC),
     2    NRES,NRESOP,NPTS,NCOL,NROW,NLAY,PERLEN,DELT,NSTP,TSMULT,
     3    IUNIT(17),IOUT)
```

Add a new call statement for the RES1AD module after the statement that calls the BAS1AD module:

```
      IF(IUNIT(17).GT.0) CALL RES1AD(X(LCHRES),X(LCHRSE),X(LCIRES),
     1 X(LCBRES),X(LCDELR),X(LCDELC),NRES,IRESPT,NCOL,NROW,
     1      PERLEN,PERTIM,TOTIM,KKSTP,KKPER,IOUT)
```

Add a new call statement for the RES1FM module after comment C7C2A and within the group of statements that call BCF1FM, WEL1FM, DRN1FM, and other formulation modules:

```
      IF(IUNIT(17).GT.0) CALL RES1FM(X(LCIRES),X(LCIRSL),X(LCBRES),
     1    X(LCCRES),X(LCBBRE),X(LCHRES),X(LCIBOU),X(LCHNEW),X(LCHCOF),
     2    X(LCRHS),NRES,NRESOP,NCOL,NROW,NLAY)
```

Add a new call statement for the RES1BD module after comment C7C4 and within the group of statements that call BCF1BD, WEL1BD, DRN1BD, and other budget modules:

```
      IF(IUNIT(17).GT.0) CALL RES1BD(X(LCIRES),X(LCIRSL),X(LCBRES),
     1      X(LCCRES),X(LCBBRE),X(LCHRES),X(LCIBOU),X(LCHNEW),
     2      X(LCBUFF),VBVL,VBNM,MSUM,KSTP,KPER,NRES,NRESOP,
     3      NCOL,NROW,NLAY,DELT,IRESCB,ICBCFL,IOUT)
```

If desired, another IUNIT element can be used rather than 17. To do this, change all above references to IUNIT(17) to the new value.

Table 1. Primary modules of MODFLOW organized by procedure and package (modified from McDonald and Harbaugh, 1988, fig. 15)

Procedure	Packages										
	BAS1	BCF1	WEL1	RCH1	RIV1	DRN1	EVT1	GHB1	SIP1	SOR1	RES1
Define (DF)	BAS1DF										
Allocate (AL)	BAS1AL	BCF1AL	WEL1AL	RCH1AL	RIV1AL	DRN1AL	EVT1AL	GHB1AL	SIP1AL	SOR1AL	RES1AL
Read and prepare (RP)	BAS1RP	BCF1RP							SIP1RP	SOR1RP	
Stress (ST)	BAS1ST										
Read and prepare (RP)			WEL1RP	RCH1RP	RIV1RP	DRN1RP	EVT1RP	GHB1RP			RES1RP
Advance (AD)	BAS1AD										RES1AD
Formulate (FM)	BAS1FM	BCF1FM	WEL1FM	RCH1FM	RIV1FM	DRN1FM	EVT1FM	GHB1FM			RES1FM
Approximate (AP)									SIP1AP	SOR1AP	
Output Control (OC)	BAS1OC										
Budget (BD)		BCF1BD	WEL1BD	RCH1BD	RIV1BD	DRN1BD	EVT1BD	GHB1BD			RES1BD
Output (OT)	BAS1OT										

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INPUT INSTRUCTIONS

Input for RES1 is read from the IUNIT(17), specified in the Basic Package input (McDonald and Harbaugh, 1988, chap. 4, p. 9–11).

FOR EACH SIMULATION

RES1AL

1. Data:	NRES	IRESCB	NRESOP	IRESPT	NPTS
Format:	I10	I10	I10	I10	I10

RES1RP

2. Data:	IRES(NCOL,NROW)	
Module:	U2INT	

IF NRESOP DOES NOT EQUAL 2, SKIP DATA ITEM 3

3. Data:	IRESL(NCOL,NROW)	
Module:	U2DINT	

4. Data:	BRES(NCOL,NROW)	
Module:	U2DREL	

5. Data:	HCres(NCOL,NROW)	
Module:	U2DREL	

6. Data:	Rbthck(NCOL,NROW)	
Module:	U2DREL	

FOR EACH STRESS PERIOD
FOR EACH OF NRES RESERVOIRS

7. Data:	Ststage	Endstage
Format:	I10	I10

Explanation of Fields Used in Input Instructions

NRES   is the number of reservoirs to be simulated. The minimum number of reservoirs that can be simulated is one and the maximum number is the number of active cells in the model grid.

IRESCB   is a flag and unit number.

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

NRESOP   is a flag to determine the layer to which reservoirs are connected.

    If IRESOP = 1   all reservoirs are connected to layer 1.

	If IRESOP = 2	all reservoirs are connected to layer specified in array IRESL.
	If IRESOP = 3	all reservoirs are connected to the highest active cell in the vertical column of cells at each reservoir location.
IRESPT	is a flag.	
	If IRESPT > 0	reservoir stage, area, and volume will be printed each time step.
	If IRESCB ≤ 0	reservoir stage, area, and volume will not be printed each time step.

NPTS is the number of values in printed table of stage, volume, and area for each reservoir. First and last stage value are minimum and maximum elevations within area of potential inundation. A value of 15 or greater is recommended for detailed representation of stage-volume and stage-area relations.

IRES is an array that specifies the model cells that are included in each reservoir. Array values of "0" or less indicate the absence of reservoirs at corresponding cell locations. Values greater than "0" indicate that the cell is part of the corresponding reservoir. For example, values of "1" indicate the location of the first of NRES reservoirs and values of "2" indicate the location of the second of NRES reservoirs.

IRESL is an array that specifies the model layer to which each reservoir cell is connected.

BRES is an array that specifies land-surface elevation for all reservoirs. Values in the array are assigned to the reservoir denoted by the corresponding element in the IRES array. Values are not used for cells where the corresponding element in the IRES array is less than or equal to zero.

HCres is an array that specifies vertical hydraulic conductivity of the reservoir bed for all reservoirs. Values in the array are assigned to the reservoir denoted by the corresponding element in the IRES array. Values are not used for cells where the corresponding element in the IRES array is less than or equal to zero.

Rbthck is an array that specifies thickness of reservoir-bed sediments for all reservoirs. Values in the array are assigned to the reservoir denoted by the corresponding element in the IRES array. Values are not used for cells where the corresponding element in the IRES array is less than or equal to zero.

Ststage is the value of reservoir stage at the start of the stress period. Because the package assigns stage values on the basis of linear interpolation to the end of each time step, the assigned reservoir stage will never equal Ststage unless Ststage and Endstage are equal. A total of NRES records with values of Ststage and Endstage are read at the start of each stress period.

Endstage is the value of reservoir stage at the end of the stress period. Endstage is the value that will be assigned as stage for the corresponding reservoir for the last time step in the stress period.

PROGRAM OUTPUT

Output from RES1 consists of printed output and information recorded to a disk or another storage device. At the start of each simulation, RES1 prints tables of relations between reservoir stage, surface area, and volume. Furthermore, if a value greater than zero is selected for the variable IRESPT, RES1 will print stress period, time step, simulation time, reservoir stage, area, and volume for each reservoir at every time step. The printed output also includes rates and volumes of flow to or from reservoirs 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 or 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 RES1 are denoted with the label "RESERV. LEAKAGE." If a value greater than zero is specified for IRESCB, RES1 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. A value of zero is recorded for cells that are not connected to an active reservoir-boundary cell for the current time step. The sign convention for nonzero values is that positive quantities denote flow from a reservoir into the ground-water system and negative quantities denote flow into a reservoir from the ground-water system. The header record for the unformatted arrays includes the label "RESERV. LEAKAGE."

MODULE DOCUMENTATION

RES1 contains five modules (subroutines). Each module 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 Reservoir Leakage in the Ground-Water Model" (p. 11). The modules in RES1 are

RES1AL   Reads package options and flags and allocates space for data arrays.

RES1RP   Reads data arrays; prints tables of reservoir stage, area, and volume; and reads starting and ending reservoir stage for each stress period.

RES1AD   Computes reservoir stage for current time step and prints value of reservoir stage, surface area, and volume.

RES1FM   Formulates terms for the finite-difference equations and adds terms to the model flow equation through the head-coefficient array (HCOF) and to the right-hand-side array (RHS).

RES1BD   Computes flow rates between the ground-water system and all reservoirs 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, RES1 uses the Advance procedure (AD) to calculate the reservoir stage at each time step.

RES1AL

Narrative for Module RES1AL

This module reads package options and flags and allocates space in the X array (McDonald and Harbaugh, 1988, chap. 3, p. 22–23) for arrays in RES1. Operations are carried out in the following order:

1. Print a message identifying the package.

2. Read number of reservoirs, NRES; unit number for cell-by-cell flow terms, IRESCB; reservoir-layer option flag, NRESOP; reservoir print flag, IRESPT, and NPTS, the number of points in stage-volume-area tables. Verify that all values read are legitimate and print informative messages.

3. Allocate storage for the following arrays:
   IRES   Indicator array showing areal extent of each reservoir,
   IRESL   Number of model layer to which each reservoir cell is connected,
   BRES   Elevation of bottom of reservoirs,
   CRES   Reservoir-bed conductance,
   BBRES   Elevation of base of reservoir bed,
   HRES   Stage for each reservoir for current time step,
   HRESSE   Starting and ending stage for each reservoir for current stress period.

4. Calculate and print the amount of space used by RES1.

5. RETURN.

Flowchart for Module RES1AL

NRES is the number of reservoirs.
IRESCB is the unit number for cell-by-cell flow terms.
NRESOP is the reservoir-layer option flag.
    = 1, reservoirs are connected to layer 1.
    = 2, reservoirs are connected to layer specified in array IRESL.
    = 3, reservoirs are connected to the highest active cell in the vertical column of cells at each reservoir location.
IRESPT is the reservoir print flag.
    > 0, reservoir stage, area, and volume will be printed each time step.
    ≤ 0, reservoir stage, area, and volume will not be printed each time step.
NPTS is the number of lines in tables of volume and area.

```
      ( ENTER RES1AL )
             |
             v
   +------------------------+
   | Print a message        | 1
   | identifying this package|
   +------------------------+
             |
             v
   +------------------------+
   | Read and print values  |
   | of NRES, IRESCB,       | 2
   | NRESOP, IRESPT,        |
   | and NPTS               |
   +------------------------+
             |
             v
   +------------------------+
   | Allocate space for     | 3
   | arrays                 |
   +------------------------+
             |
             v
   +------------------------+
   | Print space used       | 4
   +------------------------+
             |
             v
      (    RETURN    ) 5
```
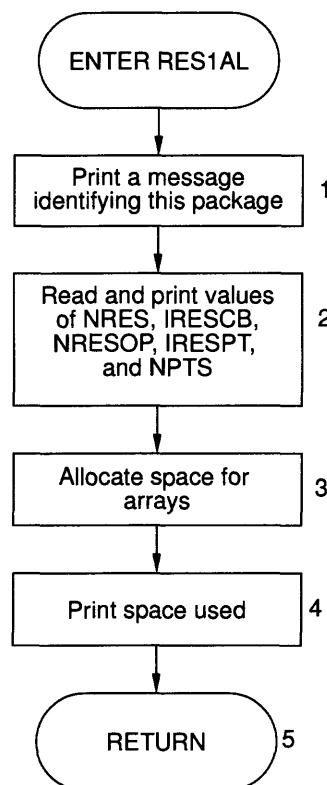
Program Listing for Module RES1AL

