EGG-2239

Idaho National Engineering Laboratory
Operated by the U.S. Department of Energy

Prickett and Lonnquist Aquifer Simulation Program For the Apple II Minicomputer

Laurence C. Hull

February 1983

Prepared for the
U.S. Department of Energy
Under DOE Contract No. DE-AC07-76IDO1570

EG&G Idaho

Printed in the United States of America

Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
NTIS Price Codes: Printed Copy A02
Microfiche A01

EGG-2239
Distribution Categories: UC66-A, D, G

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ABSTRACT

The Prickett and Lonnquist two-dimensional groundwater model has been programmed for the Apple II minicomputer. Both leaky and nonleaky confined aquifers can be simulated. The model was adapted from the FORTRAN version of Prickett and Lonnquist. In the configuration presented here, the program requires 64 K bits of of memory. Because of the large number of arrays used in the program, and memory limitations of the Apple II, the maximum grid size that can be used is 20 rows by 20 columns. Input to the program is interactive, with prompting by the computer. Output consists of predicted head values at the row-column intersections (nodes).

CONTENTS

PRICKETT AND LONNQUIST AQUIFER SIMULATION PROGRAM FOR THE APPLE II MINICOMPUTER

INTRODUCTION

This report summarizes the use of the Prickett and Lonnquist two-dimensional groundwater model, which has been programmed for the Apple II minicomputer. Both leaky and nonleaky confined aquifers can be simulated. The model was adapted from the FORTRAN version of Prickett and Lonnquist.[1] Additional information on the model and some advice on its use can be found in Reference 1. In the configuration presented here, the program requires 64 K bits of memory. Because of the large number of arrays used in the program, and memory limitations of the Apple II, the maximum grid size that can be used is 20 rows by 20 columns. Input to the program is interactive, with prompting by the computer. Output consists of predicted head values at the row-column intersections (nodes).

Funding for this project was provided by the Low-to-Moderate Temperature Reservoir Engineering Program, Department of Energy, supervised at EG&G Idaho by Max R. Dolenc. Steve A. Mizell of the Geosciences Branch, EG&G Idaho, provided assistance in adapting the program to the Apple II minicomputer.

NUMERICAL MODEL

On a microscopic scale, flow in a porous medium occurs along tortuous paths through various pore spaces. The direction and velocity of flow through each pore can be different. For a homogeneous medium, if direction and velocity are averaged over increasing numbers of pores (that is, over a larger volume of aquifer), a stable estimate of mean flow direction and velocity will be obtained once a certain minimum aquifer volume is exceeded.[2] This minimum aquifer volume is termed the representative elementary volume (REV). The minimum size of the REV will depend on the size, shape, orientation, and packing of grains. There will be a maximum REV in nonhomogeneous aquifers, where aquifer characteristics change spatially. The node spacing in a finite difference model must be selected so that aquifer characteristics are adequately represented. In this adaptation of the Prickett and Lonnquist model, the limited number of nodes requires a very coarse grid spacing when large areas are to be simulated. Thus, only major nonhomogeneities in aquifer properties can be represented. Also, because the model is a horizontal two-dimensional model, vertical differences in aquifer characteristics are averaged into a single aquifer parameter.

The equations used in the numerical simulation are based on the principle of conservation of mass. The mass of water leaving a nodal volume must be equal to the amount of water entering, plus or minus any changes in storage, plus or minus any external additions or subtractions of water (such as pumpage). This can be expressed by Equation (1), with subscripts referenced to Figure 1.

$$Q_1 + Q_3 = Q_2 + Q_4 \pm Q_s \pm Q_p \qquad (1)$$

where

$Q_1 + Q_3$ = inflow to nodal volume

$Q_2 + Q_4$ = outflow from nodal volume

Q_s = addition to or subtraction from storage

Q_p = other changes in water volume, such as pumpage (-) or injection (+).

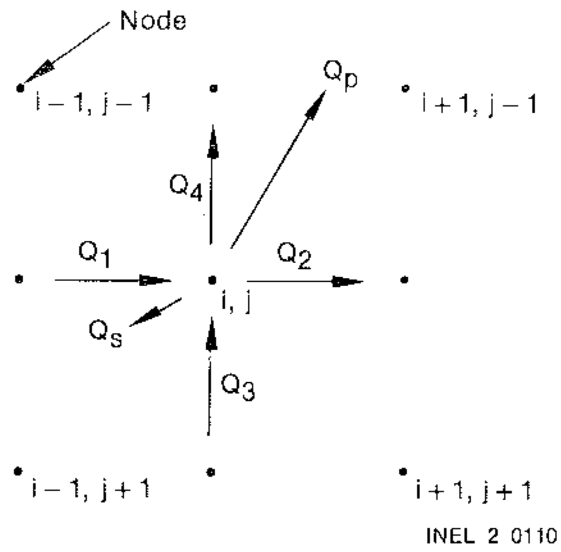

Figure 1. Finite difference grid showing flow volume relations.

