An Iterative Digital Model for Aquifer Evaluation

By

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PURPOSE

This program simulates the response of a confined or unconfined aquifer to pumping at a constant rate from one or more wells. The ground-water reservoir may be irregular in shape and non-homogeneous with infiltration from one or more lakes and streams. The program is written in FORTRAN IV for the IBM 360 system. (See Appendix for program listing).
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THEORETICAL DEVELOPMENT

The differential equation for nonsteady flow of a compressible fluid in an elastic non-homogeneous porous medium can be written (Pinder and Bredehoeft, 1968)

\[
\frac{\partial}{\partial x_i} \left( T_{ij} \frac{\partial h}{\partial x_j} \right) = S \frac{\partial h}{\partial t} + w(x,y,t)
\]

(1)

where \( T_{ij} \) is the transmissivity tensor \((L^2/T)\);

\( h \) is the hydraulic head \((L)\);

\( S \) is the storage coefficient \((\text{dimensionless})\);

\( t \) is time \((T)\);

\( w \) is the volume flux per unit area \((L/T)\).
If the coordinate axes are aligned with the principal
directions of the transmissivity tensor the finite-
difference approximation to (1) may be written (see Fig. 1)

\[
T'_{xx}(i-\frac{1}{2}, j) = \left( \frac{h_{i-1,j,k} - h_{i,j,k}}{\Delta x_i} \right)
\]

\[
+ T'_{xx}(i+\frac{1}{2}, j) = \left( \frac{h_{i+1,j,k} - h_{i,j,k}}{\Delta x_i} \right)
\]

\[
+ T'_{yy}(i, j-\frac{1}{2}) = \left( \frac{h_{i,j-1,k} - h_{i,j,k}}{\Delta y_j} \right)
\]

\[
+ T'_{yy}(i, j+\frac{1}{2}) = \left( \frac{h_{i,j+1,k} - h_{i,j,k}}{\Delta y_j} \right)
\]

\[
= S \left( \frac{h_{i,j,k} - h_{i,j,k-1}}{\Delta t} \right)
\]

\[
+ \frac{q_w(i,j)}{\Delta x_i \Delta y_j} - k (\frac{2H R(i,j) - h_{i,j,k} - h_{i,j,k-1}}{2m R(i,j)})
\]

where

\[
T'_{xx}(i+\frac{1}{2}, j) = \frac{2T_{xx}(i,j)T_{xx}(i+1,j)}{T_{xx}(i,j)\Delta x i + T_{xx}(i+1,j)\Delta x i + 1} = \text{the harmonic mean of}
\]

\[
\frac{T_{xx}(i,j)}{\Delta x i}, \frac{T_{xx}(i+1,j)}{\Delta x i + 1}
\]
\( i \) is the index in the \( x \) dimension;
\( j \) is the index in the \( y \) dimension;
\( k \) is the index in time;
\( K_s \) is the hydraulic conductivity of the stream bottom (L/T);
\( m_r \) is the thickness of the stream bottom (L);
\( q_{\omega(i,j)} \) is the rate of withdrawal or injection at the node \( x_i y_j (L^3/T) \);
\( \Delta t \) is the time increment (T);
\( \Delta x, \Delta y \) are space increments (L);
\( H_r \) is the hydraulic head in the lakes and streams.
In an unconfined aquifer the transmissivity is a function of time as well as of space. In order to approximate equation (2) without generating a non-linear set of finite-difference equations, the head from the preceding time step is used, and the transmissivity is given by

\[ T_{i,j,k} = K_{i,j} \frac{h'}{h_{i,j,k-1}} \]

where \( K \) is the hydraulic conductivity (L/T); 
\( h' \) is the saturated thickness of the aquifer (L).
METHOD OF ANALYSIS

A rectangular net or grid as indicated in figure 1 is superposed on a plan view of the groundwater reservoir.

Fig. 1. Nodal array for digital model.
At each node the transmissivity, storage coefficient, and initial head are recorded. The pumping rate is recorded at each node where a well is located and the hydraulic conductivities of stream or lake beds where they occur. In the case of an unconfined aquifer the transmissivity is replaced by the hydraulic conductivity and the elevation of the base of the aquifer is also recorded. A parameter card is prepared providing the dimensions of the grid, the head in the stream, the thickness of the stream or lake beds, information concerning the maximum duration of pumping and other constants used in the computational scheme. All computer input and output is in a consistent set of units; the program is set-up to use feet and seconds.
The objective of the program is to solve equation (2) implicitly for the desired boundary conditions at each node on the grid after $\Delta t$ seconds of pumping. These values are then used as initial conditions for the calculation of the head values at time $2\Delta t$; this procedure is continued until the reservoir has been pumped the desired length of time. The size of the time step is increased exponentially. Numerical values and an alphameric contour map of the drawdown in the aquifer are printed at selected time steps (see Fig. 2).