```
            SUBROUTINE RES1AL(ISUM,LENX,LCIRES,LCIRSL,LCBRES,LCCRES,LCBBRE,
     1      LCHRES,LCHRSE,IN,IOUT,NRES,IRESCB,NRESOP,IRESPT,
     2      NPTS,NCOL,NROW)
C
C-----VERSION 1700 20JUN1996 RES1AL
C     ****************************************************************
C     ALLOCATE ARRAY STORAGE FOR RESERVOIRS
C     ****************************************************************
C
C     SPECIFICATIONS:
C     ----------------------------------------------------------------
C     ----------------------------------------------------------------
C
C1------IDENTIFY PACKAGE AND INITIALIZE
        WRITE(IOUT,1) IN
      1 FORMAT(1H0,'RES1 -- RESERVOIR PACKAGE, VERSION 1, 1/15/95',
     1' INPUT READ FROM UNIT',I3)
C
C2------READ & PRINT NUMBER OF RESERVOIRS AND FLAGS FOR
C2------RESERVOIR OPTIONS
        READ(IN,2) NRES,IRESCB,NRESOP,IRESPT,NPTS
      2 FORMAT(5I10)
C
C2A-----CHECK TO SEE THAT NUMBER OF RESERVOIRS IS AT LEAST 1,
C2A-----PRINT VALUE
        IF(NRES.GT.0) THEN
          WRITE(IOUT,6) NRES
      6 FORMAT(1X,'TOTAL NUMBER OF RESERVOIRS: ',I3)
        ELSE
          WRITE (IOUT,7)
      7 FORMAT(1X,'ABORTING, NUMBER OF RESERVOIRS LESS THAN 1...')
        STOP
        ENDIF
C
C2B-----CHECK FLAG FOR CELL-BY-CELL OUTPUT, PRINT VALUE
        IF(IRESCB.GT.0) WRITE(IOUT,10) IRESCB
   10    FORMAT(1X,'CELL-BY-CELL FLOWS WILL BE RECORDED ON UNIT',I3)
C2C-----CHECK TO SEE THAT RESERVOIR LAYER OPTION FLAG IS LEGAL,
C2C-----PRINT VALUE
        IF(NRESOP.GE.1.AND.NRESOP.LE.3)GO TO 200
C
C2C1----IF ILLEGAL PRINT A MESSAGE AND ABORT SIMULATION
        WRITE(IOUT,8)
      8 FORMAT(1X,'ILLEGAL OPTION CODE. SIMULATION ABORTING')
        STOP
C
C2C2----IF OPTION IS LEGAL PRINT OPTION CODE.
  200   IRK=ISUM
        IF(NRESOP.EQ.1) WRITE(IOUT,201)
  201 FORMAT(1X,'OPTION 1 -- RESERVOIR CONNECTED TO TOP LAYER')
        IF(NRESOP.EQ.2) WRITE(IOUT,202)
  202 FORMAT(1X,'OPTION 2 -- RESERVOIR CONNECTED TO ONE SPECIFIED',
     1          ' NODE IN EACH VERTICAL COLUMN')
```

```
      IF(NRESOP.EQ.3) WRITE(IOUT,203)
  203 FORMAT(1X,'OPTION 3 -- RESERVOIR CONNECTED TO HIGHEST',
     1          ' ACTIVE NODE IN EACH VERTICAL COLUMN')
C
C2D-----PRINT VALUE FOR RESERVIOR PRINT OPTION FLAG
      IF(IRESPT.GT.0) WRITE(IOUT,14)
  14    FORMAT(1X,'RESERVOIR HEADS, AREAS, AND VOLUMES '
     1 'WILL BE PRINTED EACH TIME STEP')
C2E-----PRINT NUMBER OF POINTS TO BE USED IN CALCULATING TABLE
C2E-----OF RESERVOIR STAGE VS. AREA AND VOLUME
      IF(NPTS.LT.1) THEN
       WRITE(IOUT,*) ' Table of reservoir areas and volumes ',
     1 'will not be calculated.'
      ELSE
       WRITE(IOUT,9) NPTS
  9     FORMAT(I5,' points will be used in constructing table of '
     1 'reservoir areas and volumes.')
      ENDIF
C
C3------ALLOCATE SPACE FOR ARRAYS.
      LCRESR=ISUM
      NRCL=NROW*NCOL
      LCIRES=ISUM
      ISUM=ISUM+NRCL
      LCIRSL=ISUM
      IF(NRESOP.NE.2)GO TO 300
      ISUM=ISUM+NRCL
  300 LCBRES=ISUM
      ISUM=ISUM+NRCL
      LCCRES=ISUM
      ISUM=ISUM+NRCL
      LCBBRE=ISUM
      ISUM=ISUM+NRCL
      LCHRES=ISUM
      ISUM=ISUM+NRES
      LCHRSE=ISUM
      ISUM=ISUM+NRES+NRES
      ISP=ISUM-LCRESR
C
C4------PRINT AMOUNT OF SPACE USED BY RESERVOIR PACKAGE.
      WRITE (IOUT,30)ISP
  30    FORMAT(1X,I8,' ELEMENTS IN X ARRAY ARE USED FOR RESERVOIRS')
      ISUM1=ISUM-1
      WRITE(IOUT,40)ISUM1,LENX
  40    FORMAT(1X,I8,' ELEMENTS OF X ARRAY USED OUT OF',I8)
      IF(ISUM1.GT.LENX) WRITE(IOUT,50)
  50    FORMAT(1X,'   ***X ARRAY MUST BE DIMENSIONED LARGER***')
C
C5------RETURN
      RETURN
      END
```

List of Variables for Module RES1AL

Variable	Range	Definition
IN	Package	Primary unit number from which input from this package will be read.
IOUT	Global	Primary unit number for all printed output.
IRESCB	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 printed.
IRESPT	Package	Print flag:
		> 0 Reservoir stage, area, and volume will be printed each time step.
		≤ 0 Reservoir stage, area, and volume will not be printed each time step.
ISP	Module	Number of elements in the X array allocated by this package.
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
LCBBRE	Package	Location in the X array of the first element of array BBRES.
LCBRES	Package	Location in the X array of the first element of array BRES.
LCCRES	Package	Location in the X array of the first element of array CRES.
LCHRES	Package	Location in the X array of the first element of array HRES.
LCHRSE	Package	Location in the X array of the first element of array HRESSE.
LCIRES	Package	Location in the X array of the first element of array IRES.
LCIRSL	Package	Location in the X array of the first element of array IRESL.
LENX	Global	Number of elements in the X array. Value should always equal the dimension of the X array specified in the MAIN program.
NCOL	Global	Number of columns in the model grid.
NRCL	Module	Number of cells in each model layer.
NRES	Package	Number of reservoirs.
NRESOP	Package	Reservoir-option flag:
		$= 1$ Reservoirs are connected to layer 1.
		$= 2$ Reservoirs are connected to layer specified in array IRESL.
		$= 3$ Reservoirs are connected to the highest active cell in the vertical column of cells at each reservoir location.
NROW	Global	Number of rows in the model grid.

RES1RP

Narrative for Module RES1RP

This module reads arrays specifying areal extent subject to inundation, layer numbers to which reservoir cells are connected, land-surface elevation of reservoir, vertical hydraulic conductivity of reservoir-bed sediments, and thickness of reservoir-bed sediments. These arrays are read at the start of each simulation. Using the land-surface elevations and the areas of cells within each reservoir, the module computes tables of reservoir volume and area for a specified number of reservoir-stage values within the range of land-surface elevations. In addition to reading arrays at the start of a simulation, the module reads the starting and ending stage for each reservoir at the start of every stress period. Operations are carried out in the following order:

1. Read indicator array, IRES.

2. Count and print number of reservoir cells for each of NRES reservoirs. If no cells are specified for any reservoir, abort simulation.

3. If NRESOP is equal to 2, read IRESL, the array that specifies layer numbers to which reservoir cells are connected. Read two-dimensional arrays that specify land-surface elevations and reservoir-bed properties.

4. For all reservoir cells, subtract reservoir-bed thickness from land-surface elevation to get the elevation of the base of reservoir-bed sediments. Compute reservoir-bed conductance.

5. For each reservoir, make a table of reservoir volume and surface area for stage within the range of land-surface elevations.

6. For each reservoir, read reservoir stage at the start and end of the current stress period.

7. Compute the total length of the stress period, PERLEN.

8. RETURN.

Flowchart for Module RES1RP

```
        ╭─────────────────╮
        │   ENTER RES1RP  │
        ╰─────────────────╯
                 │
                 ▼
            ╱─────────╲              N
           ╱ First time ╲──────────────────────┐
           ╲  through   ╱                       │
            ╲    ?     ╱                         │
             ╲───────╱                           │
                 │ Y                             │
                 ▼                               │
        ┌─────────────────┐                      │
        │ Read indicator  │ 1                    │
        │ array, IRES     │                      │
        └─────────────────┘                      │
                 │                               │
                 ▼                               │
        ┌─────────────────┐                      │
        │ Count and print │ 2                    │
        │ number of       │                      │
        │ reservoir cells │                      │
        └─────────────────┘                      │
                 │                               │
                 ▼                               │
            ╱─────────╲      Y    ╭──────────╮   │
           ╱ Number of ╲──────────│   STOP   │   │
           ╲ reservoir ╱          ╰──────────╯   │
            ╲ cells = 0╱                         │
             ╲───?───╱                           │
                 │ N                             │
                 ▼                               │
            ╱─────────╲   3  Y  ┌──────────┐     │
           ╱ NRESOP=2  ╲────────│  Read    │     │
           ╲    ?      ╱        │  IRESL   │     │
            ╲─────────╱         └──────────┘     │
                 │ N                │            │
                 ▼◄─────────────────┘            │
        ┌─────────────────┐                      │
        │ Read BRES, CRES,│                      │
        │ and Rbthck      │                      │
        └─────────────────┘                      │
                 │                               │
                 ▼                               │
        ┌─────────────────┐                      │
        │ Compute         │ 4                    │
        │ conductance     │                      │
        │ and elevation   │                      │
        │ of base of      │                      │
        │ reservoir-bed   │                      │
        │ sediments       │                      │
        └─────────────────┘                      │
                 │                               │
                 ▼                               │
        ┌─────────────────┐                      │
        │ Make tables of  │ 5                    │
        │ surface area    │                      │
        │ and volume for  │                      │
        │ different       │                      │
        │ reservoir stages│                      │
        └─────────────────┘                      │
                 │                               │
                 └───────────────┐               │
                                 ▼◄──────────────┘
                        ┌─────────────────┐
                        │ Read reservoir  │ 6
                        │ stage at start  │
                        │ and end of      │
                        │ stress period   │
                        └─────────────────┘
                                 │
                                 ▼
                        ┌─────────────────┐
                        │ Compute PERLEN  │ 7
                        └─────────────────┘
                                 │
                                 ▼
                        ╭─────────────────╮
                        │     RETURN      │ 8
                        ╰─────────────────╯
```

FOR EACH RESERVOIR (applies to the left column loop)

FOR EACH RESERVOIR (applies to box 6)

IRES is an indicator array that shows areal distribution of each reservoir.

NRESOP is a layer-option flag:
   = 1, reservoirs are connected to layer 1.
   = 2, reservoirs are connected to layer specified in array IRESL.
   = 3, reservoirs are connected to the highest active cell in the vertical column of cells at each reservoir location.

IRESL is array that specifies layer number to which each reservoir cell is connected.

BRES is land-surface elevation of reservoir.

CRES is hydraulic conductance of reservoir bed.

Rbthck is reservoir-bed thickness.

PERLEN is length of current stress period.

Program Listing for Module RES1RP

```
                 SUBROUTINE RES1RP(IRES,IRESL,BRES,CRES,BBRES,HRESSE,IBOUND,
      1                           DELR,DELC,NRES,NRESOP,NPTS,NCOL,NROW,NLAY,
      2                           PERLEN,DELT,NSTP,TSMULT,IN,IOUT)
C
C
C-----VERSION 1700 27MAR1996 RES1RP
C     ****************************************************************
C     READ RESERVOIR LOCATIONS, LAYER, CONDUCTANCE, BOTTOM ELEVATION,
C      AND BED THICKNESS
C     ****************************************************************
C
C     SPECIFICATIONS:
C     ----------------------------------------------------------------
      CHARACTER*4 ANAME
      LOGICAL FIRST
      SAVE FIRST
      DIMENSION IRES(NCOL,NROW),IRESL(NCOL,NROW),BRES(NCOL,NROW),
     1 CRES(NCOL,NROW),BBRES(NCOL,NROW),HRESSE(2,NRES),
     2 IBOUND(NCOL,NROW,NLAY),ANAME(6,5),DELR(NCOL),DELC(NROW)
C
      DATA ANAME(1,1),ANAME(2,1),ANAME(3,1),ANAME(4,1),ANAME(5,1),
     1    ANAME(6,1) /'    ','  RE','SERV','OIR ','LOCA','TION'/
      DATA ANAME(1,2),ANAME(2,2),ANAME(3,2),ANAME(4,2),ANAME(5,2),
     1    ANAME(6,2) /'   R','ESER','VOIR',' LAY','ER I','NDEX'/
      DATA ANAME(1,3),ANAME(2,3),ANAME(3,3),ANAME(4,3),ANAME(5,3),
     1    ANAME(6,3) /'RESE','RVOI','R LA','ND S','URF ','ELEV'/
      DATA ANAME(1,4),ANAME(2,4),ANAME(3,4),ANAME(4,4),ANAME(5,4),
     1    ANAME(6,4) /'  RE','S. B','ED V','ERT ','HYD ','COND'/
      DATA ANAME(1,5),ANAME(2,5),ANAME(3,5),ANAME(4,5),ANAME(5,5),
     1    ANAME(6,5) /' RES','ERVO','IR B','ED T','HICK','NESS'/
      DATA FIRST/.TRUE./
C     ----------------------------------------------------------------
C
C
C1------READ INDICATOR ARRAY SHOWING LOCATIONS OF RESERVOIRS (IRES)
C
      IF(.NOT.FIRST) GO TO 70
      FIRST=.FALSE.
      KK=1
      CALL U2DINT(IRES,ANAME(1,1),NROW,NCOL,KK,IN,IOUT)
C2------VERIFY LOCATIONS EXIST FOR ALL RESERVOIRS
      DO 36 N=1,NRES
      NCELL=0
      DO 30 I=1,NROW
      DO 20 J=1,NCOL
      IF(IBOUND(J,I,1).LE.0) IRES(J,I)=0
      IF(IRES(J,I).EQ.N) NCELL=NCELL+1
   20 CONTINUE
   30 CONTINUE
      IF(NCELL.GT.0) THEN
        WRITE(IOUT,32) N,NCELL
   32   FORMAT(1X,'NUMBER OF CELLS IN RESERVOIR ',I2,':',I6)
      ELSE
```

