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Techniques of Water-Resources Investigations of the United States Geological Survey

Chapter A1

A MODULAR THREE-DIMENSIONAL FINITE-DIFFERENCE GROUND-WATER FLOW MODEL

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Book 6

MODELING TECHNIQUES

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Narrative for Module SBCF1H

Module SBCF1H calculates the horizontal-branch conductances (conductance between nodes) for a layer in which the transmissivity is a function of head (LAYCON = 1 or 3). It calculates the transmissivity internally and calls submodule SBCF1C to calculate the branch conductances. It is called by BCF1FM for each type 1 or type 3 layer at each iteration. Transmissivity is the product of hydraulic conductivity and saturated thickness. The saturated thickness of a completely saturated layer is computed as the elevation of the top (TOP) minus the elevation of the bottom (BOT), the thickness of the layer. For a partially saturated layer, saturated thickness is computed as the head in the cell minus the elevation of the bottom of the layer.

1. For each cell, calculate the transmissivity. DO STEPS 2-6.

2. If the cell is inactive, set the transmissivity equal to zero and move on to the next cell.

3. Calculate the thickness of the saturation. In a strictly unconfined layer, the thickness is the head (HNEW) minus the bottom (BOTTOM). In a confined/unconfined layer, the thickness is the head (HNEW) minus the bottom or the top (TOP) minus the bottom, whichever is greater.

4. Check to see if the saturated thickness is greater than zero.

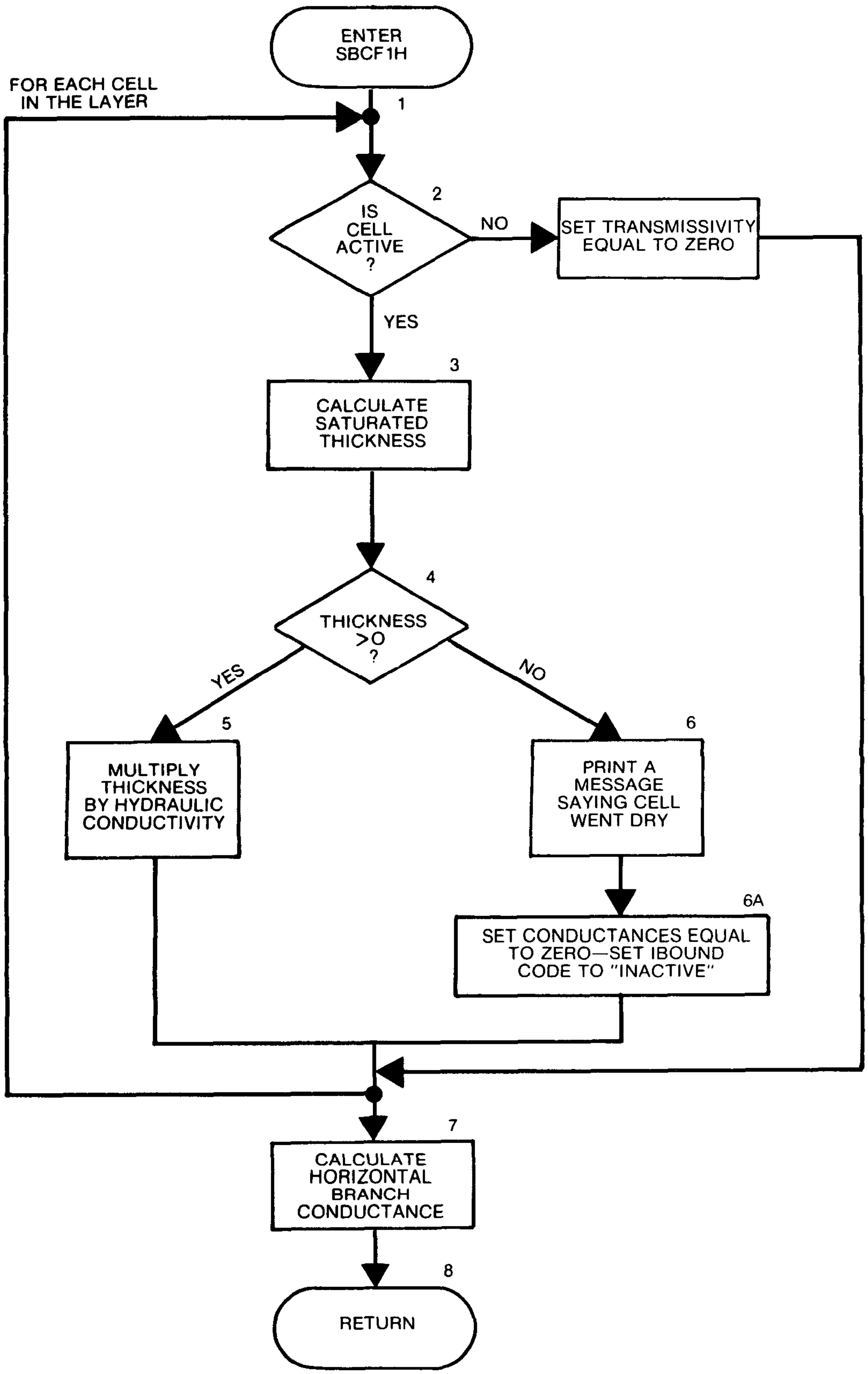
5. If the thickness is greater than zero, the transmissivity of the cell is the thickness times the hydraulic conductivity.

6. If the saturated thickness is less than zero, the cell is dry. Print a message to that effect, set all branch conductances equal to zero, and set the boundary indicator (IBOUND) equal to zero.