---

Figure 2 -- Alphameric contour map of drawdown at Antigonish Nova Scotia

---

In order to determine the precision of the calculations, a mass balance may also be computed at this time if there is no infiltration into the system.
The iterative alternating-direction implicit procedure is the mathematical technique used to solve the \( N \) simultaneous equations where \( N \) is the number of nodes in the matrix. Hydraulic head values are calculated for each node in the matrix by solving alternately the equations for rows and columns implicitly. Equation (2) for the calculation of rows is

\[
\frac{T'}{xx(i-1,j)} \left( \frac{h_{i-1,j,k}^n - h_{i,j,k}^n}{\Delta x_i} \right) + \frac{T'}{xx(i+1,j)} \left( \frac{h_{i+1,j,k}^n - h_{i,j,k}^n}{\Delta x_i} \right) + \frac{T'}{yy(i,j-1)} \left( \frac{h_{i,j-1,k}^{n-1} - h_{i,j,k}^{n-1}}{\Delta y_j} \right) + \frac{T'}{yy(i,j+1)} \left( \frac{h_{i,j+1,k}^{n-1} - h_{i,j,k}^{n-1}}{\Delta y_j} \right) = S \left( \frac{h_{i,j,k}^n - h_{i,j,k-1}^n}{\Delta t} \right) + \frac{q_w(i,j)}{\Delta x_i \Delta y_j} - K \frac{2H r(i,j) - h_{i,j,k}^n - h_{i,j,k-1}^n}{2m r(i,j)} + I(h_{i,j,k}^n - h_{i,j,k}^{n-1})
\]

where \( I \) is a normalized iteration parameter; \( n \) is the index indicating iteration number.
At each time step the row and column equations are solved alternately until the greatest head difference between a row and column computation at any node is less than a prescribed error criteria. When this closure is achieved the program begins solving for the head at the new time $t + \Delta t$. The procedure is continued until the desired period of analysis has been simulated or the aquifer becomes dewatered. When any condition arises which terminates computation the head matrix and the elapsed simulation period are punched on cards. These cards can be used as input if it is necessary to extend the period of analysis at a later time.

For a detailed explanation of the technique used for solving the finite-difference equations see Douglas and Rachford (1956).
APPLICATION

The following section describes the preparation of parameter and data cards. The arrangement of the assembled program deck is shown in figure 3.

Figure 3. Assembled program deck.

Parameter cards

All values are right justified in the data field as indicated in Fig. 4.

Figure 4. Sample coding form.

Card 1

<table>
<thead>
<tr>
<th>Column</th>
<th>Variable</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 10</td>
<td>TMAX</td>
<td>simulation period in hours</td>
</tr>
<tr>
<td>11 - 20</td>
<td>DIML</td>
<td>number of nodes in a column of the matrix *</td>
</tr>
<tr>
<td>21 - 30</td>
<td>DIMW</td>
<td>number of nodes in a row of the matrix *</td>
</tr>
<tr>
<td>31 - 40</td>
<td>NUMT</td>
<td>maximum number of time steps *</td>
</tr>
<tr>
<td>41 - 50</td>
<td>QRE</td>
<td>vertical leakage into the aquifer in feet per second</td>
</tr>
<tr>
<td>51 - 60</td>
<td>DELT</td>
<td>initial time increment in seconds</td>
</tr>
<tr>
<td>TMAX</td>
<td>DIML</td>
<td>DIMW</td>
</tr>
<tr>
<td>------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>10000</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FACT</th>
<th>RIVER</th>
<th>SPACING</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.001</td>
<td>100.</td>
<td>1.001</td>
</tr>
</tbody>
</table>

SUM: 0.001

PUNCH: WATER TABLE

FIG. 4
**ITERATIVE DIGITAL MODEL FOR AQUIFER EVALUATION**

**SAMPLE CODING FORM**

- **DATA SET 3; RATE**
  - 0. 0. 0. 0. 0.

- **DATA SET 4; PERM**
  - 0. 1. 1. 1. 0.

- **DATA SET 5; BOTTOM**
  - 0. 0. 0. 0. 0.

- **DATA SET 6; S**
  - 1. 1. 1. 1. 1.