```
      WRITE(IOUT,34)
   34 FORMAT(1X,'NO ACTIVE CELLS FOUND FOR RESERVOIR ',I2,'.',
     1 '  ABORTING...')
      ENDIF
   36 CONTINUE
C
C3------IF NRESOP=2 THEN A LAYER INDICATOR ARRAY IS NEEDED.
      IF (NRESOP.NE.2)GO TO 37
      CALL U2DINT(IRESL,ANAME(1,2),NROW,NCOL,0,IN,IOUT)
C3------READ IN BOTTOM ELEVATION, BED CONDUCTIVITY, AND BED THICKNESS
   37 CALL U2DREL(BRES,ANAME(1,3),NROW,NCOL,KK,IN,IOUT)
      CALL U2DREL(CRES,ANAME(1,4),NROW,NCOL,KK,IN,IOUT)
      CALL U2DREL(BBRES,ANAME(1,5),NROW,NCOL,KK,IN,IOUT)
C4------CONVERT RESERVOIR BED HYDRAULIC CONDUCTIVITY TO CONDUCTANCE
C4------BED THICKNESS TO ELEVATION OF BOTTOM OF RESERVOIR BED
      DO 40 I=1,NROW
      DO 38 J=1,NCOL
      IF(IRES(J,I).LE.0) GO TO 38
      IF(IRES(J,I).GT.NRES) GO TO 38
       CRES(J,I)=CRES(J,I)*DELC(I)*DELR(J)/BBRES(J,I)
       BBRES(J,I)=BRES(J,I)-BBRES(J,I)
   38 CONTINUE
   40 CONTINUE
C5------MAKE STAGE-VOLUME TABLE FOR EACH RESERVOIR
      DO 60 N=1,NRES
C5A-----FIND MAX AND MIN BOTTOM ELEVATION
      ELMIN=9.99E10
      ELMAX=-9.99E10
      DO 44 I=1,NROW
      DO 42 J=1,NCOL
      IF(IRES(J,I).NE.N) GO TO 42
      IF(BRES(J,I).LT.ELMIN) ELMIN=BRES(J,I)
      IF(BRES(J,I).GT.ELMAX) ELMAX=BRES(J,I)
   42 CONTINUE
   44 CONTINUE
C5B-----CONSTRUCT TABLE
      WRITE(IOUT,46) N,ELMIN
   46 FORMAT(1X,'STAGE-VOLUME TABLE FOR RESERVOIR',I2,/,6X,
     1 'STAGE          VOLUME          AREA',/,
     2 3X,36('-'),/,1X,G10.5,2(11X,'0.0'))
      IF(NPTS.LT.1) GO TO 60
      DEL=(ELMAX-ELMIN)/FLOAT(NPTS)
      STAGE=ELMIN
      DO 56 NP=1,NPTS
      STAGE=STAGE+DEL
      VOL=0.0
      TAREA=0.0
      DO 50 I=1,NROW
      DO 48 J=1,NCOL
      IF(IRES(J,I).NE.N) GO TO 48
      IF(STAGE.GT.BRES(J,I))THEN
       AREA=DELR(J)*DELC(I)
       TAREA=TAREA+AREA
       VOL=VOL+AREA*(STAGE-BRES(J,I))
      ENDIF
```

```
   48 CONTINUE
   50 CONTINUE
      WRITE(IOUT,54) STAGE,VOL,TAREA
   54 FORMAT(1X,G10.5,2G14.5)
   56 CONTINUE
      WRITE(IOUT,58)
   58 FORMAT(1X,' ')
   60 CONTINUE
C
C6------READ START AND END HEADS FOR EACH RESERVOIR FOR CURRENT
C6------STRESS PERIOD
   70 DO 80 N=1,NRES
      READ(IN,64) HRESSE(1,N),HRESSE(2,N)
   64 FORMAT(2F10.0)
   80 CONTINUE
C
C7------RECOMPUTE LENGTH OF PERIOD, PERLEN, A LOCAL VARIABLE IN
C7------SUBROUTINE BAS1AD
      PERLEN=DELT*FLOAT(NSTP)
      IF(TSMULT.NE.1.) PERLEN=DELT*(1.-TSMULT**NSTP)/(1.-TSMULT)
C
C8------RETURN
      RETURN
      END
```

List of Variables for Module RES1RP

Variable	Range	Definition
ANAME	Module	DIMENSION(6,5), Labels for input arrays.
AREA	Module	Area of model cell.
BBRES	Package	DIMENSION(NCOL,NROW), Elevation of base of reservoir-bed sediments.
BRES	Package	DIMENSION(NCOL,NROW), Land-surface elevation of reservoir.
CRES	Package	DIMENSION(NCOL,NROW), Hydraulic conductance of reservoir bed.
DEL	Module	Increment of reservoir stage used in constructing tables of volume and area.
DELC	Global	DIMENSION(NROW), Cell dimensions in the column direction. DELC(I) contains the width of row I.
DELR	Global	DIMENSION(NCOL), Cell dimensions in the row direction. DELR(J) contains the width of column J.
DELT	Global	Length of current time step.
ELMAX	Module	Maximum elevation of reservoir bottom.
ELMIN	Module	Minimum elevation of reservoir bottom.
FIRST	Module	Logical indicator to skip part of data input if module has been called previously.
HRESSE	Package	DIMENSION(2,NRES), Starting and ending stage for each reservoir for current stress period.
I	Module	Index for rows.
IBOUND	Global	DIMENSION(NCOL,NROW,NLAY), Status of each cell < 0 Constant-head cell. = 0 No-flow cell. > 0 Variable-head cell.
IN	Package	Primary unit number from which input from this package will be read.
IOUT	Global	Primary unit number for all printed output.
IRES	Package	DIMENSION(NCOL,NROW) array of areal distribution of each reservoir.
IRESL	Package	DIMENSION(NCOL,NROW) array that specifies layer number to which each reservoir cell is connected.
J	Module	Index for columns.
KK	Module	Index for layers.
N	Module	Index for reservoirs.
NCELL	Module	Counter for number of cells in each reservoir.
NCOL	Global	Number of columns in the model grid.
NLAY	Global	Number of layers in the model grid.
NP	Module	Index for tables of volume and area.
NPTS	Module	Number of lines in tables of volume and area.
NRES	Package	Number of reservoirs.
NRESOP	Package	Reservoir-option flag: = 1 Reservoirs are connected to layer 1. = 2 Reservoirs are connected to layer specified in array IRESL. = 3 Reservoirs are connected to the highest active cell in the vertical column of cells at each reservoir location.
NROW	Global	Number of rows in the model grid.
NSTP	Global	Number of time steps in current stress period.
PERLEN	Package	Length of current stress period.
STAGE	Module	Stage written to tables of volume and area.
TAREA	Module	Accumulator for reservoir surface area.
TSMULT	Global	Multiplier to get from one time step length to the next.
VOL	Module	Accumulator for reservoir volume.

RES1AD

Narrative for Module RES1AD

This module uses linear interpolation to compute reservoir stage at the end of the current time step. If the print option is selected, the module prints the current value of stage, surface area, and volume for each reservoir. Operations are carried out in the following order:

1. Compute the fraction of time from the start of the stress period to the end of the current time step in relation to the total time in the stress period, PERLEN.

2. Compute stage in each reservoir by linear interpolation.

3. If reservoir print option is not selected, RETURN.

4. Print values of stage, surface area, and volume for each reservoir.

5. RETURN.

Flowchart for Module RES1AD

PERTIM is the length of simulation time from the start of the current stress period to the end of the current time step.

PERLEN is the length of the current stress period.

IRESPT is a print flag:
> 0, reservoir stage, surface area, and volume will be printed at each time step.
≤ 0, reservoir stage, surface area, and volume will not be printed at each time step.
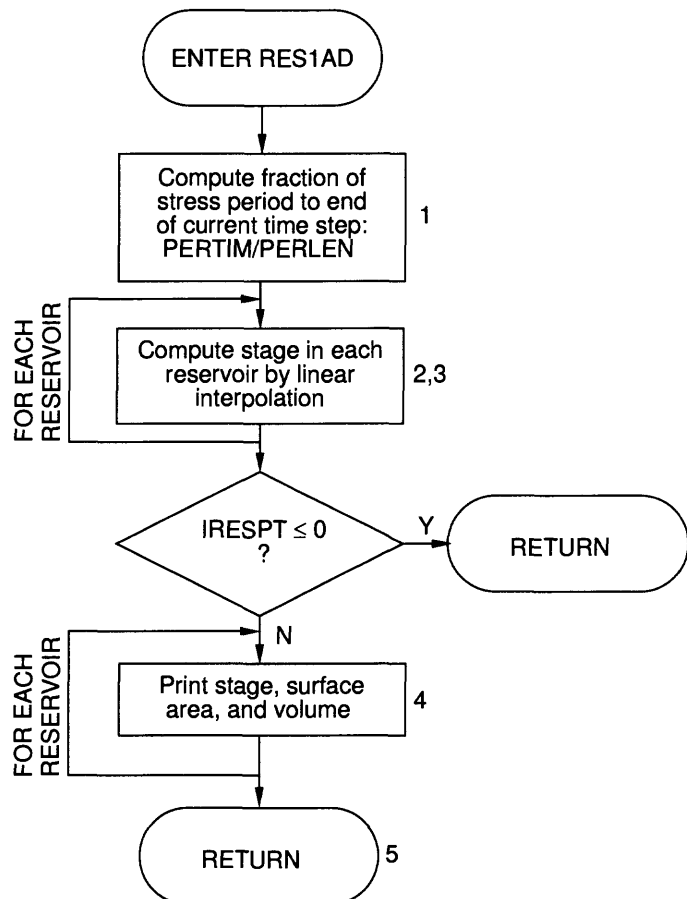
Program Listing for Module RES1AD