7. Call submodule SBCF1C to calculate the horizontal-branch conductances for the layer.

8. RETURN.

Flow Chart for Module SBCF1H



```
      SUBROUTINE SBCF1H(HNEW,IBOUND,CR,CC,CV,HY,TRPY,DELR,DELC
     1,BOT,TOP,K,KB,KT,KITER,KSTP,KPER,NCOL,NROW,NLAY,IOUT)
C
C-----VERSION 1442 31DEC1986 SBCF1H
C
C     ******************************************************************
C     COMPUTE CONDUCTANCE FROM SATURATED THICKNESS AND HYDRAULIC
C     CONDUCTIVITY
C     ******************************************************************
C
C      SPECIFICATIONS:
C     ------------------------------------------------------------------
      DOUBLE PRECISION HNEW
C
      DIMENSION HNEW(NCOL,NROW,NLAY),IBOUND(NCOL,NROW,NLAY)
     1, CR(NCOL,NROW,NLAY), CC(NCOL,NROW,NLAY), CV(NCOL,NROW,NLAY)
     2,HY(NCOL,NROW,NLAY), TRPY(NLAY), DELR(NCOL), DELC(NROW)
     3, BOT(NCOL,NROW,NLAY),TOP(NCOL,NROW,NLAY)
C
      COMMON /FLWCOM/LAYCON(80)
C     ------------------------------------------------------------------
C
C1------CALCULATE TRANSMISSIVITY AT EACH ACTIVE CELL. TRANSMISSIVITY
C1------WILL BE STORED TEMPORARILY IN THE CC ARRAY.
      DO 200 I=1,NROW
      DO 200 J=1,NCOL
C
C2------IF CELL IS INACTIVE THEN SET T=0 & MOVE ON TO NEXT CELL.
      IF(IBOUND(J,I,K).NE.0) GO TO 10
      CC(J,I,K)=0.
      GO TO 200
C
C3------CALCULATE SATURATED THICKNESS.
   10 HD=HNEW(J,I,K)
      IF(LAYCON(K).EQ.1) GO TO 50
      IF(HD.GT.TOP(J,I,KT)) HD=TOP(J,I,KT)
   50 THCK=HD-BOT(J,I,KB)
C
C4------CHECK TO SEE IF SATURATED THICKNESS IS GREATER THAN ZERO.
      IF(THCK.LE.0.) GO TO 100
C
C5------IF SATURATED THICKNESS>0 THEN T=K*THICKNESS.
      CC(J,I,K)=THCK*HY(J,I,KB)
      GO TO 200
C
C6------WHEN SATURATED THICKNESS < 0, PRINT A MESSAGE AND SET
C6------TRANSMISSIVITY, IBOUND, AND VERTICAL CONDUCTANCE =0
  100 WRITE(IOUT,150) K,I,J,KITER,KSTP,KPER
  150 FORMAT(1H0,10('*'),'NODE',3I4,' (LAYER,ROW,COL) WENT DRY'
     1      ,' AT ITERATION =',I3,'  TIME STEP =',I3
     2      ,'  STRESS PERIOD =',I3)
      HNEW(J,I,K)=1.E30
      CC(J,I,K)=0.
      IBOUND(J,I,K)=0
      IF(K.LT.NLAY) CV(J,I,K)=0.
      IF(K.GT.1) CV(J,I,K-1)=0.
      GO TO 200
  200 CONTINUE
C
C7------COMPUTE HORIZONTAL BRANCH CONDUCTANCES FROM TRANSMISSIVITY
      CALL SBCF1C(CR,CC,TRPY,DELR,DELC,K,NCOL,NROW,NLAY)
C
C8------RETURN
      RETURN
      END
```

List of Variables for Module SBCF1H

Variable	Range	Definition
BOT	Package	DIMENSION (NCOL,NROW,NBOT), Elevation of the bottom of each layer. (NBOT is the number of layers for which LAYCON = 1 or 3.)
CC	Global	DIMENSION (NCOL,NROW,NLAY), Conductance in the column direction. CC(J,I,K) contains conductance between nodes (J,I,K) and (J,I+1,K). This array is used to temporarily hold transmissivity.
CR	Global	DIMENSION (NCOL,NROW,NLAY), Conductance in the row direction. CR(J,I,K) contains conductance between nodes (J,I,K) and (J+1,I,K).
CV	Global	DIMENSION (NCOL,NROW,NLAY-1), Conductance in the vertical direction. CV(J,I,K) contains conductance between nodes (J,I,K) and (J,I,K+1).
DELC	Global	DIMENSION (NROW), Cell dimension in the column direction. DELC(I) contains the width of row I.
DELR	Global	DIMENSION (NCOL), Cell dimension in the row direction. DELR(J) contains the width of column J.
HD	Module	Temporary label for an element in HNEW.
HNEW	Global	DIMENSION (NCOL,NROW,NLAY), Most recent estimate of head in each cell. HNEW changes at each iteration.
HY	Package	DIMENSION (NCOL,NROW,NBOT), Hydraulic conductivity of the cell. (NBOT is the number of layers where LAYCON = 1 or 3.)
I	Module	Index for rows.
IBOUND	Global	DIMENSION (NCOL,NROW,NLAY), Status of each cell. < 0, constant-head cell = 0, inactive cell > 0, variable-head cell
IOUT	Global	Primary unit number for all printed output. IOUT = 6.
J	Module	Index for columns.
K	Module	Index for layers.
KB	Module	Index for bottom of layers.
KITER	Global	Iteration counter. Reset at the start of each time step.
KPER	Global	Stress period counter.
KSTP	Global	Time step counter. Reset at the start of each stress period.
KT	Module	Index for tops of layers.
LAYCON	Package	DIMENSION(80), Layer type code: 0 - Layer strictly confined. 1 - Layer strictly unconfined. 2 - Layer confined/unconfined (transmissivity is constant) 3 - Layer confined/unconfined (transmissivity varies).
NCOL	Global	Number of columns in the grid.
NLAY	Global	Number of layers in the grid.
NROW	Global	Number of rows in the grid.
THCK	Module	Saturated thickness.
TOP	Package	DIMENSION (NCOL,NROW,NTOP), Elevation of top of layers. (NTOP is number of layers for which LAYCON = 2 or 3.)
TRPY	Package	DIMENSION (NLAY), Ratio of transmissivity in the column direction to transmissivity in the row direction.