---

**Key:***
- 0 = ZERO
- U = ALPHA O
- I = ONE
- 1 = ALPHA I
- 2 = TWO
- Z = ALPHA Z
- S = SLASH
- V = VERT. BAR
- - = MINUS
- H = HORZ. BAR
<table>
<thead>
<tr>
<th>Card 2</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 10</td>
<td>M</td>
<td>thickness of stream or lake beds in feet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 - 20</td>
<td>KTH</td>
<td>number of time steps between printouts *</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21 - 30</td>
<td>FACTOR</td>
<td>multiplier for values of hydraulic conductivity of stream or lake beds</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>31 - 40</td>
<td>LENGTH</td>
<td>number of iteration parameters *</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>41 - 50</td>
<td>ERR</td>
<td>error criteria for closure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>51 - 60</td>
<td>FACS</td>
<td>multiplier for storage coefficient</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>61 - 70</td>
<td>FACB</td>
<td>multiplier for aquifer base bottom elevation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>71 - 80</td>
<td>FACP</td>
<td>multiplier for hydraulic conductivity of aquifer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Card 3</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 10</td>
<td>FACT</td>
<td>multiplier for transmissivity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 - 20</td>
<td>RIVER</td>
<td>hydraulic head in river in feet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21 - 30</td>
<td>SPACNG</td>
<td>contour interval in feet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Card 4</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 10</td>
<td>SUM</td>
<td>elapsed time at beginning of computations (usually 0. unless provided as punched output)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Card 5</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 5</td>
<td>PUNCH</td>
<td>indicator for punched output; if punched output is desired at termination of computations write PUNCH, otherwise leave card blank.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Card 6
1 - 10. WATER indicator of water-table conditions, if water-table conditions are encountered write WATERTABLE: otherwise leave card blank.

Card 7
1 - 7. CONTR indicator of contoured printout; if an alphameric contour map of hydraulic head is desired write CONTOUR; otherwise leave this card blank.

Card 8
1 - 7. NUM indicator of numerical printout; if the numerical head values are desired write NUMERIC, otherwise leave this card blank.

Card 9
1 - 5. CHECK indicator of computational check; if a mass balance on the system is desired write CHECK; otherwise leave card blank.

* values are fixed point; they must be right justified and not include a decimal point.
Data Cards

Set 1

Distance between nodes in the prototype in feet; the distance between adjacent nodes is recorded as indicated in figure 1. The values in the $x$ direction, $\text{DELX}$, are recorded first and are followed, beginning on a new card, by the values in the $y$ direction, $\text{DELY}$. As indicated in figure 1, the values for $\text{DELY}$ and $\text{DELX}$ must remain constant for each row and column respectively. Each value may occupy 10 spaces including the decimal point.
Set 2
Initial hydraulic head, STRT: the initial hydraulic head values are recorded from left to right along the rows beginning with the top row. Each row begins on a new card and each value may occupy 10 spaces including a decimal point (there will be a maximum of eight values recorded on each card). The hydraulic head values punched at the termination of the program can be read as initial hydraulic head values.

Set 3
Locations of wells, lakes, and streams, RATE: the locations of wells, lakes, and streams are recorded left to right along the rows, beginning with the top row. Each row begins on a new card and each value may occupy only 4 spaces including a negative sign and decimal point (no sign is necessary for a positive number). At any node where a lake or stream occurs the hydraulic conductivity of the bed divided by the hydraulic conductivity multiplier is recorded. At any node where a well is located the pumping rate in cfs is recorded preceded by a negative sign.
Set 4
Hydraulic conductivity: PERM or transmissivity T: this data set consists of the hydraulic conductivity values in the case of a water table problem or transmissivity values in a confined aquifer situation. The values divided by the appropriate multiplier are recorded left to right along the rows beginning with the top row. Each row begins on a new card and each value may occupy up to 4 spaces including the decimal point.

Set 5
Aquifer base elevation, BOTTOM: this data set consists of the elevation of the base of the aquifer measured from the same reference datum as the initial head, divided by an appropriate multiplier. This data set is omitted if a confined-aquifer problem is considered. The values are recorded left to right along the rows beginning with the top row. Each row begins on a new card and each value may occupy up to 4 spaces including the decimal point.

Set 6
Storage coefficient values, S: this data set consists of the storage coefficient at each node, divided by the appropriate multiplier. The values are recorded left to right along the rows, beginning with the top row. Each row begins on a new card and each value may occupy up to 4 spaces including the decimal point.
PROGRAM FEATURES

Number of nodes:
The dimensions of the nodal array considered in an aquifer problem generally depend upon the storage capacity in the computer and available funds. The larger the nodal array the more computer time is required to simulate a specified period of analysis. This program permits arrays up to 50 X 50 nodes.