```
              SUBROUTINE RES1AD(HRES,HRESSE,IRES,BRES,DELR,DELC,NRES,IRESPT,
      2 NCOL,NROW,PERLEN,PERTIM,TOTIM,KKSTP,KKPER,IOUT)
C
C
C-----VERSION 1700 20JUN1996 RES1AD
C     ******************************************************************
C     GET RESERVOIR HEADS FOR CURRENT TIME STEP
C     ******************************************************************
C
C     SPECIFICATIONS:
C     ------------------------------------------------------------------
      DIMENSION HRES(NRES),HRESSE(2,NRES),IRES(NCOL,NROW),
      1           BRES(NCOL,NROW),DELR(NCOL),DELC(NROW)
C     ------------------------------------------------------------------
C
C1------COMPUTE PROPORTION OF STRESS PERIOD TO END OF THIS TIME STEP
      FRAC=PERTIM/PERLEN
C
C2------PROCESS EACH RESERVOIR
      DO 10 N=1,NRES
      HSTART=HRESSE(1,N)
      HEND=HRESSE(2,N)
C
C3------COMPUTE HEAD FOR RESERVOIR N BY LINEAR INTERPOLATION.
      HRES(N)=HSTART+(HEND-HSTART)*FRAC
   10 CONTINUE
      IF(IRESPT.LE.0) RETURN
C4------MAKE A TABLE OF HEAD, AREA AND VOLUME FOR EACH RESERVOIR
      WRITE(IOUT,20) KKPER,KKSTP,TOTIM
   20 FORMAT(1X,'RESERVOIR CONDITIONS FOR STRESS PERIOD ',I3,', STEP ',
      1 I3,' TIME ',G12.5,/,2X,'RESERVOIR   HEAD',9X,'AREA',8X,'VOLUME',
      2 /,2X,46('-'))
      DO 60 N=1,NRES
      STAGE=HRES(N)
      VOL=0.0
      TAREA=0.0
      DO 50 I=1,NROW
      DO 48 J=1,NCOL
      IF(IRES(J,I).NE.N) GO TO 48
      IF(STAGE.GT.BRES(J,I))THEN
       AREA=DELR(J)*DELC(I)
       TAREA=TAREA+AREA
       VOL=VOL+AREA*(STAGE-BRES(J,I))
      ENDIF
   48 CONTINUE
   50 CONTINUE
      WRITE(IOUT,54) N,STAGE,TAREA,VOL
   54 FORMAT(3X,I5,3X,3G12.5)
   60 CONTINUE
C
C5------RETURN
      RETURN
      END
```

List of Variables for Module RES1AD

Variable	Range	Definition
AREA	Module	Area of model cell.
BRES	Package	Land-surface elevation of reservoir.
DELC	Global	DIMENSION(NROW), Cell dimensions in the column direction. DELC(I) contains the width of row I.
DELR	Global	DIMENSION(NCOL), Cell dimensions in the row direction. DELR(J) contains width of column J.
FRAC	Module	Fraction or proportion of time from start of current stress period to end of current time step in relation to total simulation time in stress period.
HEND	Module	Reservoir stage at end of current stress period.
HRES	Package	DIMENSION(NRES), Stage in reservoir for current time step.
HRESSE	Package	DIMENSION(2,NRES), Starting and ending stage for each reservoir for current stress period.
HSTART	Module	Reservoir stage at start of current stress period.
I	Module	Index for rows.
IOUT	Global	Primary unit number for all printed output.
IRES	Package	DIMENSION(NCOL,NROW), Indicator array that shows areal distribution of each reservoir.
IRESPT	Package	Print flag: > 0 Reservoir stage, area, and volume will be printed each time step. ≤ 0 Reservoir stage, area, and volume will not be printed each time step.
J	Module	Index for columns.
KKPER	Package	Number of current stress period.
KKSTP	Package	Number of current time step.
N	Module	Index for reservoirs.
NCOL	Global	Number of columns in the model grid.
NRES	Package	Number of reservoirs.
NROW	Global	Number of rows in the model grid.
PERLEN	Package	Length of current stress period.
PERTIM	Global	Elapsed time during the current stress period.
STAGE	Module	Reservoir stage.
TAREA	Module	Accumulator for reservoir surface area.
TOTIM	Global	Elapsed time in the simulation.
VOL	Module	Accumulator for reservoir volume.

RES1FM

Narrative for Module RES1FM

This module adds terms to the finite-difference equations to account for flow to or from reservoirs. Operations are carried out in the following order:

1. Find reservoir cell by searching IRES array.

2. Find number of model layer to which reservoir is connected.

3. If model cell to which reservoir is connected is external or constant head, skip calculations.

4. If reservoir stage is below land-surface elevation of reservoir, skip calculations.

5. Save reservoir data for cell in temporary variables.

6. Compare ground-water head to elevation of base of reservoir-bed sediments.

7. If ground-water head is above elevation of base of reservoir-bed sediments, add terms to RHS and HCOF.

8. If ground-water head is below elevation of base of reservoir-bed sediments, add term to RHS.

9. RETURN.

Flowchart for Module RES1FM

HCOF is coefficient of head in the
  finite-difference equation.
RHS is right-hand side of the
  finite-difference equation.

ENTER RES1FM

FOR EACH ROW AND COLUMN

Find reservoir cell | 1

Find layer number
for reservoir cell | 2

Is cell no-flow
or constant head
? | 3 — Y

N

Is reservoir
head below land
surface? | 4 — Y

N

Get reservoir head,
bed bottom elevation,
and bed conductance | 5

Ground-water head >
bed bottom? | 6 — N

Y

Add terms to
HCOF and RHS | 7

Add term to
RHS | 8

RETURN | 9
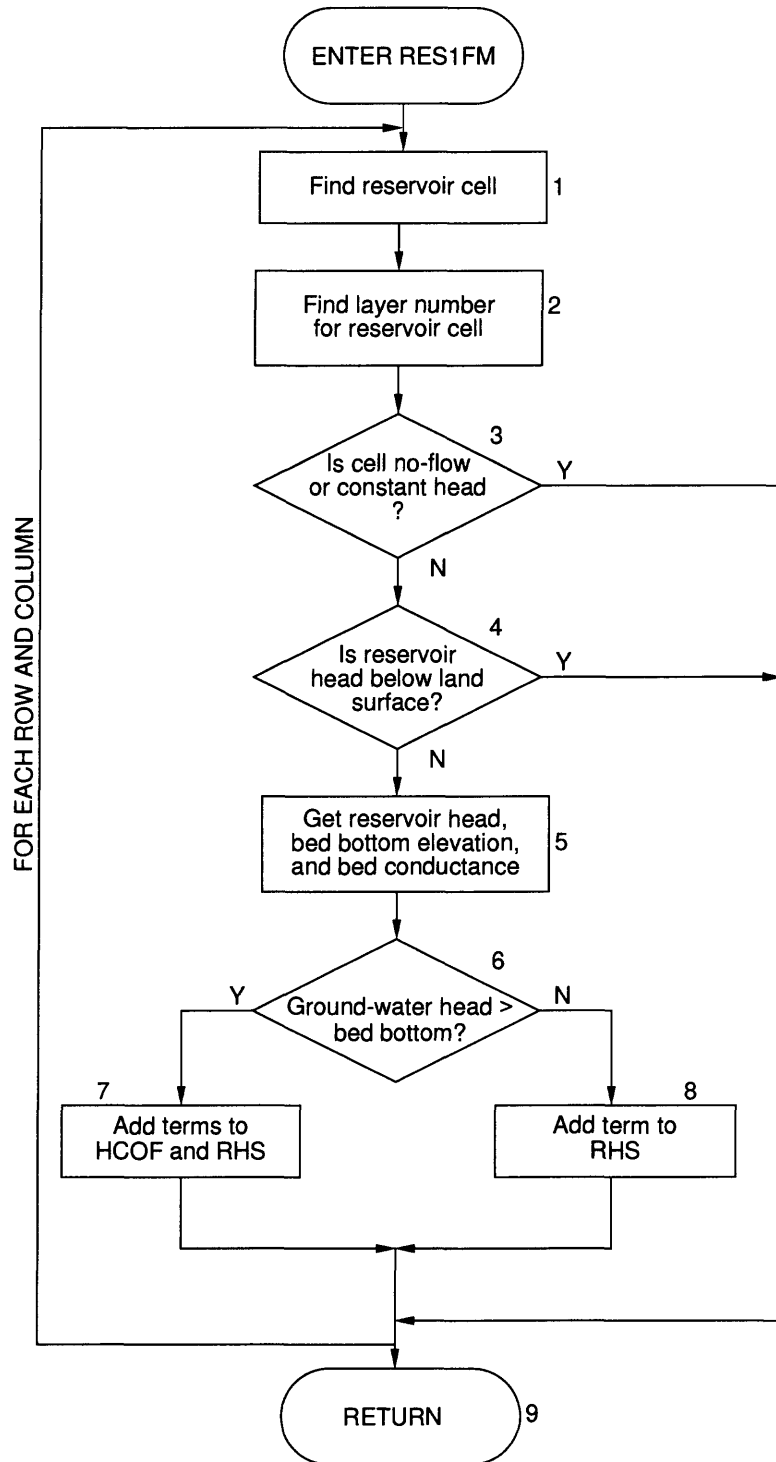
Program Listing for Module RES1FM

```
          SUBROUTINE RES1FM(IRES,IRESL,BRES,CRES,BBRES,HRES,IBOUND,
     1    HNEW,HCOF,RHS,NRES,NRESOP,NCOL,NROW,NLAY)
C
C-----VERSION 1700 27MAR1996 RES1FM
C     ************************************************************
C     ADD RESERVOIR TERMS TO RHS AND HCOF
C     ************************************************************
C
C     SPECIFICATIONS:
C     ------------------------------------------------------------
C
      DOUBLE PRECISION HNEW
      DIMENSION IRES(NCOL,NROW),IRESL(NCOL,NROW),BRES(NCOL,NROW),
     1 CRES(NCOL,NROW),BBRES(NCOL,NROW),HRES(NRES),
     2 IBOUND(NCOL,NROW,NLAY),HNEW(NCOL,NROW,NLAY),
     3 HCOF(NCOL,NROW,NLAY),RHS(NCOL,NROW,NLAY)
C     ------------------------------------------------------------
C
C
C1------PROCESS EACH ACTIVE RESERVOIR CELL
      DO 100 I=1,NROW
      DO 90 J=1,NCOL
      NR=IRES(J,I)
      IF(NR.LE.0) GO TO 90
      IF(NR.GT.NRES) GO TO 90
      IR=I
      IC=J
C
C2------FIND LAYER NUMBER FOR RESERVOIR CELL
      IF(NRESOP.EQ.1) THEN
       IL=1
      ELSE IF(NRESOP.EQ.2) THEN
       IL=IRESL(IC,IR)
      ELSE
       DO 60 K=1,NLAY
       IL=K
C2A-----UPPERMOST ACTIVE CELL FOUND, SAVE LAYER INDEX IN 'IL'
       IF(IBOUND(IC,IR,IL).GT.0) GO TO 70
C2B-----SKIP THIS CELL IF VERTICAL COLUMN CONTAINS A CONSTANT-
C2B-----HEAD CELL ABOVE RESERVOIR LOCATION
       IF(IBOUND(IC,IR,IL).LT.0) GO TO 90
   60  CONTINUE
       GO TO 90
      ENDIF
C
C3------IF THE CELL IS EXTERNAL, SKIP IT.
      IF(IBOUND(IC,IR,IL).LE.0)GO TO 90
C
C4------IF RESERVOIR STAGE IS BELOW RESERVOIR BOTTOM, SKIP IT
   70 HR=HRES(NR)
      IF(HR.LE.BRES(IC,IR))  GO TO 90
C5------SINCE RESERVOIR IS ACTIVE AT THIS LOCATION,
C5------CELL IS INTERNAL GET THE RESERVOIR DATA.
```