For flow in the aquifer, Q_1 through Q_4, Darcy's law can be used to calculate the flow volumes. Darcy's law states that the discharge through a unit width of aquifer is related to the ability of the aquifer to transmit water (the transmissivity, T), and the change in head with distance.

$$Q = T \frac{\partial h}{\partial x} \Delta y \qquad (2)$$

where

$\frac{\partial h}{\partial x}$ = head gradient or rate of change of head (h) with distance (x)

Δy = width

Q = discharge.

The transmissivity is the amount of water that can be passed through a unit width of aquifer under a unit head gradient. It is related to the hydraulic conductivity (K) by $T = K \cdot m$, where m is aquifer thickness. Therefore, the transmissivity is a vertical average of aquifer permeability, and depends on aquifer thickness.

Using Equation (2) to calculate Q_1 through Q_4 in Equation (1) gives the following relationships.

$$Q_1 = T_{i-1,j,2} \cdot \Delta y \cdot \frac{(h_{i-1,j} - h_{i,j})}{\Delta x} \qquad (3a)$$

$$Q_2 = T_{i,j,2} \cdot \Delta y \cdot \frac{(h_{i,j} - h_{i+1,j})}{\Delta x} \qquad (3b)$$

$$Q_3 = T_{i,j+1,1} \cdot \Delta x \cdot \frac{(h_{i,j+1} - h_{i,j})}{\Delta y} \qquad (3c)$$

$$Q_4 = T_{i,j,1} \cdot \Delta x \cdot \frac{(h_{i,j} - h_{i,j-1})}{\Delta y} \,. \qquad (3d)$$

The change in storage (Q_S) is given by the relation

$$Q_s = S \cdot \Delta x \cdot \Delta y \frac{(h_{i,j} - h'_{i,j})}{\Delta t} \qquad (4)$$

where

S = ratio storage coefficient (volume/volume)

t = time

$h'_{i,j}$ = head at node i,j at a previous time given by $t - \Delta t$.

External volume changes, such as from pumpage, must be known explicitly. Other Q's are possible, such as from evapotranspiration or leakage. For explanation of how these parameters are added to the model, refer to Reference 1.

Replacing the Q's in Equation (1) with Equations (3a) through (3d) and (4) gives a finite difference approximation of flow through a porous medium. An equation of the same form exists for each node in the model, and these must be solved simultaneously to determine the head distribution in the aquifer. This series of equations is solved using an iterative alternating direction implicit technique.[1]

VERIFICATION

Results generated by a numerical model must be verified to assure that they are meaningful. This adaptation of the Prickett and Lonnquist model was verified by comparing numerical solutions from the model with analytical solutions. The configuration of the model used for verification is shown pictorially in Figure 2. Table 1 gives the parameters input to the model. A single pumping well was placed at the center of a grid of sufficient size to assure that boundary effects would not influence the calculations.

Analytical solutions for nonleaky conditions were calculated using Equation (5) and hydrologic parameters given in Table 1.