Drawdown near the pumping well:
Withdrawal from a well is assumed to occur over the area of influence of the well node. Drawdown values within one node of the well, therefore, will not accurately represent field responses. The use of smaller space increments near the well will improve the accuracy of the solution.

Advantages of iterative technique:
Certain limitations inherent in the alternating direction implicit technique are overcome by introducing a relaxation factor and iteration. Some of the important advantages of an iterative analysis are:
i. abrupt changes in transmissivity between nodes is permitted,

ii. variable space increments may be used,

iii. any time increment $\Delta t$ may be used,

iv. the elliptic form of the flow equation can be treated directly (the steady-state problem),

v. the iterative procedure requires less computer time when periods extending tens or hundreds of years are simulated.

Multiplication Constants

Multiplication constants (FACTOR, FACB, FACS, FACP, FACT) are used to decrease the number of data cards when very small or very large numbers must be read. For example, if it was necessary to read a storage coefficient value of $0.0001$ the multiplication factor FACS could be set equal to $0.0001$ and 1. would be recorded on the data card; the program would convert the 1. to $0.0001$ during execution.

Program Diagnostics

Two program diagnostics may be generated if an abnormal program termination occurs. The message EXCEEDED PERMITTED NUMBER OF ITERATIONS is printed when convergence is not achieved within 100 iterations. This situation generally arises when an error in data input results in an impossible physical problem. The message WELL GOES DRY occurs when the cone of depression in an unconfined aquifer drops below the impermeable aquifer base.
Iteration Parameters

The choice of the number of iteration parameters, LENGTH, and the convergence criteria, ERR, depends upon the physical problem considered. Three to seven iteration parameters and a value for ERR of 0.001 should provide satisfactory results in most problems.

Mass Balance

The CHECK option permits the calculation of a mass balance when there is no infiltration into the system. The volume of water removed from the aquifer is computed by integration over the cone of depression and by calculating the volume removed from the wells. These values are compared and the deviation expressed as a percent of the volume pumped. If infiltration does occur the deviation is a measure of the volume of water entering the system.

This program is not designed to simulate all of the complicated hydrologic problems encountered in the field. It is intended as a starting point from which more complex models can be developed.
SELECTION REFERENCES

Douglas, J., and Rachford, H. H., Jr., 1956, On the numerical
solution of head conduction problems in two or three space

Pinder, G. F., and Bredehoeft, J. D., 1968, Application of
Digital Computer for Aquifer Evaluation; Water Resources
Research, Vol. 4, No. 5, pp. 1069-1093.
TC PROVIDE THE POTENTIAL DISTRIBUTION IN A CONFINED AQUIFER AFTER A DESIGNATED PERIOD OF TIME.

METHOD

THE ALTERNATING DIRECTION IMPLICIT-TECHNIQUE IS USED TO SOLVE THE LINEAR EQUATIONS.