```
         CR=CRES(IC,IR)
         RBOT=BBRES(IC,IR)
         HHNEW=HNEW(IC,IR,IL)
C
C6------COMPARE GROUND-WATER HEAD TO BOTTOM OF RESERVOIR BED.
         IF(HHNEW.LE.RBOT) GO TO 80
C
C7------SINCE HEAD>BOTTOM ADD TERMS TO RHS AND HCOF.
         RHS(IC,IR,IL)=RHS(IC,IR,IL)-CR*HR
         HCOF(IC,IR,IL)=HCOF(IC,IR,IL)-CR
         GO TO 90
C
C8------SINCE HEAD<BOTTOM ADD TERM ONLY TO RHS.
      80 RHS(IC,IR,IL)=RHS(IC,IR,IL)-CR*(HR-RBOT)
      90 CONTINUE
     100 CONTINUE
C
C9------RETURN
         RETURN
         END
```

List of Variables for Module RES1FM

Variable	Range	Definition
BBRES	Package	DIMENSION(NCOL,NROW), Elevation of base of reservoir-bed sediments.
BRES	Package	DIMENSION(NCOL,NROW), Land-surface elevation of reservoir.
CR	Module	Temporary storage for hydraulic conductance of reservoir bed.
CRES	Package	DIMENSION(NCOL,NROW), Hydraulic conductance of reservoir bed.
HCOF	Global	DIMENSION(NCOL,NROW,NLAY), Coefficient of head in the finite-difference equations.
HHNEW	Module	Temporary single-precision storage of value in HNEW array.
HNEW	Global	DIMENSION(NCOL,NROW,NLAY), Most recent estimate of head in each cell.
HR	Module	Temporary storage for reservoir stage.
HRES	Package	DIMENSION(NRES), Stage in reservoir for current time step.
I	Module	Index for rows.
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.
IL	Module	Index for layers.
IR	Module	Index for rows.
IRES	Package	DIMENSION(NCOL,NROW), Array of areal distribution of each reservoir.
IRESL	Package	DIMENSION(NCOL,NROW), Array that specifies layer number to which each reservoir cell is connected.
J	Module	Index for columns.
K	Module	Index for layers.
NCOL	Global	Number of columns in the model grid.
NLAY	Global	Number of layers in the model grid.
NR	Module	Reservoir number.
NRES	Package	Number of reservoirs.
NRESOP	Package	Reservoir-option flag:
		$= 1$ Reservoirs are connected to layer 1.
		$= 2$ Reservoirs are connected to layer specified in array IRESL.
		$= 3$ Reservoirs are connected to the highest active cell in the vertical column of cells at each reservoir location.
NROW	Global	Number of rows in the model grid.
RBOT	Module	Temporary storage for elevation of base of reservoir-bed sediments.
RHS	Global	DIMENSION(NCOL,NROW,NLAY), Right-hand side of finite-difference equations.

RES1BD

Narrative for Module RES1BD

This module calculates flow rates and quantities of water for flow between reservoirs and the underlying ground-water system. The module saves the sums of the flow rates and quantities for inclusion in the overall volumetric budget. If requested, the module will save cell-by-cell flow rates. Operations are carried out in the following order:

1. Initialize the cell-by-cell flow term and flag and clear the accumulators for flow rates between reservoirs and the ground-water system.

2. If cell-by-cell flow terms are to be saved, clear the buffer (BUFF) in which they will be accumulated before saving.

3. Find reservoir cell by searching IRES array.

4. Find number of model layer to which reservoir is connected.

5. If model cell to which reservoir is connected is external or constant head, skip calculations.

6. If reservoir stage is below land-surface elevation of reservoir, skip calculations.

7. Save reservoir data for cell in temporary variables.

8. Compute rate of flow between the reservoir and the ground-water system (RATE). If ground-water head is above the base of the reservoir-bed sediments, the driving force is the difference between reservoir stage and ground-water head. If ground-water head is below the base of the reservoir-bed sediments, the driving force is the difference between reservoir stage and the elevation of the base of the reservoir-bed sediments.

9. If cell-by-cell flow terms are to be saved, add rate to the buffer (BUFF).

10. See if rate of flow between reservoir and ground-water system is negative or positive.

11. Flow between reservoir and ground-water system is negative (flow is from ground-water system to reservoir), add flow rate to RATOUT.

12. Flow between reservoir and ground-water system is positive (flow is into ground-water system from reservoir), add flow rate to RATIN.

13. Save cell-by-cell flow rates if requested.

14. Calculate volumes and move rates, volumes, and labels into arrays for printing volumetric budget.

15. Increment budget term counter, MSUM.

16. RETURN.

Flowchart for Module RES1BD

IBD is a flag which, if set, causes cell-by-cell flow terms for reservoir leakage to be recorded.

HR is reservoir stage.

BRES is land-surface elevation of reservoir.

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.
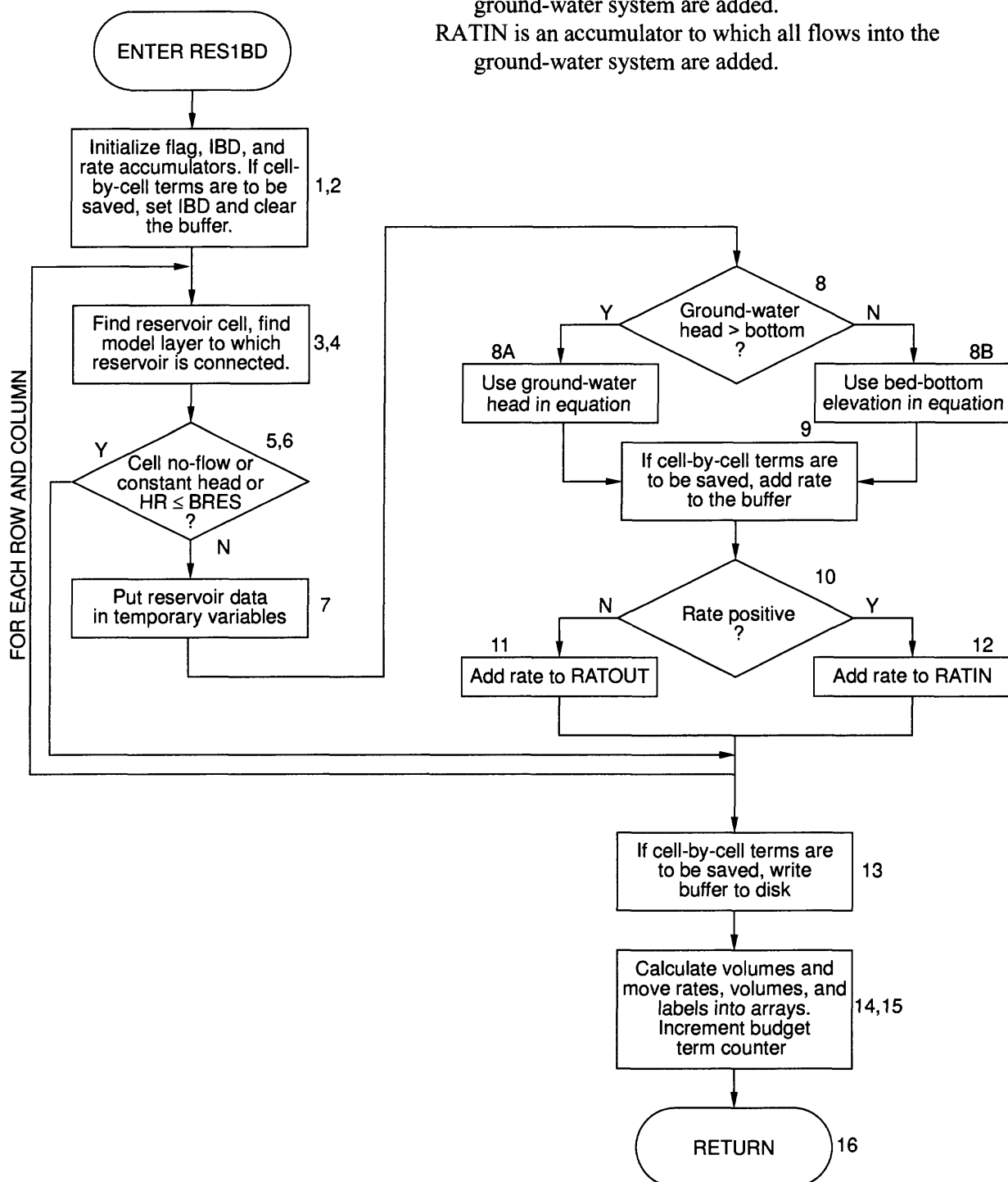
Program Listing for Module RES1BD

```
      SUBROUTINE RES1BD(IRES,IRESL,BRES,CRES,BBRES,HRES,IBOUND,HNEW,
     1        BUFF,VBVL,VBNM,MSUM,KSTP,KPER,NRES,NRESOP,NCOL,NROW,NLAY,
     2        DELT,IRESCB,ICBCFL,IOUT)
C-----VERSION 1700 27MAR1996 RES1BD
C     ******************************************************************
C     CALCULATE VOLUMETRIC BUDGET FOR RESERVOIRS
C     ******************************************************************
C
C     SPECIFICATIONS:
C     ------------------------------------------------------------------
      CHARACTER*4 VBNM,TEXT
      DOUBLE PRECISION HNEW
      DIMENSION IRES(NCOL,NROW),IRESL(NCOL,NROW),BRES(NCOL,NROW),
     1     CRES(NCOL,NROW),BBRES(NCOL,NROW),HRES(NRES),
     1     IBOUND(NCOL,NROW,NLAY),HNEW(NCOL,NROW,NLAY),VBVL(4,20),
     2     VBNM(4,20),BUFF(NCOL,NROW,NLAY)
      DIMENSION TEXT(4)
      DATA TEXT(1),TEXT(2),TEXT(3),TEXT(4) /' RES','ERV.',' LEA','KAGE'/
C     ------------------------------------------------------------------
C
C1------INITIALIZE CELL-BY-CELL FLOW TERM FLAG (IBD) AND
C1------ACCUMULATORS (RATIN AND RATOUT).
      IBD=0
      RATIN=0.
      RATOUT=0.
C
C2------TEST TO SEE IF CELL-BY-CELL FLOW TERMS ARE NEEDED.
      IF(ICBCFL.EQ.0 .OR. IRESCB.LE.0 ) GO TO 10
C
C2A-----CELL-BY-CELL FLOW TERMS ARE NEEDED SET IBD AND CLEAR BUFFER.
      IBD=1
      DO 5 IL=1,NLAY
      DO 5 IR=1,NROW
      DO 5 IC=1,NCOL
      BUFF(IC,IR,IL)=0.
    5 CONTINUE
C
C3------FOR EACH RESERVOIR REACH ACCUMULATE RESERVOIR FLOW (STEPS 5-15)
   10    DO 200 I=1,NROW
      DO 190 J=1,NCOL
      NR=IRES(J,I)
      IF(NR.LE.0) GO TO 190
      IF(NR.GT.NRES) GO TO 190
      IR=I
      IC=J
C
C4------FIND LAYER NUMBER FOR RESERVOIR CELL
      IF(NRESOP.EQ.1) THEN
       IL=1
      ELSE IF(NRESOP.EQ.2) THEN
       IL=IRESL(IC,IR)
      ELSE
       DO 60 K=1,NLAY
```

```
         IL=K
C4A-----UPPERMOST ACTIVE CELL FOUND, SAVE LAYER INDEX IN 'IL'
         IF(IBOUND(IC,IR,IL).GT.0) GO TO 70
C4B-----SKIP THIS CELL IF VERTICAL COLUMN CONTAINS A CONSTANT-
C4B-----HEAD CELL ABOVE RESERVOIR LOCATION
         IF(IBOUND(IC,IR,IL).LT.0) GO TO 190
   60    CONTINUE
         GO TO 190
         ENDIF
C
C5------IF THE CELL IS EXTERNAL SKIP IT.
         IF(IBOUND(IC,IR,IL).LE.0)GO TO 190
C
C6------IF RESERVOIR STAGE IS BELOW RESERVOIR BOTTOM, SKIP IT
   70    HR=HRES(NR)
         IF(HR.LE.BRES(IC,IR))  GO TO 190
C7------SINCE RESERVOIR IS ACTIVE AT THIS LOCATION,
C7------GET THE RESERVOIR DATA.
         CR=CRES(IC,IR)
         RBOT=BBRES(IC,IR)
         HHNEW=HNEW(IC,IR,IL)
C
C8------COMPUTE RATE OF FLOW BETWEEN GROUND-WATER SYSTEM AND RESERVOIR.
C
C8A-----GROUND-WATER HEAD > BOTTOM THEN RATE=CR*(HR-HNEW).
         IF(HHNEW.GT.RBOT)RATE=CR*(HR-HHNEW)
C
C8B-----GROUND-WATER HEAD < BOTTOM THEN RATE=CR*(HR-RBOT)
         IF(HHNEW.LE.RBOT)RATE=CR*(HR-RBOT)
C
C9-------IF C-B-C FLOW TERMS ARE TO BE SAVED, THEN ADD RATE TO BUFFER.
         IF(IBD.EQ.1) BUFF(IC,IR,IL)=BUFF(IC,IR,IL)+RATE
C
C10-----SEE IF FLOW IS INTO GROUND-WATER SYSTEM OR INTO RESERVOIR.
         IF(RATE)94,190,96
C
C11-----GROUND-WATER SYSTEM IS DISCHARGING TO RESERVOIR
C11-----SUBTRACT RATE FROM RATOUT.
   94 RATOUT=RATOUT-RATE
         GO TO 190
C
C12-----GROUND-WATER SYSTEM IS RECHARGED FROM RESERVOIR
C12-----ADD RATE TO RATIN.
   96 RATIN=RATIN+RATE
  190 CONTINUE
  200 CONTINUE
C
C13-----IF C-B-C FLOW TERMS WILL BE SAVED, CALL UBUDSV TO RECORD THEM.
      IF(IBD.EQ.1) CALL UBUDSV(KSTP,KPER,TEXT,IRESCB,BUFF,NCOL,NROW,
     1                              NLAY,IOUT)
C
C14-----MOVE RATES,VOLUMES AND LABELS INTO ARRAYS FOR PRINTING.
         VBVL(3,MSUM)=RATIN
         VBVL(4,MSUM)=RATOUT
         VBVL(1,MSUM)=VBVL(1,MSUM)+RATIN*DELT
```