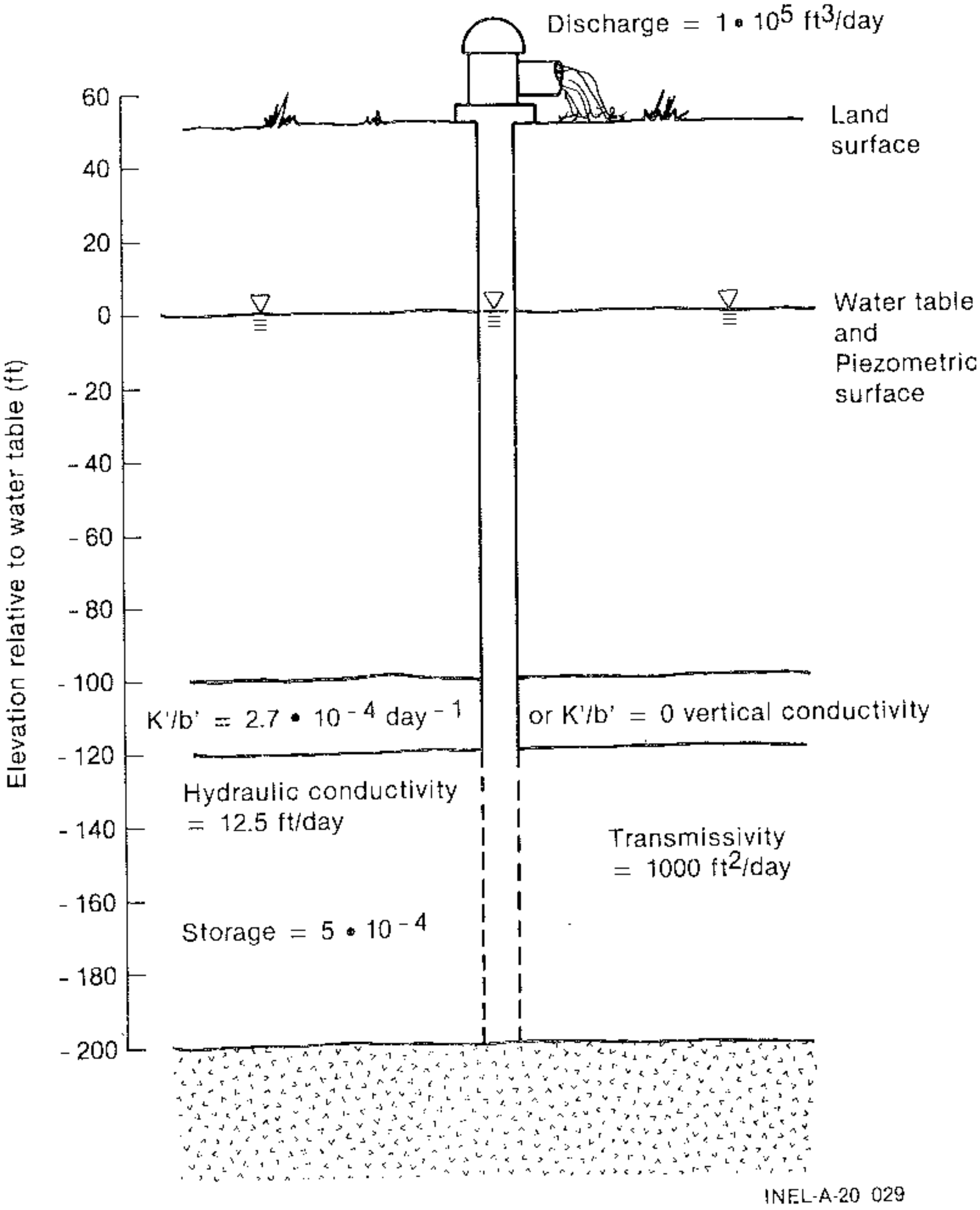

Figure 2. Schematic of aquifer system used to validate the computer code.

Table 1. Configuration of model for validation runs

MODEL DESCRIPTION

STEPS	10
COLUMNS	19
ROWS	19
DELTA T	0.385
ERROR	3

DEFAULT PARAMETERS

TRANSMSSVTY	1000
STORAGE	5E-04
HEADS	0
PUMPAGE	0
VERT COND	2.7E-04
SOURCE BED	0
GRIDS	1000

VARIABLE GRID SPACINGS

X SPACING	Y SPACING
10000	10000
7500	7500
5000	5000
3000	3000
1000	1000
500	500
300	300
100	100
100	100
100	100
100	100
300	300
500	500
1000	1000
3000	3000
5000	5000
7500	7500
10000	10000

LOCATIONS OF PUMPING WELLS

PUMPAGE	COLUMN	ROW
100000	10	10

$$s = \frac{2.3\,Q}{4\pi T} \log \frac{2.25\,Tt}{r^2 S} \qquad (5)$$

where

- s = drawdown
- Q = discharge of pumped well
- T = transmissivity
- t = time
- r = distance from pumped well
- S = storage coefficient.