DESCRIPTION OF PARAMETERS

A=COEFFICIENT IN FINITE DIFFERENCE EQUATION
B=COEFFICIENT IN FINITE DIFFERENCE EQUATION
C=DUHMY VARIABLE DEFINED AS C/W
D=DUHMY VARIABLE REPRESENTING PARAMETERS OF EQUATION WHOSE VALUES ARE KNOWN FROM PREVIOUS ITERATION
DAYS=NUMBER OF DAYS SINCE PUMPING STARTED
DFLT=LENGTH OF INITIAL TIME STEP (SECONDS)
DELX=DISTANCE BETWEEN NODES IN THE PROTOTYPE IN THE X DIRECTION (FEET)
DELY=DISTANCE BETWEEN NODES IN THE PROTOTYPE IN THE Y DIRECTION (FEET)
DIML=NUMBER OF NODES IN COLUMN OF MATRIX
DIMT=NUMBER OF NODES IN ROW OF MATRIX
FR.1=CLOSURE CRITERIA FOR ITERATION
FACTO=MULTIPLICATION FACTOR FOR ADJUSTING STORAGE COEFFICIENT
FACT1=MULTIPLICATION FACTOR FOR ADJUSTING STORAGE COEFFICIENT
FACT2=MULTIPLICATION FACTOR FOR ADJUSTING STORAGE COEFFICIENT
FACT3=MULTIPLICATION FACTOR FOR ADJUSTING STORAGE COEFFICIENT
FACT=COEFFICIENT IN FINITE DIFFERENCE EQUATION
FACD=MULTIPLICATION FACTOR FOR BOTTOM ELEVATION
FC=COEFFICIENT IN FINITE DIFFERENCE EQUATION
FCAP=MULTIPLICATION FACTOR FOR HYDRAULIC CONDUCTIVITY
FACT=MULTIPLICATION FACTOR FOR TRANSMISSIVITY
G=DUHMY VARIABLE DEFINED AS (D-A*G(J-1))/W
HEL=A=HEADING FROM THE CONFINING LAYER (CUBIC FEET PER SECOND)
PNTU,J)=ARRAY FOR PRINTING OUT HEAD MATRIX IN CONTOUR FORM
PHII(J)=HEAD IN AQUIFER AT NODE (I,J) IN FEET
PHI0(J)=INITIAL VALUE OF HYDRAULIC HEAD IN AQUIFER
P=HYDRAULIC CONDUCTIVITY OF STREAM OR LAKE BOTTOM IF POSITIVE
Q=COEFFICIENT IN FINITE DIFFERENCE EQUATION
QV=VARIABLE ACCOUNTING FOR VERTICAL LEAKAGE
QW=VARIABLE ACCOUNTING FOR PUMPING
QX=VARIABLE ACCOUNTING FOR PUMPING
R=COEFFICIENT IN FINITE DIFFERENCE EQUATION
RHO=DUHMY VARIABLE DEFINED AS SI(I,J)/DEL
RIVER=HEAD IN RIVER
RR=VARIABLE ACCOUNTING FOR VERTICAL LEAKAGE
S=COEFFICIENT IN FINITE DIFFERENCE EQUATION
S=VARIABLE ACCOUNTING FOR PUMPING
SI(I,J)=STORAGE COEFFICIENT (DIMENSIONLESS)
SSTR=INITIAL VALUE OF HYDRAULIC HEAD IN AQUIFER
SUM=SUMMARY OF PUMPING IN SECONDS
SYM(J)=LINEAR ARRAY CONTAINING SYMBOLS FOR PRINTING OUT HEAD
MATPX      51
T(I,J)=TRANSMISSIVITY (FEET**2/SECOND)
TEMP(I)=TEMPORARY LOCATION OF CURRENTLY CALCULATED VALUES OF HEAD
TMPX=MAXIMUM ALLOTED PERIOD OF PUMPING
W=DUMMY VARIABLE DEFINED AS D=A*BE(J-1)
COMMON PHI,SUM,DELX,DELY,DIML,DIMW,VAP,SPACNG
DIMENSION S(50,50),PERM(50,50),BOTTOM(50,50),RATE(50,50),KEEP(50,50),T1,T2,T3,T4,RO,A,B,C,DELT
DATA CHK(1)/SHPUNCH/,CHK(2)/SHHKTERTAB/,CHK(3)/8HCONTOUR/,CHK(4)/7HNUMERIC/,CHK(5)/7HCHECK/
READ (5,570) TMAX,DIML,DIMW,NUM,QRE,DELT,M,KTH,FACTOR,LENGTH,ERR,
READ (5,610) SUM
READ (5,620) PCHN,WATR,CONTR,NUM,CHK
READ (5,630) (DELFX(I),J=1,DIMW)
READ (5,640) (DFLY(I),I=1,DIML)
DO 10 I=1,DIML
READ (5,620) (STRT(I,J),J=1,DIML)
WHILE (I=J)=STRT(I,J)
DO 20 J=1,DIML
READ (5,590) (RATE(I,J),J=1,DIML)
DO 20 J=1,DIML
IF (RATE(I,J)>0) RATE(I,J)=RATE(I,J)*FACTOR
IF (RATE(I,J)<0) GO TO 50
DO 30 I=1,DIML
READ (5,520) (PERM(I,J),J=1,DIML)
DO 30 J=1,DIML
PERM(I,J)=PERM(I,J)*FACP
DO 40 I=1,DIML
READ (5,530) (BOTTOM(I,J),J=1,DIML)
DO 40 J=1,DIML
BOTTOM(I,J)=BOTTOM(I,J)*FACB
DO 70 I=1,DIML
GO TO 70
DO 60 J=1,DIML
GO TO 70
DO 50 J=1,DIML
READ (5,530) (T(I,J),J=1,DIW)
DO 60 J=1,DIW
60 T(I,J)=T(I,J)*FACT
70 DO I=1,DIML
    RIA(5,530) (S(I,J),J=1,DIW)
    DO 90 J=1,DIW
90 S(I,J)=S(I,J)*FACT
C
C                          ************ PARAMETER VALUES
C                      WRITE (6,550) DEL,TMAX,NUMT,QRE,DIML,DIW,LENGTH,EBR,FACTOR,FACS
C                      IFAC,FACP,FACT,RIVER,KTH
C                      WRITE (6,600) (DELX(J),J=1,DIW)
C                      WRITE (6,650) (DELY(I),I=1,DIML)
C                      TMAX=TMAX*3600.
C                      IF (WATER.EQ.CHK(2)) GO TO 100
C                      WRITE (6,560)
C                      DO DO I=1,DIML
C                      WRITE (6,570) I,(T(I,J),J=1,DIW)
C                      100 WRITE (6,580)
C                      DO 110 I=1,DIML
C                      WRITE (6,570) I,(S(I,J),J=1,DIW)
C                      WRITE (6,590)
C                      DO 120 I=1,DIML
C                      WRITE (6,570) I,(RATE(I,J),J=1,DIW)
C                      IF (RATEP.EQ.CHK(2)) GO TO 150
C                      WRITE (6,630)
C                      DO 130 I=1,DIML
C                      WRITE (6,670) I,(PERM(I,J),J=1,DIW)
C                      WRITE (6,680)
C                      DO 140 I=1,DIWL
C                      WRITE (6,570) I,(BOTTOM(I,J),J=1,DIW)
C                      150 JNOI=DIWL-1
C
C                      ************ COMPUTE ITERATION PARAMETERS
C                      COMPUTE HMIN
C                      HMIN=2.
C                      XVAL=3.141592/2*(1./DIML)**2
C                      YVAL=3.141592/2*(1./DIW)**2
C                      DO 160 I=2,DIML
C                      DO 160 J=2,DIW
C                      IF (T(I,J).EQ.0.) GO TO 160
C                      XPART=XVAL*(1./1+DELX(J)**2/DELY(I)**2)
C                      YPART=YVAL*(1./1+DELY(I)**2/DELX(J)**2)
C                      HMIN=MIN(HMIN,XPART,YPART)
C                      CONTINUE
C                      ALPHA=EXP(ALOG(1/HMIN)/(LENGTH-1))
DO 170 NTIME=2,LENGTH
170 RHOP(NTIME)=RHOP(NTIME-1)*ALPHA
PARAM=RHO(1)
WRITE (6,550) (RHOP(J),J=1,LENGTH)