```
        VBVL(2,MSUM)=VBVL(2,MSUM)+RATOUT*DELT
        VBNM(1,MSUM)=TEXT(1)
        VBNM(2,MSUM)=TEXT(2)
        VBNM(3,MSUM)=TEXT(3)
        VBNM(4,MSUM)=TEXT(4)
C
C15-----INCREMENT BUDGET TERM COUNTER
        MSUM=MSUM+1
C
C16-----RETURN
        RETURN
        END
```

List of Variables for Module RES1BD

Variable	Range	Definition
BBRES	Package	DIMENSION(NCOL,NROW), Elevation of base of reservoir-bed sediments.
BRES	Package	DIMENSION(NCOL,NROW), Land-surface elevation of reservoir.
BUFF	Global	DIMENSION(NODES1), Buffer used for temporary storage of flow rates prior to recording cell-by-cell budgets.
CR	Module	Temporary storage for hydraulic conductance of reservoir bed.
CRES	Package	DIMENSION(NCOL,NROW), Hydraulic conductance of reservoir bed.
DELT	Global	Length of the current time step.
HHNEW	Module	Temporary single-precision storage of value in HNEW array.
HNEW	Global	DIMENSION(NCOL,NROW,NLAY), Most recent estimate of head in each cell.
HR	Module	Temporary storage for reservoir stage.
HRES	Package	DIMENSION(NRES), Stage in reservoir for current time step.
I	Module	Index for rows.
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.
IL	Module	Index for layers.
IOUT	Global	Primary unit number for all printed output.
IR	Module	Index for rows.
IRES	Package	DIMENSION(NCOL,NROW), Indicator array that shows areal distribution of each reservoir.
IRESCB	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 printed.
IRESL	Package	DIMENSION(NCOL,NROW), Array that specifies layer number to which each reservoir cell is connected.
J	Module	Index for columns.
K	Module	Index for layers.
KPER	Global	Stress period counter.
KSTP	Global	Time step counter, reset at the start of each stress period.
MSUM	Global	Counter for budget entries in VBVL and VBNM.
NCOL	Global	Number of columns in the model grid.
NLAY	Global	Number of layers in the model grid.
NR	Module	Reservoir number.
NRES	Package	Number of reservoirs.
NRESOP	Package	Reservoir-option flag:
		= 1 Reservoirs are connected to layer 1.
		= 2 Reservoirs are connected to layer specified in array IRESL.
		= 3 Reservoirs are connected to the highest active cell in the vertical column of cells at each reservoir location.

List of Variables for Module RES1BD—Continued

Variable	Range	Definition
NROW	Global	Number of rows in the model grid.
RATE	Module	Flow between reservoir and model cell, positive for flow into model cell.
RATIN	Module	Accumulator for total flow into the flow field from reservoirs.
RATOUT	Module	Accumulator for total flow out of the flow field into reservoirs.
RBOT	Module	Temporary storage elevation of base of reservoir-bed sediments.
TEXT	Module	DIMENSION(4), Label for volumetric budget and cell-by-cell budget.
VBNM	Global	DIMENSION(4,20), Labels for entries in volumetric budget.
VBVL	Global	DIMENSION(4,20), 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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Leake, S.A., and Prudic, D.E., 1991, Documentation of a computer program to simulate aquifer-system compaction using the modular finite-difference ground-water flow model: U.S. Geological Survey Techniques of Water-Resources Investigations, book 6, chap. A2, 68 p.

McDonald, M.G., and Harbaugh, A.W., 1988, A modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Techniques of Water-Resources Investigations, book 6, chap. A1, 586 p.

Prudic, D.E., 1989, Documentation of a computer program to simulate stream-aquifer relations using the modular finite-difference ground-water flow model: U.S. Geological Survey Open-File Report 88–729, 113 p.

APPENDIX—Input data sets and printed results for example problem

page 43 follows

APPENDIX—Input Data Sets and Printed Results for Example Problem

Listing of Input Data for Basic Package

Input for the Basic Package follows the column numbers. The input consists of 23 records (lines). Input is read from the FORTRAN unit number specified in the MAIN program.

```
                                  Column Numbers
            1          2          3          4          5          6          7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012345
Reservoir Package Example Problem
June 25, 1996
            1          12         12         3          4
 11  0  0  0  0  0 17  0 19  0  0 22  0  0  0  0 27
            0          1
            5          1(12I2)                            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 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
 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 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
 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1
      999.9
         0          0.0
         2          2          1.0
         2          2          1.0
         5          5          1.0
```

Listing of Input Data for Block-Centered Flow Package

Input for the Basic Package follows the column numbers. The input consists of 7 records (lines). Input is read from the FORTRAN unit number specified in IUNIT(1).

```
                                  Column Numbers
            1          2          3          4          5          6          7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012345
         0          0
         0
         0          1                                              TRPY
         0          100                                            DELR
         0          100                                            DELC
         0          0.20                                           sf1
         0          10000                                          Tran
```

Listing of Input Data for Strongly-Implicit Procedure Package

Input for the Basic Package follows the column numbers. The input consists of 2 records (lines). Input is read from the FORTRAN unit number specified in IUNIT(9).

Column Numbers

```
         1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123 45
      50        5
     1.0    0.001          0   0.00080        999
```

Listing of Input Data for Output Control Package

Input for the Basic Package follows the column numbers. The input consists of 16 records (lines). Input is read from the FORTRAN unit number specified in IUNIT(12).

Column Numbers

```
         1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123 45
         4         4         0         0
         1         0         0         0              per 1, step 1
         0         0         0         0
         1         1         1         0              per 1, step 2
         1         0         1         0
         1         0         0         0              per 2, step 1
         0         0         0         0
         1         1         1         0              per 2, step 2
         1         0         1         0
         1         0         0         0              per 3, step 1
         0         0         0         0
        -1         0         0         0              per 3, step 2
        -1         0         0         0              per 3, step 3
        -1         0         0         0              per 3, step 4
         1         1         1         0              per 3, step 5
         1         0         1         0
```

Listing of Input Data for General-Head Boundary Package

Input for the General-Head Boundary Package follows the column numbers. The input consists of 34 records (lines). Input is read from the FORTRAN unit number specified in IUNIT(7).

```
                                    Column Numbers
           1         2         3         4         5         6         7
  12345678901234567890123456789012345678901234567890123456789012345678901234 5
            24        0
            24
             1         1         1         0      1000
             1         2         1         0      1000
             1         3         1         0      1000
             1         4         1         0      1000
             1         5         1         0      1000
             1         6         1         0      1000
             1         7         1         0      1000
             1         8         1         0      1000
             1         9         1         0      1000
             1        10         1         0      1000
             1        11         1         0      1000
             1        12         1         0      1000
             1         1        12         0      1000
             1         2        12         0      1000
             1         3        12         0      1000
             1         4        12         0      1000
             1         5        12         0      1000
             1         6        12         0      1000
             1         7        12         0      1000
             1         8        12         0      1000
             1         9        12         0      1000
             1        10        12         0      1000
             1        11        12         0      1000
             1        12        12         0      1000
            -1
            -1
            -1
            -1
            -1
            -1
            -1
            -1
```

Listing of Input Data for Reservoir Package

Input for the Basic Package follows the column numbers. The input consists of 32 records (lines). Input is read from the FORTRAN unit number specified in IUNIT(17).

```
                                   Column Numbers
           1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012345
           1         0         1         1        15
              27              1(12I2)                        3                    IRES
  0 0 0 0 0 0 0 0 0 0 0 0
  0 0 0 0 0 0 0 0 0 0 0 0
  0 0 0 0 1 1 1 1 1 1 0 0
  0 0 0 1 1 1 1 1 1 1 0 0
  0 0 0 1 1 1 1 1 1 1 0 0
  0 0 0 1 1 1 1 1 1 1 1 0
  0 0 0 1 1 1 1 1 1 1 0 0
  0 0 0 1 1 1 1 1 1 1 0 0
  0 0 0 0 1 1 1 1 1 1 0 0
  0 0 0 0 0 0 0 0 0 0 0 0
  0 0 0 0 0 0 0 0 0 0 0 0
  0 0 0 0 0 0 0 0 0 0 0 0
              27              1(12F4.0)                       8                    BRES
    0   0   0   0   0   0   0   0   0   0   0   0
    0   0   0   0   0   0   0   0   0   0   0   0
    0   0   0   0   6   7   8   9  10  10   0   0
    0   0   0   6   6   7   8   9  10  10   0   0
    0   0   0   6   6   7   8   9  10  10   0   0
    0   0   0   6   6   7   8   9  10  10  21   0
    0   0   0   6   6   7   8   9  10  10   0   0
    0   0   0   6   6   7   8   9  10  10   0   0
    0   0   0   0   6   7   8   9  10  10   0   0
    0   0   0   0   0   0   0   0   0   0   0   0
    0   0   0   0   0   0   0   0   0   0   0   0
    0   0   0   0   0   0   0   0   0   0   0   0
         0              1                                               HCres
         0              2                                               Rbthck
         4             12                        Ststage,  Endstage  Res 1 SP 1
        12             14                        Ststage,  Endstage  Res 1 SP 2
        14              4                        Ststage,  Endstage  Res 1 SP 3
```

Printed Results for Example Problem

```
                    U.S. GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUND-WATER MODEL
Reservoir Package Example Problem                                           June 25, 1996
   1 LAYERS         12 ROWS         12 COLUMNS
   3 STRESS PERIOD(S) IN SIMULATION
MODEL TIME UNIT IS DAYS
I/O UNITS:
ELEMENT OF IUNIT:  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
      I/O UNIT: 11  0  0  0  0  0 17  0 19  0  0 22  0  0  0 27  0  0  0  0  0  0  0
BAS1 -- BASIC MODEL PACKAGE, VERSION 1, 9/1/87 INPUT READ FROM UNIT  5
ARRAYS RHS AND BUFF WILL SHARE MEMORY.
START HEAD WILL BE SAVED
    1324 ELEMENTS IN X ARRAY ARE USED BY BAS
    1324 ELEMENTS OF X ARRAY USED OUT OF  500000
BCF3 -- BLOCK-CENTERED FLOW PACKAGE, VERSION 3, 7/9/92 INPUT READ FROM UNIT 11
TRANSIENT SIMULATION
HEAD AT CELLS THAT CONVERT TO DRY=  0.00000E+00
WETTING CAPABILITY IS NOT ACTIVE
      LAYER  AQUIFER TYPE    INTERBLOCK T
      -------------------------------------
        1         0          0-HARMONIC
     145 ELEMENTS IN X ARRAY ARE USED BY BCF
    1469 ELEMENTS OF X ARRAY USED OUT OF  500000
GHB1 -- GHB PACKAGE, VERSION 1, 9/1/87 INPUT READ FROM UNIT 17
MAXIMUM OF   24 HEAD-DEPENDENT BOUNDARY NODES
     120 ELEMENTS IN X ARRAY ARE USED FOR HEAD-DEPENDENT BOUNDARIES
    1589 ELEMENTS OF X ARRAY USED OUT OF  500000
SIP1 -- STRONGLY IMPLICIT PROCEDURE SOLUTION PACKAGE, VERSION 1, 9/1/87 INPUT READ FROM UNIT 19
MAXIMUM OF  50 ITERATIONS ALLOWED FOR CLOSURE
   5 ITERATION PARAMETERS
     781 ELEMENTS IN X ARRAY ARE USED BY SIP
    2370 ELEMENTS OF X ARRAY USED OUT OF  500000
RES1 -- RESERVOIR PACKAGE, VERSION 1, 1/15/95 INPUT READ FROM UNIT 27
TOTAL NUMBER OF RESERVOIRS:    1
OPTION 1 -- RESERVOIR CONNECTED TO TOP LAYER
RESERVOIR HEADS, AREAS, AND VOLUMES WILL BE PRINTED EACH TIME STEP
   15 points will be used in constructing table of reservoir areas and volumes.
     579 ELEMENTS IN X ARRAY ARE USED FOR RESERVOIRS
    2949 ELEMENTS OF X ARRAY USED OUT OF  500000
Reservoir Package Example Problem                                           June 25, 1996


                    BOUNDARY ARRAY FOR LAYER  1 WILL BE READ ON UNIT  5 USING FORMAT: (12I2)
          ----------------------------------------------------------------------------------------


          1  2  3  4  5  6  7  8  9 10 11 12
    .............................................
    1    1  1  1  1  1  1  1  1  1  1  1  1
    2    1  1  1  1  1  1  1  1  1  1  1  1
    3    1  1  1  1  1  1  1  1  1  1  1  1
    4    1  1  1  1  1  1  1  1  1  1  1  1
    5    1  1  1  1  1  1  1  1  1  1  1  1
    6    1  1  1  1  1  1  1  1  1  1  1  1
    7    1  1  1  1  1  1  1  1  1  1  1  1
    8    1  1  1  1  1  1  1  1  1  1  1  1
    9    1  1  1  1  1  1  1  1  1  1  1  1
   10    1  1  1  1  1  1  1  1  1  1  1  1
   11    1  1  1  1  1  1  1  1  1  1  1  1
   12    1  1  1  1  1  1  1  1  1  1  1  1
AQUIFER HEAD WILL BE SET TO  999.00    AT ALL NO-FLOW NODES (IBOUND=0).
                                          INITIAL HEAD =  0.0000000E+00 FOR LAYER  1
HEAD PRINT FORMAT IS FORMAT NUMBER   4    DRAWDOWN PRINT FORMAT IS FORMAT NUMBER   4
HEADS WILL BE SAVED ON UNIT  0     DRAWDOWNS WILL BE SAVED ON UNIT  0
OUTPUT CONTROL IS SPECIFIED EVERY TIME STEP
                                COLUMN TO ROW ANISOTROPY =   1.000000
                                                  DELR =   100.0000
                                                  DELC =   100.0000
                                PRIMARY STORAGE COEF =   0.2000000     FOR LAYER  1
                                TRANSMIS. ALONG ROWS =   10000.00      FOR LAYER  1



                                SOLUTION BY THE STRONGLY IMPLICIT PROCEDURE
                                -------------------------------------------
                        MAXIMUM ITERATIONS ALLOWED FOR CLOSURE =        50
                                    ACCELERATION PARAMETER =      1.0000
                            HEAD CHANGE CRITERION FOR CLOSURE =   0.10000E-02
                            SIP HEAD CHANGE PRINTOUT INTERVAL =       999