Narrative for Module SBCF1C

The module SBCF1C calculates horizontal-branch conductances for a layer from transmissivity and cell dimensions. It is called by submodules SBCF1N and SBCF1H. Recall that the branch conductances between two nodes can be expressed by

$$C = C_1C_2/(C_1 + C_2).$$

However, C_1 and C_2 can be represented by

$$C_1 = T_1W/(L_1/2)$$

$$C_2 = T_2W/(L_2/2).$$

Thus,

$$C = 2T_1T_2W/(T_1L_2 + T_2L_1).$$

This equation is used to calculate conductances along rows and columns. When calculating conductance along rows, L_1 and L_2 are DELR(J) and DELR(J+1), respectively, and W is DELC(I). When calculating conductance along columns, L_1 and L_2 are DELC(I) and DELC(I+1), respectively, and W is DELR(J). Conductance along columns is also multiplied by TRPY(K), the ratio of conductivity in the column direction to conductivity in the row direction in layer K.

1. Process cells one at a time calculating branch conductances from that cell to the one on the right and the one in front.

2. If the transmissivity is equal to zero, set the branch conductance equal to zero and skip to the next cell.

3. If the transmissivity of the cell is not zero and if there is a cell to the right, calculate the branch conductance (CR) along the row.

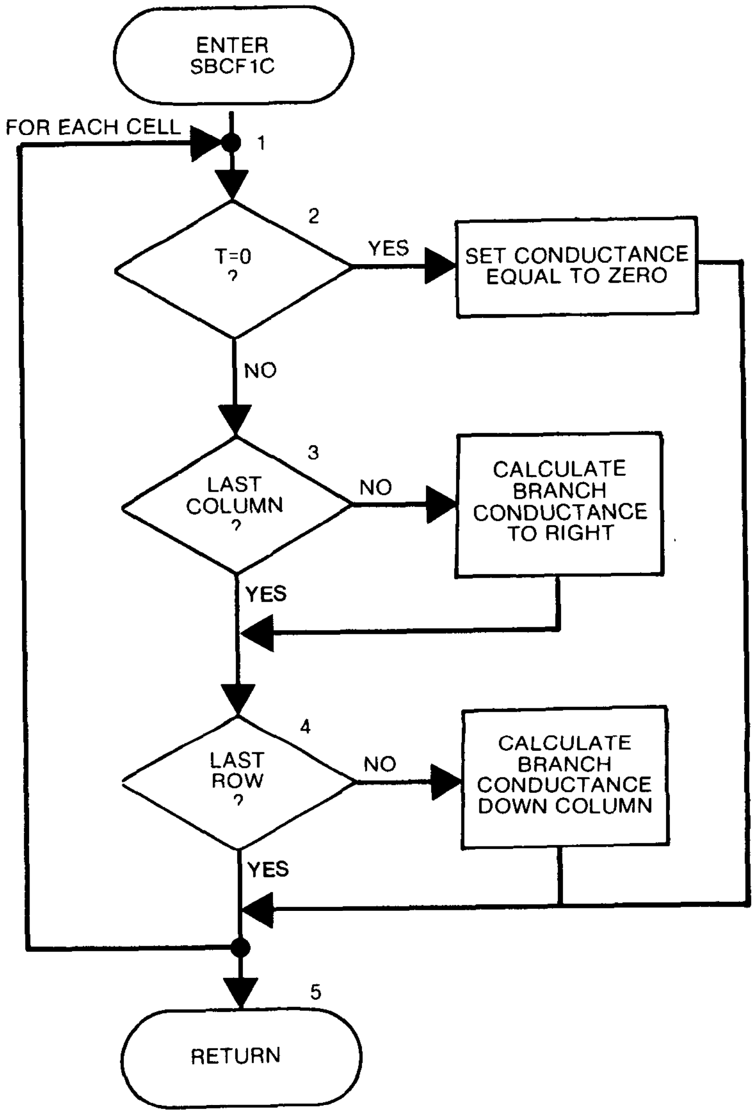
4. If the transmissivity of the cell is not zero and there is a cell in front, calculate the conductance along the column.

5. RETURN.

Note: Transmissivity, which was temporarily stored in CC, will be lost when conductances are calculated.

CR(J,I,K) contains the conductance $CR_{i,j+1/2,k}$ between node J,I,K and node J+1,I,K.

Flow Chart for Module SBCF1C



```
      SUBROUTINE SBCF1C(CR,CC,TRPY,DELR,DELC,K,NCOL,NROW,NLAY)
C
C
C-----VERSION 1334 22AUG1987 SBCF1C
C     ******************************************************************
C     COMPUTE BRANCH CONDUCTANCE USING HARMONIC MEAN OF BLOCK
C     CONDUCTANCES -- BLOCK TRANSMISSIVITY IS IN CC UPON ENTRY
C     ******************************************************************
C
C      SPECIFICATIONS:
C     ------------------------------------------------------------------
C
      DIMENSION CR(NCOL,NROW,NLAY), CC(NCOL,NROW,NLAY)
     2   , TRPY(NLAY), DELR(NCOL), DELC(NROW)
C
C     ------------------------------------------------------------------
      YX=TRPY(K)*2.
C
C1------FOR EACH CELL CALCULATE BRANCH CONDUCTANCES FROM THAT CELL
C1------TO THE ONE ON THE RIGHT AND THE ONE IN FRONT.
      DO 40 I=1,NROW
      DO 40 J=1,NCOL
      T1=CC(J,I,K)
C
C2------IF T=0 THEN SET CONDUCTANCE EQUAL TO 0. GO ON TO NEXT CELL.
      IF(T1.NE.0.) GO TO 10
      CR(J,I,K)=0.
      GO TO 40
C
C3------IF THIS IS NOT THE LAST COLUMN(RIGHTMOST) THEN CALCULATE
C3------BRANCH CONDUCTANCE IN THE ROW DIRECTION (CR) TO THE RIGHT.
   10 IF(J.EQ.NCOL) GO TO 30
      T2=CC(J+1,I,K)
      CR(J,I,K)=2.*T2*T1*DELC(I)/(T1*DELR(J+1)+T2*DELR(J))
C
C4------IF THIS IS NOT THE LAST ROW(FRONTMOST) THEN CALCULATE
C4------BRANCH CONDUCTANCE IN THE COLUMN DIRECTION (CC) TO THE FRONT.
   30 IF(I.EQ.NROW) GO TO 40
      T2=CC(J,I+1,K)
      CC(J,I,K)=YX*T2*T1*DELR(J)/(T1*DELC(I+1)+T2*DELC(I))
   40 CONTINUE
C
C5------RETURN
      RETURN
      END
```