IF TEST EQUALS 1 CONTINUE ITERATION, IF TEST EQUALS 0 GO TO NEXT TIME STEP
180 IF (TEST.EQ.1) GO TO 250
190 DO 200 K=1,DIML
200 WRITE (7,620) (PHI(I,J),J=1,DIMW)
210 CONTINUE
K=K+1
Q=Q+1
DO 220 I=1,DIML
220 KEEP(I,J)=PHI(I,J)
230 CONTINUE
DEL=DEL+DEL
SUM=SUM+DEL
HRS=SUM/3600
MINS=HRS*60
DAYS=HRS/24
GO TO 270
250 IF (KOUNT.LT.100) GO TO 260
WRITE (6,670)
GO TO 190
260  KOUNT=KOUNT+1
270  IF (MOD(KOUNT,LENGTH)) 270,270,280
270  NTH=C
280  NTH=NTH+1.
290  PARA=RHO(NTH)
290  TEST=*
300  DO 30; J=1, DIMW
300  TEMP(J)=PHI(J)
300  DO 400; I=1, DIML
300  NO 360; J=2, J+1
C
C
C
C DETERMINE WHETHER NODE IS OUTSIDE AQUIFER BOUNDARY
C IF (T[I,J]) 310,36C,310
C
C
C
C
C 310  RHO=S[I,J]/DELT
C
C
C
C
C CALCULATE AVERAGE VALUES OF T BETWEEN ADJACENT NODES
C NODE CONFIGURATION T1=LEFT, T2=RIGHT, T3=UPPER, T4=LOWER
C T1=(((2.*T[I,J-1]*T[I,J])/(T[I,J]*DELX(J-1)+T[I,J-1]*DELX(J)))/DELX
C I(J)
C T2=(((2.*T[I,J+1]*T[I,J])/(T[I,J]*DELX(J+1)+T[I,J+1]*DELX(J)))/DELX
C I(J)
C T3=(((2.*T[I-1,J]*T[I,J])/(T[I,J]*DELY(1)+T[I-1,J]*DELY(I)))/DELY
C I(I)
C T4=(((2.*T[I+1,J]*T[I,J])/(T[I,J]*DELY(I+1)+T[I+1,J]*DELY(I))))/DELY
C I(I)
C T=[PARA*(T1+T2+T3+T4)
C K=0.6
C
C
C
C CHECK WHETHER NODE IS ALONG A STREAM OR ON A LAKE
C IF (RATE[I,J]) 330,330,320
C
C
C
C
C 320  K=RATE[I,J]
C
C
C
C
C CALCULATE VALUES FOR PARAMETERS A, B, C, AND BE
C
C
C
C
C 330  B=T1-T2-RHO*K/(2.*M)-1MK
C
C A=T1
C C=T2
C W=B-A+3E(J-1)
C BE(J)=C/W