       5 ITERATION PARAMETERS CALCULATED FROM SPECIFIED WSEED = 0.00080000 :

           0.0000000E+00  0.8318207E+00  0.9717157E+00  0.9952432E+00  0.9992000E+00
                                    STRESS PERIOD NO.   1, LENGTH =   2.000000
                                    -------------------------------------------

                                NUMBER OF TIME STEPS =      2

                                MULTIPLIER FOR DELT =     1.000

                                INITIAL TIME STEP SIZE =   1.000000
```

```
24 HEAD-DEPENDENT BOUNDARY NODES
            LAYER      ROW      COL    ELEVATION    CONDUCTANCE    BOUND NO.
          -----------------------------------------------------------------
               1         1        1   0.0000E+00      1000.            1
               1         2        1   0.0000E+00      1000.            2
               1         3        1   0.0000E+00      1000.            3
               1         4        1   0.0000E+00      1000.            4
               1         5        1   0.0000E+00      1000.            5
               1         6        1   0.0000E+00      1000.            6
               1         7        1   0.0000E+00      1000.            7
               1         8        1   0.0000E+00      1000.            8
               1         9        1   0.0000E+00      1000.            9
               1        10        1   0.0000E+00      1000.           10
               1        11        1   0.0000E+00      1000.           11
               1        12        1   0.0000E+00      1000.           12
               1         1       12   0.0000E+00      1000.           13
               1         2       12   0.0000E+00      1000.           14
               1         3       12   0.0000E+00      1000.           15
               1         4       12   0.0000E+00      1000.           16
               1         5       12   0.0000E+00      1000.           17
               1         6       12   0.0000E+00      1000.           18
               1         7       12   0.0000E+00      1000.           19
               1         8       12   0.0000E+00      1000.           20
               1         9       12   0.0000E+00      1000.           21
               1        10       12   0.0000E+00      1000.           22
               1        11       12   0.0000E+00      1000.           23
               1        12       12   0.0000E+00      1000.           24
```

RESERVOIR LOCATION FOR LAYER   1 WILL BE READ ON UNIT 27 USING FORMAT: (12I2)

```
        1   2   3   4   5   6   7   8   9  10  11  12
     .................................................
  1   0   0   0   0   0   0   0   0   0   0   0   0
  2   0   0   0   0   0   0   0   0   0   0   0   0
  3   0   0   0   0   1   1   1   1   1   1   0   0
  4   0   0   0   1   1   1   1   1   1   1   0   0
  5   0   0   0   1   1   1   1   1   1   1   0   0
  6   0   0   0   1   1   1   1   1   1   1   1   0
  7   0   0   0   1   1   1   1   1   1   1   0   0
  8   0   0   0   1   1   1   1   1   1   1   0   0
  9   0   0   0   0   1   1   1   1   1   1   0   0
 10   0   0   0   0   0   0   0   0   0   0   0   0
 11   0   0   0   0   0   0   0   0   0   0   0   0
 12   0   0   0   0   0   0   0   0   0   0   0   0
NUMBER OF CELLS IN RESERVOIR  1:     48
```

RESERVOIR LAND SURF ELEV FOR LAYER   1 WILL BE READ ON UNIT 27 USING FORMAT: (12F4.0)

```
        1     2     3     4     5     6     7     8     9    10    11    12
     ..........................................................................
  1   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  2   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  3   0.0   0.0   0.0   0.0   6.0   7.0   8.0   9.0  10.0  10.0   0.0   0.0
  4   0.0   0.0   0.0   6.0   6.0   7.0   8.0   9.0  10.0  10.0   0.0   0.0
  5   0.0   0.0   0.0   6.0   6.0   7.0   8.0   9.0  10.0  10.0   0.0   0.0
  6   0.0   0.0   0.0   6.0   6.0   7.0   8.0   9.0  10.0  10.0  21.0   0.0
  7   0.0   0.0   0.0   6.0   6.0   7.0   8.0   9.0  10.0  10.0   0.0   0.0
  8   0.0   0.0   0.0   6.0   6.0   7.0   8.0   9.0  10.0  10.0   0.0   0.0
  9   0.0   0.0   0.0   0.0   6.0   7.0   8.0   9.0  10.0  10.0   0.0   0.0
 10   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 11   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 12   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
                                 RES. BED VERT HYD COND =    1.000000    FOR LAYER   1
                                 RESERVOIR BED THICKNESS =    2.000000    FOR LAYER   1
STAGE-VOLUME TABLE FOR RESERVOIR 1
      STAGE        VOLUME          AREA
   ---------------------------------------
   6.0000             0.0             0.0
   7.0000        0.12000E+06    0.12000E+06
   8.0000        0.31000E+06    0.19000E+06
   9.0000        0.57000E+06    0.26000E+06
  10.000         0.90000E+06    0.33000E+06
  11.000         0.13700E+07    0.47000E+06
  12.000         0.18400E+07    0.47000E+06
  13.000         0.23100E+07    0.47000E+06
  14.000         0.27800E+07    0.47000E+06
  15.000         0.32500E+07    0.47000E+06
  16.000         0.37200E+07    0.47000E+06
  17.000         0.41900E+07    0.47000E+06
  18.000         0.46600E+07    0.47000E+06
  19.000         0.51300E+07    0.47000E+06
  20.000         0.56000E+07    0.47000E+06
  21.000         0.60700E+07    0.47000E+06
```

```
RESERVOIR CONDITIONS FOR STRESS PERIOD   1, STEP   1 TIME   1.0000
RESERVOIR   HEAD          AREA          VOLUME
-----------------------------------------------
       1   8.0000     0.19000E+06  0.31000E+06
     8 ITERATIONS FOR TIME STEP   1 IN STRESS PERIOD  1
HEAD/DRAWDOWN PRINTOUT FLAG = 0      TOTAL BUDGET PRINTOUT FLAG = 0      CELL-BY-CELL FLOW TERM FLAG = 0
OUTPUT FLAGS FOR EACH LAYER:
        HEAD    DRAWDOWN  HEAD   DRAWDOWN
LAYER  PRINTOUT PRINTOUT  SAVE    SAVE
-----------------------------------------------
   1      0        0        0       0
RESERVOIR CONDITIONS FOR STRESS PERIOD   1, STEP   2 TIME   2.0000
RESERVOIR   HEAD          AREA          VOLUME
-----------------------------------------------
       1   12.000     0.47000E+06  0.18400E+07
     8 ITERATIONS FOR TIME STEP   2 IN STRESS PERIOD  1
MAXIMUM HEAD CHANGE FOR EACH ITERATION:
  HEAD CHANGE LAYER,ROW,COL HEAD CHANGE LAYER,ROW,COL HEAD CHANGE LAYER,ROW,COL HEAD CHANGE LAYER,ROW,COL HEAD CHANGE LAYER,ROW,COL
-------------------------------------------------------------------------------------------------------------------------------
  3.773     ( 1,  6,  7) 3.154     ( 1,  6,  8) 0.9343    ( 1,  3,  9) 0.1868     ( 1, 10,  9) -0.2571E-01 ( 1, 12,  7)
 -0.6576E-02 ( 1, 10,  9) -0.4163E-02 ( 1, 11, 10) -0.9969E-03 ( 1, 11, 11)

HEAD/DRAWDOWN PRINTOUT FLAG = 1      TOTAL BUDGET PRINTOUT FLAG = 1      CELL-BY-CELL FLOW TERM FLAG = 0
OUTPUT FLAGS FOR EACH LAYER:
        HEAD    DRAWDOWN  HEAD   DRAWDOWN
LAYER  PRINTOUT PRINTOUT  SAVE    SAVE
-----------------------------------------------
   1      1        0        1       0
            HEAD IN LAYER  1 AT END OF TIME STEP  2 IN STRESS PERIOD  1
        .....................................................................

        1     2     3     4     5     6     7     8     9    10    11    12
     ...............................................................................
  1   2.07  2.43  2.93  3.50  4.00  4.24  4.22  3.97  3.55  3.03  2.49  2.09
  2   2.20  2.63  3.26  4.05  4.80  5.13  5.10  4.79  4.26  3.58  2.80  2.28
  3   2.42  2.97  3.87  5.15  6.66  7.10  7.04  6.65  5.86  4.86  3.35  2.58
  4   2.66  3.34  4.57  6.65  7.71  8.04  7.94  7.54  6.72  5.56  3.77  2.85
  5   2.82  3.59  4.96  7.19  8.18  8.46  8.33  7.93  7.12  5.89  4.00  3.02
  6   2.86  3.65  5.07  7.33  8.30  8.57  8.43  8.02  7.22  5.97  4.06  3.06
  7   2.77  3.53  4.91  7.15  8.13  8.42  8.28  7.88  7.06  5.83  3.94  2.96
  8   2.54  3.21  4.44  6.53  7.60  7.93  7.82  7.42  6.57  5.41  3.64  2.74
  9   2.23  2.75  3.62  4.90  6.42  6.85  6.79  6.37  5.58  4.61  3.13  2.39
 10   1.91  2.29  2.86  3.59  4.30  4.60  4.56  4.28  3.79  3.16  2.45  1.98
 11   1.65  1.94  2.32  2.76  3.14  3.33  3.31  3.11  2.78  2.38  1.96  1.65
 12   1.52  1.75  2.05  2.37  2.63  2.76  2.74  2.58  2.33  2.02  1.72  1.48


         VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  2 IN STRESS PERIOD  1
         -----------------------------------------------------------------------------
         CUMULATIVE VOLUMES      L**3                      RATES FOR THIS TIME STEP      L**3/T
         ------------------                                ------------------------

              IN:                                               IN:
              ---                                               ---
           STORAGE =   0.00000E+00                           STORAGE =   0.00000E+00
     CONSTANT HEAD =   0.00000E+00                     CONSTANT HEAD =   0.00000E+00
    HEAD DEP BOUNDS =   0.00000E+00                   HEAD DEP BOUNDS =   0.00000E+00
    RESERV. LEAKAGE =  0.13519E+07                    RESERV. LEAKAGE =  0.10069E+07
          TOTAL IN =   0.13519E+07                         TOTAL IN =   0.10069E+07
             OUT:                                              OUT:
             ----                                              ----
           STORAGE =   0.12833E+07                           STORAGE =   0.95019E+06
     CONSTANT HEAD =   0.00000E+00                     CONSTANT HEAD =   0.00000E+00
    HEAD DEP BOUNDS =      68621.                    HEAD DEP BOUNDS =      56723.
    RESERV. LEAKAGE =  0.00000E+00                    RESERV. LEAKAGE =  0.00000E+00
         TOTAL OUT =   0.13519E+07                        TOTAL OUT =   0.10069E+07
          IN - OUT =      -17.125                         IN - OUT =      -24.375
  PERCENT DISCREPANCY =            0.00          PERCENT DISCREPANCY =            0.00




        TIME SUMMARY AT END OF TIME STEP  2 IN STRESS PERIOD  1
                         SECONDS      MINUTES      HOURS       DAYS        YEARS
                         -------------------------------------------------------------
       TIME STEP LENGTH   86400.0     1440.00     24.0000     1.00000    0.273785E-02
      STRESS PERIOD TIME   172800.     2880.00     48.0000     2.00000    0.547570E-02
  TOTAL SIMULATION TIME   172800.     2880.00     48.0000     2.00000    0.547570E-02

                              STRESS PERIOD NO.  2, LENGTH =   2.000000
                              ------------------------------------------

                              NUMBER OF TIME STEPS =    2

                              MULTIPLIER FOR DELT =    1.000

                              INITIAL TIME STEP SIZE =   1.000000

REUSING HEAD-DEPENDENT BOUNDS FROM LAST STRESS PERIOD
RESERVOIR CONDITIONS FOR STRESS PERIOD   2, STEP   1 TIME   3.0000
RESERVOIR   HEAD          AREA          VOLUME
-----------------------------------------------
       1   13.000     0.47000E+06  0.23100E+07
```

```
       8 ITERATIONS FOR TIME STEP    1 IN STRESS PERIOD  2
HEAD/DRAWDOWN PRINTOUT FLAG = 0      TOTAL BUDGET PRINTOUT FLAG = 0      CELL-BY-CELL FLOW TERM FLAG = 0
OUTPUT FLAGS FOR EACH LAYER:
          HEAD    DRAWDOWN  HEAD   DRAWDOWN
LAYER  PRINTOUT  PRINTOUT  SAVE    SAVE
-------------------------------------------
   1      0         0        0       0
RESERVOIR CONDITIONS FOR STRESS PERIOD  2, STEP   2 TIME   4.0000
  RESERVOIR  HEAD         AREA         VOLUME
--------------------------------------------------
      1    14.000    0.47000E+06  0.27800E+07
       8 ITERATIONS FOR TIME STEP    2 IN STRESS PERIOD  2
MAXIMUM HEAD CHANGE FOR EACH ITERATION:
  HEAD CHANGE LAYER,ROW,COL HEAD CHANGE LAYER,ROW,COL HEAD CHANGE LAYER,ROW,COL HEAD CHANGE LAYER,ROW,COL HEAD CHANGE LAYER,ROW,COL
-----------------------------------------------------------------------------------------------------------------------------------
   1.015     ( 1,  9, 10) 0.9675     ( 1,  1, 10) 0.4340     ( 1, 11,  4) 0.5330E-01 ( 1,  2,  4) -0.5397E-02 ( 1,  2,  3)
   0.1282E-02 ( 1, 10,  3) 0.1056E-02 ( 1, 11,  3) 0.3297E-03 ( 1, 12,  1)