The drawdown as a function of distance from the pumped well after 10 days of pumping is shown in Figure 3. Equation (5) is applicable to a limited range of times and distances. At a given distance from the pumped well, there is a minimum time that must pass before the assumptions inherent in Equation (5) are valid. For nonleaky artesian conditions, this time is given by the relation

$$t = \frac{12.533\, r^2 S}{T} \qquad (6)$$

where

- t = days
- r = feet
- T = ft^2/day
- S = a fraction

and where the indicated units must be used for consistency with the constant in the equation. For a time of 10 days, simulated drawdowns beyond 1263 ft will not be strictly comparable to values given by Equation (5). For greater distances and leaky artesian conditions, analytical solutions were obtained using the Theis equation, as described by Lohman.[3]

Comparison of drawdowns from the analytical and numerical solution methods for both time and distance drawdown (Tables 2 and 3) show

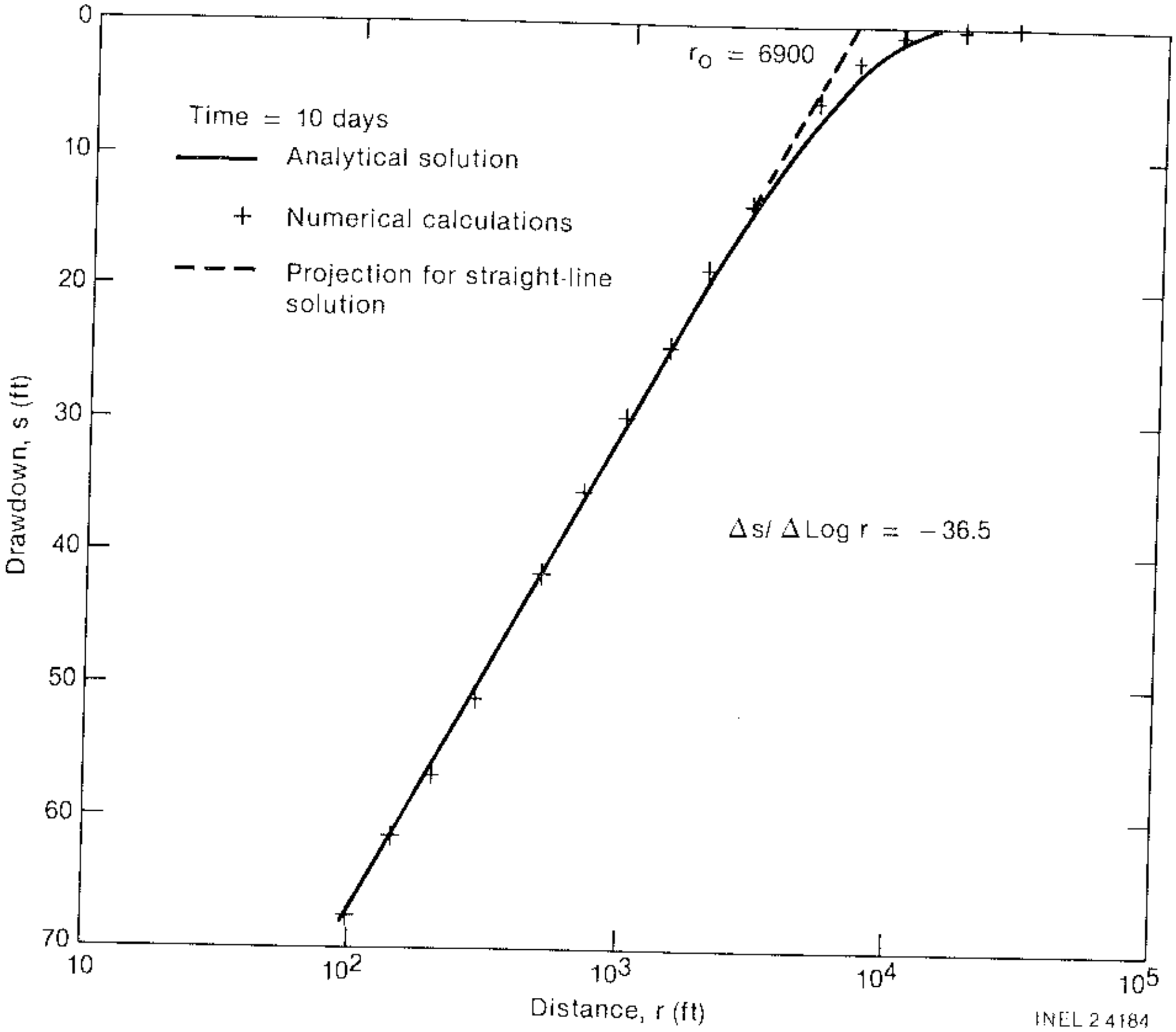

Figure 3. Plot of distance versus drawdown for nonleaky aquifer simulation after a time of 10 days.