C
CHECK NODE FOR POSSIBLE WELL LOCATION

IF (RATE(I,J)) 340,350,360
340 RW=RATE(I,J)/(DELX(J)*DELY(I))
350 D=FI*(PHI(I-1,J)+T4*PHI(I+1,J)-RHO*KEEP(I,J)-
1(K/U)*(RIVER-KEEP(I,J)+2)+RW-RR
G(J)=(0-A*G(J-1))/J
360 CONTINUE

CALCULATE HEAD VALUES FOR ROWS OF MATRIX AND PLACE THEM IN
TEMPORARY LOCATION TEMP
N03=DIMW-2
N04=1,N03
N04=0,N04
PHI(I-1,N04)=TEMP(N04)
IF (T(I,N04)) 380,370,380
370 TEMP(N04)=G(N04)-8E(N04)*TEMP(N04+1)
380 CONTINUE
400 CONTINUE

FOLLOW SIMILAR PROCEDURE FOR COLUMNS OF MATRIX AS THAT CONSIDERED
FOR ROWS
DO 410 I=1,DIML
410 TEMP(I)=PHI(I,1)
N01=DIML-1
N02=1,N01
N02=2,N02
N02=3,N02
IF (T(I,J)) 420,470,420
420 RHO=S(I,J)/DELT
470 CONTINUE

CALCULATE AVERAGE VALUES OF T BETWEEN ADJACENT NODES
T1={2.*T(I,J-1)*T(I,J-1)}/(T(I,J)*DELX(J-1)+T(I,J-1)*DELX(J))/DELX
T(J}
T2={2.*T(I,J+1)*T(I,J+1)}/(T(I,J)*DELX(J+1)+T(I,J+1)*DELX(J))/DELX
T(J}
T3={2.*T(I-1,J)*T(I-1,J)}/(T(I,J)*DELY(I-1)+T(I-1,J)*DELY(I))/DELY
I(I) A 301
T4=((2.0*T(I+1,J)+T(I,J))/(T(I,J)*DELY(I+1)+T(I+1,J)*DELY(I)))/DELY
1(I)
1MK=PARAM*(T1+T2+T3+T4)
K=2.C

C CHECK WHETHER NODE IS ALONG A STREAM OR ON A LAKE
IF (RATE(I,J)> 440,440,430 K=RATE(I,J)
C
C CALCULATE VALUES FOR PARAMETERS A,T,C,AND BE
A=T3
C=T4
3=T4-T3-RHO-K/(2.*M)-1MK
W=B-A*RIFI(1-1)
BRI(I)=CA:

C CHECK NODE FOR POSSIBLE WELL LOCATION
RW=0.0
IF (RATE(I,J)) 450,460,460
450 RW=-RATE(I,J)/(DELX(J)*DELY(I))
460 N=R*I+PHI(I,J)+T1+T2-1MK)*PHI(I,J)-T2*PHI(I,J)-RHO*K/2.*MM
1(K/M)*(K1*VFR-KEEP(I,J)/2.1+RW-RR
G(I)=(D-A*G(I-1))/N
470 CONTINUE
C
C CALCULATE HEAD VALUES FOR COLUMNS OF MATRIX AND PLACE IN TEMPORARY
C LOCATION TEMP
N03=DI[4L-2
DO 500 K=1,N03
500 N04=DI[4L-K'M04
PHI(N04,J-1)=TEMP(K)=PHI(N04,J-1)+T1*PHI(I,J)+T1*PHI(I,J)+RHO*KEEP(I,J)-
1(K/M)*(K1*VFR-KEEP(I,J)/2.1+RW-RR
G(I)=(D-A*G(I-1))/N
480 TEMP(N04)+PHI(N04,I)
GO TO 50C
490 TEMP(N04)=G(N04)-BF(N04)*TEMP(N04+1)
500 CONTINUE
510 CONTINUE
GO TO 180
C
C ** SUROUTINE PRNTA **
C ** SUROUTINE PRINTS OUT THE HEAD MATRIX AS ALPHABETIC CONTOURS **
C
COMMON PHI, SUM, DELX, DELY, DIML, DIMN, RATE, STRT, SPACNG
C
INTEGER DIML, DIMN

REAL K

DIMENSION RATE(50,50), PHI(50,50), STRT(50,50),
           PRNT(60), SYM(39), BLANK(50,50)

DIMENSION DELY(50), DELX(50)

DOUBLE PRECISION PHI

WRITE (6,5)