HEAD/DRAWDOWN PRINTOUT FLAG = 1      TOTAL BUDGET PRINTOUT FLAG = 1      CELL-BY-CELL FLOW TERM FLAG = 0
OUTPUT FLAGS FOR EACH LAYER:
          HEAD    DRAWDOWN  HEAD   DRAWDOWN
LAYER  PRINTOUT  PRINTOUT  SAVE    SAVE
-------------------------------------------
   1      1         0        1       0
                 HEAD IN LAYER  1 AT END OF TIME STEP  2 IN STRESS PERIOD  2
          -------------------------------------------------------------------------

          1      2      3      4      5      6      7      8      9     10     11     12
          ...............................................................................
   1    5.23   5.92   6.75   7.63   8.42   8.94   9.15   9.06   8.68   8.03   7.21   6.42
   2    5.37   6.11   7.05   8.10   9.07   9.65   9.87   9.78   9.38   8.64   7.59   6.68
   3    5.59   6.44   7.59   9.01  10.48  11.11  11.31  11.22  10.83   9.99   8.24   7.09
   4    5.83   6.79   8.20  10.19  11.32  11.86  12.03  11.93  11.52  10.61   8.72   7.44
   5    5.99   7.01   8.53  10.64  11.70  12.20  12.36  12.25  11.82  10.88   8.96   7.64
   6    6.00   7.05   8.60  10.73  11.78  12.27  12.43  12.31  11.88  10.93   9.00   7.67
   7    5.86   6.88   8.41  10.53  11.61  12.11  12.27  12.16  11.74  10.79   8.84   7.51
   8    5.57   6.51   7.91   9.95  11.10  11.64  11.82  11.72  11.31  10.38   8.43   7.15
   9    5.17   5.98   7.09   8.50  10.03  10.65  10.86  10.77  10.39   9.54   7.74   6.60
  10    4.77   5.44   6.29   7.27   8.19   8.73   8.93   8.85   8.48   7.79   6.79   5.95
  11    4.44   5.02   5.70   6.42   7.07   7.50   7.67   7.59   7.27   6.74   6.05   5.40
  12    4.27   4.79   5.39   6.00   6.53   6.90   7.05   6.97   6.69   6.23   5.67   5.11


                   VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  2 IN STRESS PERIOD  2
                 ----------------------------------------------------------------------------------
           CUMULATIVE VOLUMES     L**3                         RATES FOR THIS TIME STEP      L**3/T
           ------------------                                  ------------------------

                   IN:                                                 IN:
                   ---                                                 ---
              STORAGE =   0.00000E+00                             STORAGE =   0.00000E+00
        CONSTANT HEAD =   0.00000E+00                       CONSTANT HEAD =   0.00000E+00
       HEAD DEP BOUNDS =  0.00000E+00                      HEAD DEP BOUNDS =  0.00000E+00
       RESERV. LEAKAGE =  0.27705E+07                      RESERV. LEAKAGE =  0.64018E+06
              TOTAL IN =  0.27705E+07                             TOTAL IN =  0.64018E+06
                  OUT:                                                OUT:
                  ----                                                ----
              STORAGE =   0.24523E+07                             STORAGE =   0.49544E+06
        CONSTANT HEAD =   0.00000E+00                       CONSTANT HEAD =   0.00000E+00
       HEAD DEP BOUNDS =  0.31825E+06                      HEAD DEP BOUNDS =  0.14474E+06
       RESERV. LEAKAGE =  0.00000E+00                      RESERV. LEAKAGE =  0.00000E+00
             TOTAL OUT =  0.27706E+07                            TOTAL OUT =  0.64018E+06
              IN - OUT =  -21.750                                 IN - OUT =  -2.4375
       PERCENT DISCREPANCY =            0.00               PERCENT DISCREPANCY =            0.00



          TIME SUMMARY AT END OF TIME STEP  2 IN STRESS PERIOD  2
                          SECONDS       MINUTES       HOURS         DAYS        YEARS
                      ---------------------------------------------------------------------
         TIME STEP LENGTH     86400.0      1440.00      24.0000      1.00000    0.273785E-02
      STRESS PERIOD TIME      172800.      2880.00      48.0000      2.00000    0.547570E-02
   TOTAL SIMULATION TIME      345600.      5760.00      96.0000      4.00000    0.109514E-01

                                 STRESS PERIOD NO.   3, LENGTH =   5.000000
                                 -------------------------------------------------

                                 NUMBER OF TIME STEPS =     5

                                 MULTIPLIER FOR DELT =     1.000

                                 INITIAL TIME STEP SIZE =   1.000000
REUSING HEAD-DEPENDENT BOUNDS FROM LAST STRESS PERIOD
RESERVOIR CONDITIONS FOR STRESS PERIOD  3, STEP   1 TIME   5.0000
  RESERVOIR  HEAD         AREA         VOLUME
--------------------------------------------------
      1    12.000    0.47000E+06  0.18400E+07
```

```
       6 ITERATIONS FOR TIME STEP   1 IN STRESS PERIOD  3
HEAD/DRAWDOWN PRINTOUT FLAG = 0      TOTAL BUDGET PRINTOUT FLAG = 0      CELL-BY-CELL FLOW TERM FLAG = 0
OUTPUT FLAGS FOR EACH LAYER:
          HEAD    DRAWDOWN  HEAD   DRAWDOWN
LAYER  PRINTOUT  PRINTOUT  SAVE    SAVE
-----------------------------------------------
   1      0         0        0       0
RESERVOIR CONDITIONS FOR STRESS PERIOD   3, STEP   2 TIME   6.0000
 RESERVOIR    HEAD         AREA          VOLUME

-----------------------------------------------
      1     10.000     0.33000E+06 0.90000E+06
       6 ITERATIONS FOR TIME STEP   2 IN STRESS PERIOD  3
HEAD/DRAWDOWN PRINTOUT FLAG = 0      TOTAL BUDGET PRINTOUT FLAG = 0      CELL-BY-CELL FLOW TERM FLAG = 0
REUSING PREVIOUS VALUES OF IOFLG
RESERVOIR CONDITIONS FOR STRESS PERIOD   3, STEP   3 TIME   7.0000
 RESERVOIR    HEAD         AREA          VOLUME

-----------------------------------------------
      1     8.0000     0.19000E+06 0.31000E+06
       6 ITERATIONS FOR TIME STEP   3 IN STRESS PERIOD  3
HEAD/DRAWDOWN PRINTOUT FLAG = 0      TOTAL BUDGET PRINTOUT FLAG = 0      CELL-BY-CELL FLOW TERM FLAG = 0
REUSING PREVIOUS VALUES OF IOFLG
RESERVOIR CONDITIONS FOR STRESS PERIOD   3, STEP   4 TIME   8.0000
 RESERVOIR    HEAD         AREA          VOLUME

-----------------------------------------------
      1     6.0000     0.00000E+00 0.00000E+00
       6 ITERATIONS FOR TIME STEP   4 IN STRESS PERIOD  3
HEAD/DRAWDOWN PRINTOUT FLAG = 0      TOTAL BUDGET PRINTOUT FLAG = 0      CELL-BY-CELL FLOW TERM FLAG = 0
REUSING PREVIOUS VALUES OF IOFLG
RESERVOIR CONDITIONS FOR STRESS PERIOD   3, STEP   5 TIME   9.0000
 RESERVOIR    HEAD         AREA          VOLUME

-----------------------------------------------
      1     4.0000     0.00000E+00 0.00000E+00
       5 ITERATIONS FOR TIME STEP   5 IN STRESS PERIOD  3
MAXIMUM HEAD CHANGE FOR EACH ITERATION:
  HEAD CHANGE LAYER,ROW,COL  HEAD CHANGE LAYER,ROW,COL  HEAD CHANGE LAYER,ROW,COL  HEAD CHANGE LAYER,ROW,COL  HEAD CHANGE LAYER,ROW,COL
-----------------------------------------------------------------------------------------------------------------------------------
  -0.2055   ( 1,  1,  8) -0.2675   ( 1,  2,  9) -0.1547   ( 1,  5,  8) -0.2046E-01 ( 1,  5,  7)  0.8916E-03 ( 1,  1, 11)

HEAD/DRAWDOWN PRINTOUT FLAG = 1      TOTAL BUDGET PRINTOUT FLAG = 1      CELL-BY-CELL FLOW TERM FLAG = 0
OUTPUT FLAGS FOR EACH LAYER:
          HEAD    DRAWDOWN  HEAD   DRAWDOWN
LAYER  PRINTOUT  PRINTOUT  SAVE    SAVE
-----------------------------------------------
   1      1         0        1       0
                  HEAD IN LAYER  1 AT END OF TIME STEP  5 IN STRESS PERIOD  3
              ...........................................................

        1      2      3      4      5      6      7      8      9     10     11     12
   ........................................................................................
   1   5.81   6.32   6.76   7.11   7.37   7.52   7.57   7.50   7.32   7.02   6.61   6.10
   2   5.81   6.32   6.75   7.10   7.36   7.52   7.57   7.50   7.32   7.02   6.61   6.10
   3   5.80   6.31   6.74   7.09   7.35   7.51   7.55   7.49   7.31   7.01   6.60   6.09
   4   5.79   6.30   6.73   7.08   7.33   7.49   7.54   7.47   7.29   6.99   6.59   6.07
   5   5.77   6.27   6.71   7.05   7.31   7.46   7.51   7.45   7.27   6.97   6.56   6.05
   6   5.74   6.24   6.67   7.02   7.27   7.43   7.47   7.41   7.23   6.94   6.53   6.02
   7   5.70   6.21   6.64   6.98   7.23   7.38   7.43   7.37   7.19   6.89   6.49   5.98
   8   5.66   6.17   6.59   6.93   7.18   7.33   7.38   7.31   7.13   6.84   6.44   5.94
   9   5.62   6.12   6.54   6.88   7.13   7.28   7.33   7.26   7.08   6.79   6.39   5.89
  10   5.59   6.08   6.50   6.84   7.09   7.24   7.28   7.21   7.03   6.74   6.35   5.85
  11   5.56   6.05   6.47   6.81   7.05   7.20   7.24   7.17   6.99   6.71   6.31   5.82
  12   5.54   6.03   6.45   6.79   7.03   7.18   7.22   7.15   6.97   6.69   6.29   5.80


                VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  5 IN STRESS PERIOD  3
     -----------------------------------------------------------------------------------------
              CUMULATIVE VOLUMES      L**3                        RATES FOR THIS TIME STEP      L**3/T
              ------------------                                  ------------------------


                  IN:                                                  IN:
                  ---                                                  ---

              STORAGE =   0.67165E+06                             STORAGE =   0.14013E+06
        CONSTANT HEAD =   0.00000E+00                       CONSTANT HEAD =   0.00000E+00
       HEAD DEP BOUNDS =   0.00000E+00                      HEAD DEP BOUNDS =   0.00000E+00
        RESERV. LEAKAGE =   0.30880E+07                     RESERV. LEAKAGE =   0.00000E+00
             TOTAL IN =   0.37597E+07                            TOTAL IN =   0.14013E+06
                 OUT:                                                 OUT:
                 ----                                                 ----

              STORAGE =   0.26255E+07                             STORAGE =   0.00000E+00
        CONSTANT HEAD =   0.00000E+00                       CONSTANT HEAD =   0.00000E+00
      HEAD DEP BOUNDS =   0.10985E+07                      HEAD DEP BOUNDS =   0.14011E+06
      RESERV. LEAKAGE =     35688.                        RESERV. LEAKAGE =   0.00000E+00
            TOTAL OUT =   0.37597E+07                           TOTAL OUT =   0.14011E+06
             IN - OUT =  -32.750                                 IN - OUT =   19.078
   PERCENT DISCREPANCY =              0.00             PERCENT DISCREPANCY =                0.01


          TIME SUMMARY AT END OF TIME STEP  5 IN STRESS PERIOD  3
                           SECONDS      MINUTES      HOURS       DAYS        YEARS
                        --------------------------------------------------------------
       TIME STEP LENGTH   86400.0     1440.00      24.0000     1.00000    0.273785E-02
     STRESS PERIOD TIME   432000.     7200.00      120.000     5.00000    0.136893E-01
 TOTAL SIMULATION TIME   777600.     12960.0       216.000     9.00000    0.246407E-01
```