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

Chapter A1

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

By Michael G. McDonald and Arlen W. Harbaugh

This chapter supersedes U.S. Geological Survey Open-File Report 83-875

Book 6

MODELING TECHNIQUES
Module SBCFlH 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 SBCFlC 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 SBCFlC to calculate the horizontal-branch conductances for the layer.

8. RETURN.
Flow Chart for Module SBCF1H

1. ENTER SBCF1H

2. IS CELL ACTIVE?
   - NO: SET TRANSMISSIVITY EQUAL TO ZERO
   - YES: CALCULATE SATURATED THICKNESS

3. CALCULATE SATURATED THICKNESS

4. THICKNESS > 0?
   - YES: MULTIPLY THICKNESS BY HYDRAULIC CONDUCTIVITY
   - NO: PRINT A MESSAGE SAYING CELL WENT DRY

5. SET CONDUCTANCES EQUAL TO ZERO—SET IBOUND CODE TO "INACTIVE"

6. RETURN

FOR EACH CELL IN THE LAYER
SUBROUTINE SBCFLH(HNEW, IBOUND, CR, CC, CV, HY, TRPY, DELR, DELC,  
1, BOT, TOP, K, KD, KT, KITER, KSTP, KPER, NCOL, NROW, NLAY, IOUT)
C
C------VERSION 1442 31DEC1986 SBCFLH
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), CR(NCOL,NROW,NLAY), 
1, CC(NCOL,NROW,NLAY), CV(NCOL,NROW,NLAY), HY(NCOL,NROW,NLAY), 
2, TRPY(NLAY), DELR(NCOL), DELC(NROW)
3, BOT(NCOL,NROW,NLAY), TOP(NCOL,NROW,NLAY)

COMMON /FLWCOM/LAYCON(BO)
C--------------------------------------------------------------------
C
C1------CALCULATE TRANSMISSIVITY AT EACH ACTIVE CELL. TRANSMISSIVITY
C1------WILL BE STORED TEMPORARILY IN THE CC ARRAY.
 DO 200 I=1,NRCM
   DO 200 J=1,NCOL
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.TG.TOP(J,I,KT)) HD=TOP(J,I,KT)
  50 THCK=HD-BOT(J,I,KD)
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,J,KITER,KSTP,KPER
  150 FORMAT(1X,*'NODE ',314,*(LAYER,ROW,COL) WENT DRY'
110 ,1 AT ITERATION = ',I3,' TIME STEP = ',I3
120 ,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 SBCFLC(CR,CC,TRPY,DELR,DELC,K,NCOL,NROW,NLAY)
C
C8------RETURN
RETURN
END
### List of Variables for Module SBCFH