DATA SYM/1HI, 1H2, 1H3, 1H4, 1H5, 1H6, 1H7, 1H8, 1H9, 1HA, 1HB, 1HC, 1HD, 1HE,
       1HF, 1HG, 1HI, 1HJ, 1HK, 1HL, 1HM, 1HN, 1HO, 1HP, 1HQ, 1HR, 1HS, 1HT, 1HU, 1MV

1, 1MY, 1MX, 1MY, 1M2, 1M3, 1M4, 1M5, 1M6, 1M7, 1M8, 1M9, 1MA, 1MB, 1MC, 1MD,
       1ME, 1MF, 1MG, 1MH, 1MI, 1MJ, 1MK, 1ML, 1MM, 1MN, 1MO, 1MP, 1MQ, 1MR, 1MS,
       1MT, 1MU, 1MV, 1MD, 1MD, 1MD, 1MD, 1MD, 1MD, 1MD, 1MD, 1MD, 1MD, 1MD, 1MD

1MY=65-DIMN/2

DO 4 J=1, DIMN
   GO TO 9
   K=AVOD(K, 36.)
   IF (K.LT.1.) PRNT(J)=SYM(36)
   IF (K.LT.0.) PRNT(J)=SYM(37)
   N=K
   IF (N.LT.1.) GO TO 20
   PRNT(J)=SYM(N)

20 IF (RATE(IH, JB).GT.0.) PRNT(JB)=SYM(27)

30 CONTINUE

40 WRITE (6,60) (BLANK(I), I=1, IND), (PRNT(JB), JB=1, DIMW)

WRITE (6,70) SPACNG
RETURN


C

C

C

C

C

C

C

50 FORMAT (1HC, 50X, 32HALPHABETIC CONTOURS FOR DRAWDOWN,////)

60 FORMAT (1HC, 65A2)

70 FORMAT (1HC=LEGEND###18H=CONTOUR INTERVAL=.F10.3/32H=LOCATION OF

1RECHARGE BOUNDARY=W/16HOWELL LOCATION=W/21H=GONE OF IMPRESSION=G)

END
SUBROUTINE PRNT1

THIS SUBROUTINE PRINTS OUT THE HEAD MATRIX IN NUMERICAL FORM

COMMON PHI, SUM, DELX, DEYY, DIML, DIMW, RATE, S, STRT, SPACNG
DIMENSION RATE(50,50), DON(50), PHI(50,50), S(50,50), STRT(50,50)
DIMENSION DELY(50), DELX(50)
INTEGER DIML, DIMW

DOUBLE PRECISION PHI
WRITE (6,30)
DO 10 J=1,DIMW
   10 DON(J)=STRT(I,J)-PHI(I,J)
WRITE (6,40) I,(DON(K),K=1,DIMW)
RETURN

30 FORMAT (IH1,58X,16DRAWDOWN IN FEET//)
40 FORMAT (1H0,15,1H ,11E11.3))
END
SUBROUTINE CHECK

THIS SUBROUTINE COMPUTES THE ERROR IN THE SOLUTION ON A MASS BALANCE BASIS

**WARNING - USE THIS SUBROUTINE ONLY WHEN THERE IS NO INFILTRATION INTO THE SYSTEM**

COMMON PHI,S,DELX,DELY,DIML,DIMW,RATE,S,STRT,SPACING

INTEGER DIML,DIMW

DIMENSION RATE(50,50), S(50,50), PHI(50,50), STRT(50,50)

DOUBLE PRECISION PHI

TOTL=0.0

PUMP=0.0

DO 10 IC=2,DIML

DO 10 JC=2,DIMW

TOTL=TOTL+S(IC,JC)*DELX(JC)*DELY(IC)*(STRT(IC,JC)-PHI(IC,JC))

10 IF (RATE(IC,JC)*LT.O) PUMP=PUMP-RATE(IC,JC)*SUM

DIFF=PUMP-TOTL

PERCNT=(DIFF/PUMP)*100.

WRITE (6,20: TOTL,PUMP,DIFF,PERCNT)

RETURN

C

C

C

C

C

C

**FORMAT (63HOQUANTITY PUMPED ACCORDING TO CONE OF DEPRESSION IN CUB D**

1C FEET=,E20.10//59H QUANTITY PUMPED ACCORDING TO WELL DISCHARGE I D 29

2N CUBIC FEET=,E20.10//51H ESTIMATE FROM PUMPING LESS ESTIMATE FROM D 30

3 DRAWDOWN=,E20.10//42H DIFFERENCE AS A PERCENT OF VOLUME PUMPED=,E D 31

420.1C)

END