reasonable agreement. Using straight-line plots for nonleaky conditions (Figure 3) and type-curve matching for leaky conditions (Figure 4), aquifer parameters were estimated from output of the numerical simulations. For nonleaky conditions, transmissivity was calculated from Figure 3 and the equation

$$T = -\frac{2.3\ Q}{2\pi\ (\Delta s/\Delta \log r)} \qquad (7)$$

and storage from

$$S = 2.25\ T\left(\frac{t}{r_o^2}\right). \qquad (8)$$

For leaky conditions, the points in Figure 4 were matched to type curves given by Lohman.[3] Parts of the curves for v = 0.02 and v = 0.05 are shown. From this it was concluded that 0.03 was the best estimate for v. The match point was selected and the values shown in Figure 4 used to calculate aquifer parameters using

$$T = \frac{Q}{4\pi s}\ W\ (u,\ r/b) \qquad (9)$$

for transmissivity and

$$S = 4\ T\left(\frac{t/r^2}{1/u}\right) \qquad (10)$$

Table 2. Comparison of analytical and numerical values for time-drawdown at a distance of 100 ft

Time (d)	Drawdown (ft) Analytical	Numerical	Difference[a] (%)
Nonleaky			
2.9	-56.9	-56.4	1.0
3.8	-59.2	-58.9	0.6
5.0	-61.3	-61.3	0.0
6.4	-63.3	-63.7	-0.7
8.0	-65.1	-66.0	-1.5
10.0	-66.9	-68.2	-2.0
Leaky			
1.4	-46.2	-46.0	0.4
2.3	-47.6	-47.9	-0.6
3.6	-48.4	-48.9	-1.0
5.5	-48.7	-49.3	-1.3
8.2	-48.8	-49.5	-1.4
10.0	-48.8	-49.5	-1.5

a. Percentage difference is defined as:

$$\frac{\text{Analytical - Numerical}}{\text{Analytical}} \cdot 100.$$

Table 3. Comparison of analytical and numerical values for distance—drawdown at a time of 10 days

Distance (ft)	Drawdown (ft) Analytical	Numerical	Difference (%)
Nonleaky			
20.8	-91.8	-93.3	-1.5
100	-68.9	-68.2	-2.1
141	-61.4	-61.5	-0.1
200	-55.8	-56.8	-1.7
283	-50.3	-51.1	-1.4
500	-41.3	-41.5	-0.6
207	-35.8	-35.6	0.5
1000	-30.3	-29.8	1.5
Leaky			
20.8	-73.8	-74.5	-0.9
100	-49.0	-49.5	-1.2
141	-43.6	-42.8	1.8
200	-38.6	-38.2	1.1
283	-32.3	-32.6	-0.8
500	-24.0	-23.5	2.0
207	-18.9	-18.2	3.7
1000	-14.2	-13.2	7.0