<table>
<thead>
<tr>
<th>Variable</th>
<th>Range</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOT</td>
<td>Package</td>
<td>DIMENSION (NCOL,NROW,NBOT), Elevation of the bottom of each layer. (NBOT is the number of layers for which LAYCON = 1 or 3.)</td>
</tr>
<tr>
<td>CC</td>
<td>Global</td>
<td>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.</td>
</tr>
<tr>
<td>CR</td>
<td>Global</td>
<td>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).</td>
</tr>
<tr>
<td>CV</td>
<td>Global</td>
<td>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).</td>
</tr>
<tr>
<td>DELC</td>
<td>Global</td>
<td>DIMENSION (NROW), Cell dimension in the column direction. DELC(I) contains the width of row I.</td>
</tr>
<tr>
<td>DELR</td>
<td>Global</td>
<td>DIMENSION (NCOL), Cell dimension in the row direction. DELR(J) contains the width of column J.</td>
</tr>
<tr>
<td>HD</td>
<td>Module</td>
<td>Temporary label for an element in HNEW.</td>
</tr>
<tr>
<td>HNEW</td>
<td>Global</td>
<td>DIMENSION (NCOL,NROW,NLAY), Most recent estimate of head in each cell. HNEW changes at each iteration.</td>
</tr>
<tr>
<td>HY</td>
<td>Package</td>
<td>DIMENSION (NCOL,NROW,NBOT), Hydraulic conductivity of the cell. (NBOT is the number of layers where LAYCON = 1 or 3.)</td>
</tr>
<tr>
<td>I</td>
<td>Module</td>
<td>Index for rows.</td>
</tr>
<tr>
<td>IBOUND</td>
<td>Global</td>
<td>DIMENSION (NCOL,NROW,NLAY), Status of each cell.&lt;br&gt;(&lt; 0), constant-head cell&lt;br&gt;(= 0), inactive cell&lt;br&gt;(&gt; 0), variable-head cell</td>
</tr>
<tr>
<td>IOUT</td>
<td>Global</td>
<td>Primary unit number for all printed output. IOUT = 6.</td>
</tr>
<tr>
<td>J</td>
<td>Module</td>
<td>Index for columns.</td>
</tr>
<tr>
<td>K</td>
<td>Module</td>
<td>Index for layers.</td>
</tr>
<tr>
<td>KB</td>
<td>Module</td>
<td>Index for bottom of layers.</td>
</tr>
<tr>
<td>KITER</td>
<td>Global</td>
<td>Iteration counter. Reset at the start of each time step.</td>
</tr>
<tr>
<td>KPER</td>
<td>Global</td>
<td>Stress period counter.</td>
</tr>
<tr>
<td>KSTP</td>
<td>Global</td>
<td>Time step counter. Reset at the start of each stress period.</td>
</tr>
<tr>
<td>KT</td>
<td>Module</td>
<td>Index for tops of layers.</td>
</tr>
<tr>
<td>LAYCON</td>
<td>Package</td>
<td>DIMENSION (80), Layer type code:&lt;br&gt;(0) - Layer strictly confined.&lt;br&gt;(1) - Layer strictly unconfined.&lt;br&gt;(2) - Layer confined/unconfined (transmissivity is constant)&lt;br&gt;(3) - Layer confined/unconfined (transmissivity varies).</td>
</tr>
<tr>
<td>NCOL</td>
<td>Global</td>
<td>Number of columns in the grid.</td>
</tr>
<tr>
<td>NLAY</td>
<td>Global</td>
<td>Number of layers in the grid.</td>
</tr>
<tr>
<td>NROW</td>
<td>Global</td>
<td>Number of rows in the grid.</td>
</tr>
<tr>
<td>THCK</td>
<td>Module</td>
<td>Saturated thickness.</td>
</tr>
<tr>
<td>TOP</td>
<td>Package</td>
<td>DIMENSION (NCOL,NROW,NTOP), Elevation of top of layers.&lt;br&gt;(NTOP is number of layers for which LAYCON = 2 or 3.)</td>
</tr>
<tr>
<td>TRPY</td>
<td>Package</td>
<td>DIMENSION (NLAY), Ratio of transmissivity in the column direction to transmissivity in the row direction.</td>
</tr>
</tbody>
</table>
The module SBCFlC calculates horizontal-branch conductances for a layer from transmissivity and cell dimensions. It is called by submodules SBCFlN and SBCFlH. Recall that the branch conductances between two nodes can be expressed by

\[ C = \frac{C_1 C_2}{C_1 + C_2}. \]

However, \( C_1 \) and \( C_2 \) can be represented by

\[ C_1 = T_1 W / (L_1/2) \]
\[ C_2 = T_2 W / (L_2/2). \]

Thus,

\[ C = \frac{2T_1 T_2 W}{T_1 L_2 + T_2 L_1}. \]

This equation is used to calculate conductances along rows and columns. When calculating conductance along rows, \( L_1 \) and \( L_2 \) are \( \text{DELR}(J) \) and \( \text{DELR}(J+1) \), respectively, and \( W \) is \( \text{DELC}(I) \). When calculating conductance along columns, \( L_1 \) and \( L_2 \) are \( \text{DELC}(I) \) and \( \text{DELC}(I+1) \), respectively, and \( W \) is \( \text{DELR}(J) \). Conductance along columns is also multiplied by \( \text{TRPY}(K) \), 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.