List of Variables for Module SBCF1C

Variable	Range	Definition
CC	Global	DIMENSION (NCOL,NROW,NLAY), Conductance in the column direction. CC(J,I,K) contains conductance between nodes (J,I,K) and (J,I+1,K). This array is used to temporarily hold transmissivity.
CR	Global	DIMENSION (NCOL,NROW,NLAY), Conductance in the row direction. CR(J,I,K) contains conductance between nodes (J,I,K) and (J+1,I,K).
DELC	Global	DIMENSION (NROW), Cell dimension in the column direction. DELC(I) contains the width of row I.
DELR	Global	DIMENSION (NCOL), Cell dimension in the row direction. DELR(J) contains the width of column J.
I	Module	Index for rows.
J	Module	Index for columns.
K	Module	Index for layers.
NCOL	Global	Number of columns in the grid.
NLAY	Global	Number of layers in the grid.
NROW	Global	Number of rows in the grid.
TRPY	Package	DIMENSION (NLAY), Ratio of transmissivity in the column direction to transmissivity in the row direction.
T1	Module	Temporary field for CC(J,I,K).
T2	Module	Temporary field for CC(J+1,I,K).
YX	Module	TRPY(K)*2.

Narrative for Module SBCF1B

This module calculates flow across cell faces. It is called by module BCF1BD when the user has requested cell-by-cell flow terms. It performs its tasks in the following order:

1. Clear the buffer (BUFF) in which cell-by-cell flow terms are gathered as they are calculated.

2. For each cell, calculate the flow in the row direction through the right face of the cell and store it in the buffer.

3. Call utility module UBUDSV to write the contents of the buffer.

4. Clear the buffer (BUFF) in which cell-by-cell flow terms are gathered as they are calculated.

5. For each cell, calculate the flow in the column direction through the front face of the cell and store it in the buffer.

6. Call utility module UBUDSV to write the contents of the buffer.

7. Clear the buffer (BUFF) in which cell-by-cell flow terms are gathered as they are calculated.

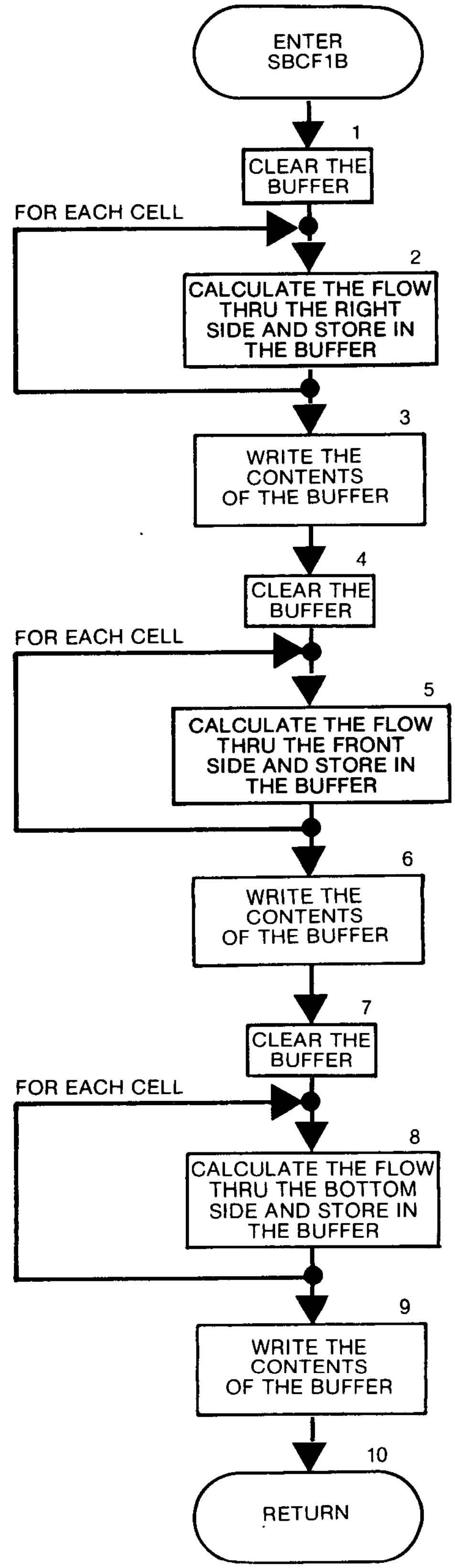
8. For each cell, calculate the flow in the vertical direction through the lower face of the cell and store it in the buffer.