\( \text{CR}(J,I,K) \) contains the conductance \( \text{CR}_{i,j+1/2,k} \) between node \( J,I,K \) and node \( J+1,I,K \).
Flow Chart for Module SBCF1C

FOR EACH CELL
1. CALCULATE BRANCH CONDUCTANCE DOWN COLUMN

2. T=0?
   - YES: SET CONDUCTANCE EQUAL TO ZERO
   - NO: GO TO 3

3. LAST COLUMN?
   - NO: GO TO 4
   - YES: CALCULATE BRANCH CONDUCTANCE TO RIGHT

4. LAST ROW?
   - NO: CALCULATE BRANCH CONDUCTANCE DOWN COLUMN
   - YES: RETURN

5. RETURN
SUBROUTINE SBCFLIC(CR, CC, TRPY, DELR, DELC, K, NCOL, NROW, NLAY)

C
C
C-----VERSION 1334 22AUG1987 SBCFLIC
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
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)+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)+T2*DELC(I))
 40 CONTINUE
C
C5------RETURN
 RETURN
END
### List of Variables for Module SBCFIC

<table>
<thead>
<tr>
<th>Variable</th>
<th>Range</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC</td>
<td>Global</td>
<td>DIMENSION (NCOL,NROW,NLAY), Conductance in the column direction. CC(J,I,K) contains conductance between nodes (J,I,K) and (J+1,I,K). This array is used to temporarily hold transmissivity.</td>
</tr>
<tr>
<td>CR</td>
<td>Global</td>
<td>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).</td>
</tr>
<tr>
<td>DELC</td>
<td>Global</td>
<td>DIMENSION (NROW), Cell dimension in the column direction. DELC(I) contains the width of row I.</td>
</tr>
<tr>
<td>DELR</td>
<td>Global</td>
<td>DIMENSION (NCOL), Cell dimension in the row direction. DELR(J) contains the width of column J.</td>
</tr>
<tr>
<td>I</td>
<td>Module</td>
<td>Index for rows.</td>
</tr>
<tr>
<td>J</td>
<td>Module</td>
<td>Index for columns.</td>
</tr>
<tr>
<td>K</td>
<td>Module</td>
<td>Index for layers.</td>
</tr>
<tr>
<td>NCOL</td>
<td>Global</td>
<td>Number of columns in the grid.</td>
</tr>
<tr>
<td>NLAY</td>
<td>Global</td>
<td>Number of layers in the grid.</td>
</tr>
<tr>
<td>NROW</td>
<td>Global</td>
<td>Number of rows in the grid.</td>
</tr>
<tr>
<td>TRPY</td>
<td>Package</td>
<td>DIMENSION (NLAY), Ratio of transmissivity in the column direction to transmissivity in the row direction.</td>
</tr>
<tr>
<td>T1</td>
<td>Module</td>
<td>Temporary field for CC(J,I,K).</td>
</tr>
<tr>
<td>T2</td>
<td>Module</td>
<td>Temporary field for CC(J+1,I,K).</td>
</tr>
<tr>
<td>YX</td>
<td>Module</td>
<td>TRPY(K)*2.</td>
</tr>
</tbody>
</table>
Narrative for Module SBCF1B

This module calculates flow across cell faces. It is called by module BCFLBD 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.
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 SBCFIB(HNEW, IBOUND, CR, CC, CV, TOP, NCOL, NROW, NLAY,
1 KSTP, KPER, IBCFCB, BUFF, IOUT)

C-----VERSION 1548 12MAY1987 SBCFIB

******************************************************************************

COMPUTE FLOW ACROSS EACH CELL WALL
******************************************************************************

SPECIFICATIONS:

CHARACTER*4 TEXT
DOUBLE PRECISION HNEW, HD

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)

COMMON /FLWCOM/LAYCON(80)
DIMENSION TEXT(12)
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 ',
3 '"FLOW', 'FRO', 'NT F', 'ACE ', '"FLOW', 'LOW', 'ER F', 'ACE '/

NCM1=NCOL-1
IF(NCM1.LT.1) GO TO 405

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

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

C3-----RECORD CONTENTS OF BUFFER
CALL UBUDSV(KSTP, KPER, TEXT(1), IBCFCB, BUFF, NCOL, NROW, NLAY, IOUT)

5-83
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 SBCFLB

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

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 SBCFlF is called by module BCF1BD and calls utility module UBUDSV.

Module SBCFlF 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.

5-86
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.
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 SBCFLF(VBNM, VBVL, MSUM, HNEW, IBOUND, CR, CC, CV, 
1  TOP, DELT, NCOL, NROW, NLAY, KSTP, KPER, IBD, IBCFGB, IBCFL, 
2  BUFF, IOUT)
C-----VERSION 1549 12MAY1987 SBCFLF
C
C ---------------------------------------------------------------
COMPUTE FLOW FROM CONSTANT HEAD NODES
***Ytt**tt****t***~******~~****~*********~*******~******~~**~~*
C
C SPECIFICATIONS:
---------------------------------------------------------------
CHARACTER*4 VBNM, TEXT
DOUBLE PRECISION HNEW, HD

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)

COMMON /FLWCOM/LAYCON(80)

DIMENSION TEXT(4)
DATA TEXT(1),TEXT(2),TEXT(3),TEXT(4) /' C','ONST','ANT ','HEAD'/

C1------CLEAR BUDGET ACCUMULATORS
CHIN=0.
CHOUT=0.

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

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

C4------IF CELL IS NOT CONSTANT HEAD SKIP IT & GO ON TO NEXT CELL.
IF (IBOUND(J,I,K).GE.0) GO TO 200

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 6A-6F.
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(BOUND(J-1,I,K).LE.0) GO TO 30
   HDIFF=HNEW(J-1,I,K)-HNEW(J,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 DOMAINTo CONSTANT HEAD).
   10 CHOUT=CHOUT+X1
   GO TO 30
C
C11------IF POSITIVE ADD TO CHIN (FLOW INTO DOMAINTo CONSTANT HEAD).
   20 CHIN=CHIN+X1
C
C6B----CALCULATE FLOW THROUGH THE RIGHT FACE
30 IF(J.EQ.NCOL) GO TO 60
   IF(BOUND(J+1,I,K).LE.0) GO TO 60
   HDIFF=HNEW(J+1,I,K)-HNEW(J,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 (BOUND(I-1,J,K).LE.0) GO TO 90
   HDIFF=HNEW(I-1,J,K)-HNEW(I,J,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 (BOUND(I+1,J,K).LE.0) GO TO 120
   HDIFF=HNEW(I+1,J,K)-HNEW(I,J,K)
   X4=HDIFF*CC(J,I+1,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 (BOUND(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,K)) HD=TOP(J,I,K)
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

5-90
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(JrIrK+l)
      IF(LAYCON(K+l).NE.3 .AND. LAYCCN(K+l).NE.2) GO TO 152
      TMP=HD
      IF(TMP.LT.TOP(JrIrI,KT+l)) HD=TOP(JrIrI,KT+l)
   152 HDIFF=HNEW(JrIrI,K)-HD
      X6=HDDIFF*CV(JrIrI,K)
      IF(X6) 160,180,170
   160 CHDUT=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(I4,6X,' PERIOD',I3,1X,' STEP',I3,1X,' LAYER',I3,1X,' ROW',I4,1X,' COL',I4,1X,' RATE ',G15.7)
C
C14-----IF CELL-BY-CELL FLAG SET STORE SUM OF FLOWS FOR CELL IN BUFFER
   IF(IBCFL.EQ.1) BUFF(J,I,K)=RATE
C
C200 CONTINUE
C
C15-----IF CELL-BY-CELL FLAG SET THEN RECORD CONTENTS OF BUFFER
   IF(IBCFL.EQ.1) CALL UBUDSV(KSTP,KPER,TEXT(1),
      1 IBCFCB,BUFF,NCOL,NROW,NLAY,IOUT)
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
C   MSUM=MSUM+1
C
C
C17-----RETURN
RETURN
END
### List of Variables for Module SBCF1F