9. Call utility module UBUDSV to write the contents of the buffer.

10. RETURN.

Flow Chart for Module SBCF1B

BUFFER: the buffer is an array with one element for each cell in the grid. It is used to store the results of cell-by-cell calculations until all cells have been processed. The contents of the buffer are then recorded as a unit.



```
      SUBROUTINE SBCF1B(HNEW,IBOUND,CR,CC,CV,TOP,NCOL,NROW,NLAY,
     1       KSTP,KPER,IBCFCB,BUFF,IOUT)
C
C-----VERSION 1548 12MAY1987 SBCF1B
C
C     ******************************************************************
C     COMPUTE FLOW ACROSS EACH CELL WALL
C     ******************************************************************
C
C     SPECIFICATIONS:
C     ------------------------------------------------------------------
      CHARACTER*4 TEXT
      DOUBLE PRECISION HNEW,HD
C
      DIMENSION HNEW(NCOL,NROW,NLAY), IBOUND(NCOL,NROW,NLAY),
     1      CR(NCOL,NROW,NLAY), CC(NCOL,NROW,NLAY),
     2      CV(NCOL,NROW,NLAY), TOP(NCOL,NROW,NLAY),
     3      BUFF(NCOL,NROW,NLAY)
C
      COMMON /FLWCOM/LAYCON(80)
C
      DIMENSION TEXT(12)
C
      DATA TEXT(1),TEXT(2),TEXT(3),TEXT(4),TEXT(5),TEXT(6),TEXT(7),
     1   TEXT(8),TEXT(9),TEXT(10),TEXT(11),TEXT(12)
     2   /'FLOW',' RIG','HT F','ACE ',
     2    'FLOW',' FRO','NT F','ACE ','FLOW',' LOW','ER F','ACE '/
C     ------------------------------------------------------------------
C
      NCM1=NCOL-1
      IF(NCM1.LT.1) GO TO 405
C
C1------CLEAR THE BUFFER
      DO 310 K=1,NLAY
      DO 310 I=1,NROW
      DO 310 J=1,NCOL
      BUFF(J,I,K)=0.
  310 CONTINUE
C
C2------FOR EACH CELL CALCULATE FLOW THRU RIGHT FACE & STORE IN BUFFER
      DO 400 K=1,NLAY
      DO 400 I=1,NROW
      DO 400 J=1,NCM1
      IF((IBOUND(J,I,K).LE.0) .AND. (IBOUND(J+1,I,K).LE.0)) GO TO 400
      HDIFF=HNEW(J,I,K)-HNEW(J+1,I,K)
      BUFF(J,I,K)=HDIFF*CR(J,I,K)
  400 CONTINUE
C
C3------RECORD CONTENTS OF BUFFER
      CALL UBUDSV(KSTP,KPER,TEXT(1),IBCFCB,BUFF,NCOL,NROW,NLAY,IOUT)
C
```

```
C4-----CLEAR THE BUFFER
  405 NRM1=NROW-1
      IF(NRM1.LT.1) GO TO 505
      DO 410 K=1,NLAY
      DO 410 I=1,NROW
      DO 410 J=1,NCOL
      BUFF(J,I,K)=0.
  410 CONTINUE
C
C5-----FOR EACH CELL CALCULATE FLOW THRU FRONT FACE & STORE IN BUFFER
      DO 500 K=1,NLAY
      DO 500 I=1,NRM1
      DO 500 J=1,NCOL
      IF((IBOUND(J,I,K).LE.0) .AND. (IBOUND(J,I+1,K).LE.0)) GO TO 500
      HDIFF=HNEW(J,I,K)-HNEW(J,I+1,K)
      BUFF(J,I,K)=HDIFF*CC(J,I,K)
  500 CONTINUE
C
C6-----RECORD CONTENTS OF BUFFER.
      CALL UBUDSV(KSTP,KPER,TEXT(5),IBCFCB,BUFF,NCOL,NROW,NLAY,IOUT)
  505 NLM1=NLAY-1
      IF(NLM1.LT.1) GO TO 1000
C
C7-----CLEAR THE BUFFER
      DO 510 K=1,NLAY
      DO 510 I=1,NROW
      DO 510 J=1,NCOL
      BUFF(J,I,K)=0.
  510 CONTINUE
C
C8-----FOR EACH CELL CALCULATE FLOW THRU LOWER FACE & STORE IN BUFFER
      KT=0
      DO 600 K=1,NLM1
      IF(LAYCON(K).EQ.3 .OR. LAYCON(K).EQ.2) KT=KT+1
      DO 600 I=1,NROW
      DO 600 J=1,NCOL
      IF((IBOUND(J,I,K).LE.0) .AND. (IBOUND(J,I,K+1).LE.0)) GO TO 600
      HD=HNEW(J,I,K+1)
      IF(LAYCON(K+1).NE.3 .AND. LAYCON(K+1).NE.2) GO TO 580
      TMP=HD
      IF(TMP.LT.TOP(J,I,KT+1)) HD=TOP(J,I,KT+1)
  580 HDIFF=HNEW(J,I,K)-HD
      BUFF(J,I,K)=HDIFF*CV(J,I,K)
  600 CONTINUE
C
C9-----RECORD CONTENTS OF BUFFER.
      CALL UBUDSV(KSTP,KPER,TEXT(9),IBCFCB,BUFF,NCOL,NROW,NLAY,IOUT)
C
C10----RETURN
 1000 RETURN
      END
```

List of Variables for Module SBCF1B

Variable	Range	Definition
BUFF	Global	DIMENSION (NCOL,NROW,NLAY), Buffer used to accumulate information before printing or recording it.
CC	Global	DIMENSION (NCOL,NROW,NLAY), Conductance in the column direction. CC(J,I,K) contains conductance between nodes (J,I,K) and (J,I+1,K).
CR	Global	DIMENSION (NCOL,NROW,NLAY), Conductance in the row direction. CR(J,I,K) contains conductance between nodes (J,I,K) and (J+1,I,K).
CV	Global	DIMENSION (NCOL,NROW,NLAY-1), Conductance in the vertical direction. CV(J,I,K) contains conductance between nodes (J,I,K) and (J,I,K+1).
HD	Module	Temporary field for head.
HDIFF	Module	Head difference between two adjacent nodes.
HNEW	Global	DIMENSION (NCOL,NROW,NLAY), Most recent estimate of head in each cell. HNEW changes at each iteration.
I	Module	Index for rows.
IBCFCB	Package	Flag and a unit number. > 0, unit number on which the cell-by-cell flow terms will be recorded whenever ICBCFL is set. = 0, cell-by-cell flow terms will be not be printed or recorded < 0, flow from each constant-head cell will be printed whenever ICBCFL is set.
IBOUND	Global	DIMENSION (NCOL,NROW,NLAY), Status of each cell. < 0, constant-head cell = 0, inactive cell > 0, variable-head cell
IOUT	Global	Primary unit number for all printed output. IOUT = 6.
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.
KT	Module	Index for tops of layers.
LAYCON	Package	DIMENSION(80), Layer type code: 0 - Layer strictly confined. 1 - Layer strictly unconfined. 2 - Layer confined/unconfined (transmissivity is constant) 3 - Layer confined/unconfined (transmissivity varies).
NCM1	Module	NCOL-1.
NCOL	Global	Number of columns in the grid.
NLAY	Global	Number of layers in the grid.
NLM1	Module	NLAY-1.
NRM1	Module	NROW-1.
NROW	Global	Number of rows in the grid.
TEXT	Module	Label to be printed or recorded with array data.
TMP	Module	Temporary field for head.
TOP	Package	DIMENSION (NCOL,NROW,NTOP), Elevation of top of layers. (NTOP is number of layers for which LAYCON = 2 or 3.)