<table>
<thead>
<tr>
<th>Variable</th>
<th>Range</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>BUFF</td>
<td>Global</td>
<td>DIMENSION (NCOL,NROW,NLAY). Buffer used to accumulate information before printing or recording it.</td>
</tr>
<tr>
<td>CC</td>
<td>Global</td>
<td>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).</td>
</tr>
<tr>
<td>CHIN</td>
<td>Module</td>
<td>Accumulator for flow into the model area from constant heads.</td>
</tr>
<tr>
<td>CHOUT</td>
<td>Module</td>
<td>Accumulator for flow out of the model area to constant heads.</td>
</tr>
<tr>
<td>CR</td>
<td>Global</td>
<td>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).</td>
</tr>
<tr>
<td>CV</td>
<td>Global</td>
<td>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).</td>
</tr>
<tr>
<td>DELT</td>
<td>Global</td>
<td>Length of the current time step.</td>
</tr>
<tr>
<td>HD</td>
<td>Module</td>
<td>Temporary field containing a value from HNEW.</td>
</tr>
<tr>
<td>HDIFF</td>
<td>Module</td>
<td>Head difference between one node and the adjacent node.</td>
</tr>
<tr>
<td>HNEW</td>
<td>Global</td>
<td>DIMENSION (NCOL,NROW,NLAY), Most recent estimate of head in each cell. HNEW changes at each iteration.</td>
</tr>
<tr>
<td>I</td>
<td>Module</td>
<td>Index for rows.</td>
</tr>
<tr>
<td>IBCFBCB</td>
<td>Package</td>
<td>Flag and a unit number.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 0, unit number on which cell-by-cell flow terms will be recorded whenever ICBCF1L is set.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>= 0, cell-by-cell flow terms will not be printed or recorded.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; 0, flow from each constant-head cell will be printed whenever ICBCF1L is set.</td>
</tr>
<tr>
<td>IBD</td>
<td>Package</td>
<td>Flag.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>= 0, cell-by-cell flow terms for this package will not be recorded.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≠ 0, cell-by-cell flow terms for this package will be recorded.</td>
</tr>
<tr>
<td>IBOUND</td>
<td>Global</td>
<td>DIMENSION (NCOL,NROW,NLAY), Status of each cell.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; 0, constant-head cell</td>
</tr>
<tr>
<td></td>
<td></td>
<td>= 0, inactive cell</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 0, variable-head cell</td>
</tr>
<tr>
<td>ICBCF1L</td>
<td>Global</td>
<td>Flag.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>= 0, cell-by-cell flow terms will not be recorded or printed for the current time step.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≠ 0, cell-by-cell flow terms (flow to constant heads) will be either printed or recorded for the current time step.</td>
</tr>
<tr>
<td>IOUT</td>
<td>Global</td>
<td>Primary unit number for all printed output. IOUT = 6.</td>
</tr>
<tr>
<td>J</td>
<td>Module</td>
<td>Index for columns.</td>
</tr>
<tr>
<td>K</td>
<td>Module</td>
<td>Index for layers.</td>
</tr>
<tr>
<td>KPER</td>
<td>Global</td>
<td>Stress period counter.</td>
</tr>
<tr>
<td>KSTP</td>
<td>Global</td>
<td>Time step counter. Reset at the start of each stress period.</td>
</tr>
</tbody>
</table>
### List of Variables for Module SBCFLF (Continued)

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