Narrative for Module SBCF1F

This module calculates flow from constant-head cells. The flows are accumulated by sign to get flow into (CHIN) and out of (CHOUT), the flow field for inclusion in the overall volumetric budget. The flows are also accumulated by cell to get the total flow from each constant-head cell on a cell-by-cell basis. Module SBCF1F is called by module BCF1BD and calls utility module UBUDSV.

Module SBCF1F performs its functions in the following order:

1. Clear the fields CHIN and CHOUT in which flow into and out of the flow field, respectively, will be accumulated.

2. If cell-by-cell flow terms will be recorded, clear the buffer (BUFF) in which they will be stored as they are calculated.

3. For each cell, calculate the flow to and from constant-head cells. DO STEPS 4-12.

4. If the cell is not a constant-head cell, skip further processing and go on to the next cell.

5. Clear the six fields corresponding to the six faces through which the flows will be calculated.

6. For each face of the cell, calculate the flow out of the cell through that face (STEPS 7-11).

7. If there is not a variable-head cell which shares the face, go on to the next face.

8. Calculate the flow through the face into the adjacent cell.

9. Test the sign of the flow to see if it is positive (into the adjacent variable-head cell from the constant-head cell) or negative (out of the adjacent variable-head cell into the constant-head cell). GO TO EITHER STEP 10 OR 11.

10. If the sign is negative, add the flow rate to CHOUT (flow out of the flow domain).

11. If the sign is positive, add the flow rate to CHIN (flow out of the flow domain).

12. Add together the flow terms (x_1, x_2, x_3, x_4, x_5, x_6) corresponding to the six faces and leave in the field RATE.

13. If the user specified a negative number for IBCFCB, and ICBCFL $\neq$ 0, print the flows (RATE) from the constant-head cell into the aquifer.

14. If the cell-by-cell terms are to be recorded, add the six flow rates out of the cell and store them in the buffer until all cells are finished.

15. If the cell-by-cell terms are to be recorded, call utility module UBUDSV to record them.

16. Put flow rates, into and out of the flow domain from constant-head cells, into the VBVL array for inclusion in the overall volumetric budget. Put labels for those budget terms into VBNM.

17. RETURN.

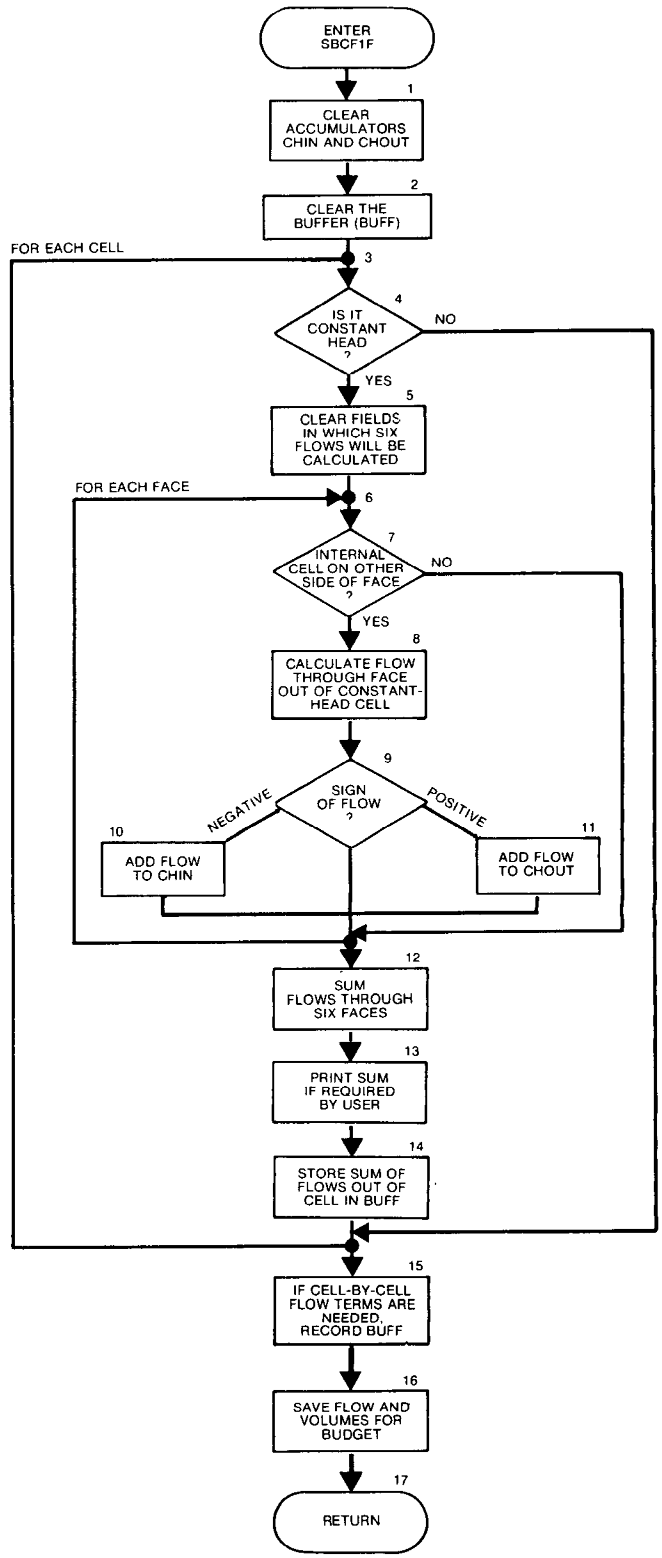
Flow Chart for Module SBCF1F

CHIN is a field in which flows, into the flow domain from constant-head cells, will be accumulated.

CHOUT is a field in which flows, out of the flow domain to constant-head cells, will be accumulated.

BUFF is a buffer in which cell-by-cell flow terms will be stored as they are calculated prior to recording them on disk.

INTERNAL CELLS are those in which head varies. They are in opposition to EXTERNAL CELLS (inactive or constant head) which are on or outside of a boundary.



```
      SUBROUTINE SBCF1F(VBNM,VBVL,MSUM,HNEW,IBOUND,CR,CC,CV,
     1   TOP,DELT,NCOL,NROW,NLAY,KSTP,KPER,IBD,IBCFCB,ICBCFL,
     2   BUFF,IOUT)
C-----VERSION 1549 12MAY1987 SBCF1F
C
C     ******************************************************************
C     COMPUTE FLOW FROM CONSTANT HEAD NODES
C     ******************************************************************
C
C     SPECIFICATIONS:
C     ------------------------------------------------------------------
      CHARACTER*4 VBNM,TEXT
      DOUBLE PRECISION HNEW,HD
C
      DIMENSION HNEW(NCOL,NROW,NLAY), IBOUND(NCOL,NROW,NLAY),
     1      CR(NCOL,NROW,NLAY), CC(NCOL,NROW,NLAY),
     2      CV(NCOL,NROW,NLAY), VBNM(4,20), VBVL(4,20),
     3      TOP(NCOL,NROW,NLAY),BUFF(NCOL,NROW,NLAY)
C
      COMMON /FLWCOM/LAYCON(80)
C
      DIMENSION TEXT(4)
C
      DATA TEXT(1),TEXT(2),TEXT(3),TEXT(4) /'   C','ONST','ANT ','HEAD'/
C     ------------------------------------------------------------------
C
C1------CLEAR BUDGET ACCUMULATORS
      CHIN=0.
      CHOUT=0.
C
C2------CLEAR BUFFER IF CELL-BY-CELL FLOW TERM FLAG(IBD) IS SET
      IF(IBD.EQ.0) GO TO 8
      DO 5 K=1,NLAY
      DO 5 I=1,NROW
      DO 5 J=1,NCOL
      BUFF(J,I,K)=0.
    5 CONTINUE
C
C3------FOR EACH CELL IF IT IS CONSTANT HEAD COMPUTE FLOW ACROSS 6
C3-----FACES.
    8 KT=0
      DO 200 K=1,NLAY
      LC=LAYCON(K)
      IF(LC.EQ.3 .OR. LC.EQ.2) KT=KT+1
      DO 200 I=1,NROW
      DO 200 J=1,NCOL
C
C4-----IF CELL IS NOT CONSTANT HEAD SKIP IT & GO ON TO NEXT CELL.
      IF (IBOUND(J,I,K).GE.0)GO TO 200
C
C5-----CLEAR FIELDS FOR SIX FLOW RATES.
      X1=0.
      X2=0.
      X3=0.
      X4=0.
      X5=0.
      X6=0.
C6-----FOR EACH FACE OF THE CELL CALCULATE FLOW THROUGH THAT FACE
C6-----OUT OF THE CONSTANT HEAD CELL AND INTO THE FLOW DOMAIN.
C6-----COMMENTS 7-11 APPEAR ONLY IN THE SECTION HEADED BY COMMENT 6A
C6-----BUT THEY APPLY IN A SIMILAR MANNER TO THE SECTIONS HEADED
C6-----BY COMMENTS 6B-6F.
C
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C6A----CALCULATE FLOW THROUGH THE LEFT FACE
C
C7-----IF THERE IS NOT A VARIABLE HEAD CELL ON THE OTHER SIDE OF THIS
C7-----FACE THEN GO ON TO THE NEXT FACE.
      IF(J.EQ.1) GO TO 30
      IF(IBOUND(J-1,I,K).LE.0)GO TO 30
      HDIFF=HNEW(J,I,K)-HNEW(J-1,I,K)
C
C8-----CALCULATE FLOW THROUGH THIS FACE INTO THE ADJACENT CELL.
      X1=HDIFF*CR(J-1,I,K)
C
C9-----TEST TO SEE IF FLOW IS POSITIVE OR NEGATIVE
      IF (X1) 10,30,20
C
C10----IF NEGATIVE ADD TO CHOUT(FLOW OUT OF DOMAIN TO CONSTANT HEAD).
   10 CHOUT=CHOUT-X1
      GO TO 30
C
C11----IF POSITIVE ADD TO CHIN(FLOW INTO DOMAIN FROM CONSTANT HEAD).
   20 CHIN=CHIN+X1
C
C6B----CALCULATE FLOW THROUGH THE RIGHT FACE
   30 IF(J.EQ.NCOL) GO TO 60
      IF(IBOUND(J+1,I,K).LE.0) GO TO 60
      HDIFF=HNEW(J,I,K)-HNEW(J+1,I,K)
      X2=HDIFF*CR(J,I,K)
      IF(X2)40,60,50
   40 CHOUT=CHOUT-X2
      GO TO 60
   50 CHIN=CHIN+X2
C
C6C----CALCULATE FLOW THROUGH THE BACK FACE.
   60 IF(I.EQ.1) GO TO 90
      IF (IBOUND(J,I-1,K).LE.0) GO TO 90
      HDIFF=HNEW(J,I,K)-HNEW(J,I-1,K)
      X3=HDIFF*CC(J,I-1,K)
      IF(X3) 70,90,80
   70 CHOUT=CHOUT-X3
      GO TO 90
   80 CHIN=CHIN+X3
C
C6D----CALCULATE FLOW THROUGH THE FRONT FACE.
   90 IF(I.EQ.NROW) GO TO 120
      IF(IBOUND(J,I+1,K).LE.0) GO TO 120
      HDIFF=HNEW(J,I,K)-HNEW(J,I+1,K)
      X4=HDIFF*CC(J,I,K)
      IF (X4) 100,120,110
  100 CHOUT=CHOUT-X4
      GO TO 120
  110 CHIN=CHIN+X4
C
C6E----CALCULATE FLOW THROUGH THE UPPER FACE
  120 IF(K.EQ.1) GO TO 150
      IF (IBOUND(J,I,K-1).LE.0) GO TO 150
      HD=HNEW(J,I,K)
      IF(LC.NE.3 .AND. LC.NE.2) GO TO 122
      TMP=HD
      IF(TMP.LT.TOP(J,I,KT)) HD=TOP(J,I,KT)
  122 HDIFF=HD-HNEW(J,I,K-1)
      X5=HDIFF*CV(J,I,K-1)
      IF(X5) 130,150,140
  130 CHOUT=CHOUT-X5
      GO TO 150
  140 CHIN=CHIN+X5
```

```
C
C6F----CALCULATE FLOW THROUGH THE LOWER FACE.
  150 IF(K.EQ.NLAY) GO TO 180
      IF(IBOUND(J,I,K+1).LE.0) GO TO 180
      HD=HNEW(J,I,K+1)
      IF(LAYCON(K+1).NE.3 .AND. LAYCON(K+1).NE.2) GO TO 152
      TMP=HD
      IF(TMP.LT.TOP(J,I,KT+1)) HD=TOP(J,I,KT+1)
  152 HDIFF=HNEW(J,I,K)-HD
      X6=HDIFF*CV(J,I,K)
      IF(X6) 160,180,170
  160 CHOUT=CHOUT-X6
      GO TO 180
  170 CHIN=CHIN+X6
C
C12-----SUM UP FLOWS THROUGH SIX SIDES OF CONSTANT HEAD CELL.
 180  RATE=X1+X2+X3+X4+X5+X6
C
C13-----PRINT THE INDIVIDUAL RATES IF REQUESTED(IBCFCB<0).
      IF(IBCFCB.LT.0.AND.ICBCFL.NE.0) WRITE(IOUT,900) (TEXT(N),N=1,4),
     1    KPER,KSTP,K,I,J,RATE
  900 FORMAT(1H0,4A4,'   PERIOD',I3,'   STEP',I3,'   LAYER',I3,
     1     '   ROW',I4,'   COL',I4,'   RATE ',G15.7)
C
C14----IF CELL-BY-CELL FLAG SET STORE SUM OF FLOWS FOR CELL IN BUFFER
      IF(IBD.EQ.1) BUFF(J,I,K)=RATE
C
  200 CONTINUE
C
C15----IF CELL-BY-CELL FLAG SET THEN RECORD CONTENTS OF BUFFER
      IF(IBD.EQ.1) CALL UBUDSV(KSTP,KPER,TEXT(1),
     1                    IBCFCB,BUFF,NCOL,NROW,NLAY,IOUT)
C
C
C16----SAVE TOTAL CONSTANT HEAD FLOWS AND VOLUMES IN VBVL TABLE
C16----FOR INCLUSION IN BUDGET. PUT LABELS IN VBNM TABLE.
      VBVL(1,MSUM)=VBVL(1,MSUM)+CHIN*DELT
      VBVL(2,MSUM)=VBVL(2,MSUM)+CHOUT*DELT
      VBVL(3,MSUM)=CHIN
      VBVL(4,MSUM)=CHOUT
C
C     ---SETUP VOLUMETRIC BUDGET NAMES
      VBNM(1,MSUM)=TEXT(1)
      VBNM(2,MSUM)=TEXT(2)
      VBNM(3,MSUM)=TEXT(3)
      VBNM(4,MSUM)=TEXT(4)
C
      MSUM=MSUM+1
C
C
C17----RETURN
      RETURN
      END
```

List of Variables for Module SBCF1F

Variable	Range	Definition
BUFF	Global	DIMENSION (NCOL,NROW,NLAY), Buffer used to accumulate information before printing or recording it.
CC	Global	DIMENSION (NCOL,NROW,NLAY), Conductance in the column direction. CC(J,I,K) contains conductance between nodes (J,I,K) and (J,I+1,K).
CHIN	Module	Accumulator for flow into the model area from constant heads.
CHOUT	Module	Accumulator for flow out of the model area to constant heads.
CR	Global	DIMENSION (NCOL,NROW,NLAY), Conductance in the row direction. CR(J,I,K) contains conductance between nodes (J,I,K) and (J+1,I,K).
CV	Global	DIMENSION (NCOL,NROW,NLAY-1), Conductance in the vertical direction. CV(J,I,K) contains conductance between nodes (J,I,K) and (J,I,K+1).
DELT	Global	Length of the current time step.
HD	Module	Temporary field containing a value from HNEW.
HDIFF	Module	Head difference between one node and the adjacent node.
HNEW	Global	DIMENSION (NCOL,NROW,NLAY), Most recent estimate of head in each cell. HNEW changes at each iteration.
I	Module	Index for rows.
IBCFCB	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 or recorded. < 0, flow from each constant-head cell will be printed whenever ICBCFL is set.
IBD	Package	Flag. = 0, cell-by-cell flow terms for this package will not be recorded. ≠ 0, cell-by-cell flow terms for this package will be recorded.
IBOUND	Global	DIMENSION (NCOL,NROW,NLAY), Status of each cell. < 0, constant-head cell = 0, inactive cell > 0, variable-head cell
ICBCFL	Global	Flag. = 0, cell-by-cell flow terms will not be recorded or printed for the current time step. ≠ 0, cell-by-cell flow terms (flow to constant heads) will be either printed or recorded for the current time step.
IOUT	Global	Primary unit number for all printed output. IOUT = 6.
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.

List of Variables for Module SBCF1F (Continued)

Variable	Range	Definition
KT	Module	Index for tops of layers.
LAYCON	Package	DIMENSION(80), Layer type code: 0 - Layer strictly confined. 1 - Layer strictly unconfined. 2 - Layer confined/unconfined (transmissivity is constant). 3 - Layer confined/unconfined (transmissivity varies).
LC	Module	Temporary label for an element of LAYCON.
MSUM	Global	Counter for budget entries and labels in VBVL and VBNM.
NCOL	Global	Number of columns in the grid.
NLAY	Global	Number of layers in the grid.
NROW	Global	Number of rows in the grid.
RATE	Module	Flow from the constant-head cell into the aquifer. (Reverse the sign to get the flow from the aquifer into the constant-head cell.)
TEXT	Module	Label to be printed or recorded with array data.
TMP	Module	Temporary field for head.
TOP	Package	DIMENSION (NCOL,NROW,NTOP), Elevation of top of layers. (NTOP is the number of layers for which LAYCON = 2 or 3.)
VBNM	Global	DIMENSION (4,20), Labels for entries in the 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 the current time step into the flow field. (2,N), Rate for the current time step out of the flow field. (3,N), Volume into the flow field during simulation. (4,N), Volume out of the flow field during simulation.
X1	Module	Flow through the left face.
X2	Module	Flow through the right face.
X3	Module	Flow through the back face.
X4	Module	Flow through the front face.
X5	Module	Flow through the upper face.
X6	Module	Flow through the lower face.