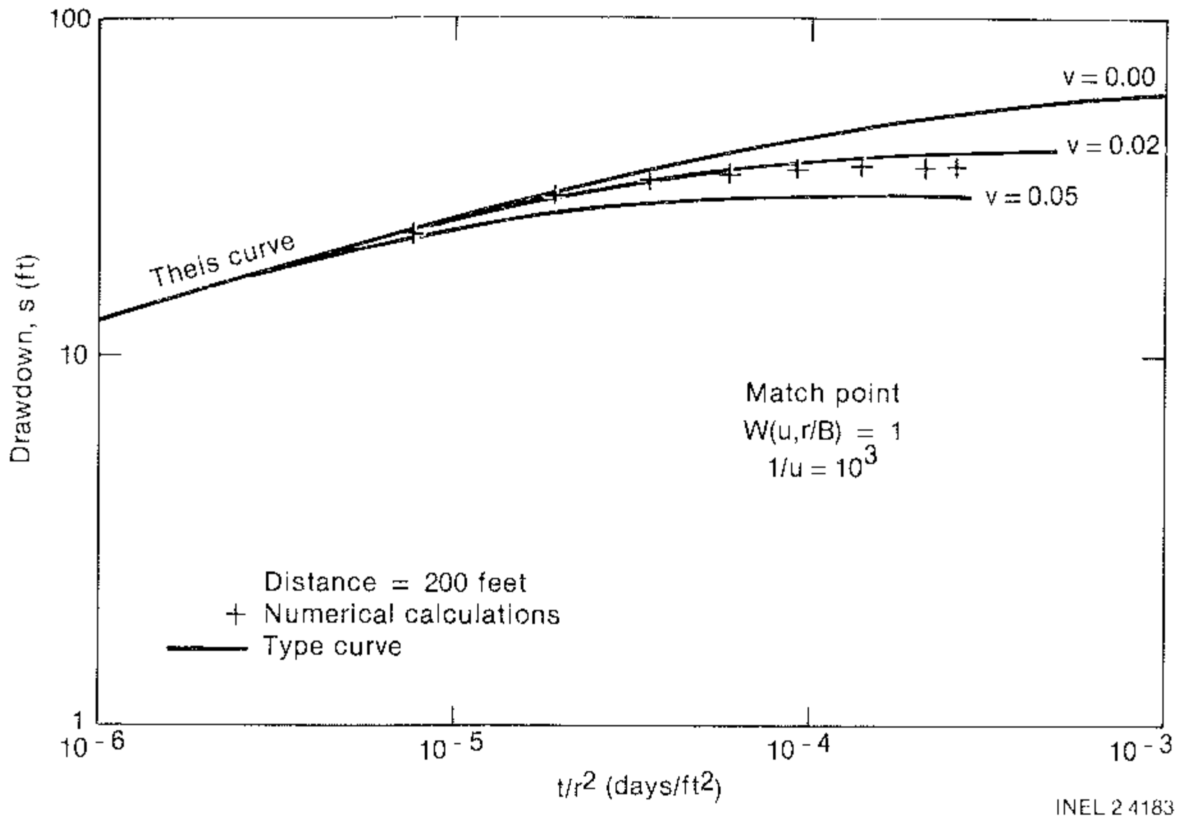

Figure 4. Comparison of simulated drawdown data at a distance of 200 ft to the type curve for leaky artesian aquifers.

for storage. Leakage was calculated from

$$K'/b' = 4\,T\,\frac{v^2}{r^2}\,. \qquad (11)$$

Input and estimated values for transmissivity (T), storage (S), and vertical hydraulic conductivity (K'/b') are shown in Table 4. The parameters calculated from the numerical solutions show very close agreement to transmissivity, storage coefficient, and leakage initially input to the model.

Simulation runs produce reasonably accurate head distributions. Two factors that probably contribute to the observed discrepancies are problems in scaling aquifer coefficients for variable grid spacings, and numerically approximating the solution to analytical equations. Because of the relatively small grid size possible with the minicomputer, the model is best used for simulations of small areas.

Table 4. Comparison of hydrologic parameters[a]

	Leaky			Nonleaky	
	T (ft^2/d)	S	K′/b′ (d^{-1})	T (ft^2/d)	S
Model parameter	1000	$5 \cdot 10^{-4}$	$2.7 \cdot 10^{-4}$	1000	$5 \cdot 10^{-4}$
Numerical solution	1190	$4.8 \cdot 10^{-4}$	$1.1 \cdot 10^{-4}$	1006	$4.8 \cdot 10^{-4}$

a. Analyses for leaky conditions were performed by type-curve matching and for nonleaky conditions by the straight-line method.

PROGRAM USE

Input to the model is in two stages. The first stage is for input of model parameters and default hydrologic parameters. Default hydrologic parameters are assigned to each node, so that all nodes have equal values of transmissivity, storage, etc. The second stage of input is for modifying individual parameters for a node or for subareas within the model, and for changing the grid spacing.

The units must be internally consistent for proper use. Unit combinations of gal/day/ft, ft^3/day/ft, m^3/s/m, are all equally valid. For example, if transmissivity is given in m^2/s, the time increment must be in seconds and heads in meters. Input variables in the following list are labeled as to the unit combinations. The letters symbolize: t—time (min, d); L—length (ft, m); v—volume (gal, ft^3, m^3).

The input variables, in order of appearance are:

1. Number of steps—The number of time steps that are simulated by the model. The time duration modeled is a function of the time increment and the number of steps. At least six time steps should precede the time period for which head values are desired. Large numbers of steps will require large amounts of time; simulation of a 19 x 19 grid required 0.5 h of real time per time step.

2. Time increment (Δt)—The time increment increases by a factor of 1.2 with each time step. This results in more stable solutions for early time steps and still allows later time steps to simulate longer time periods.

3. Error check (L)—The maximum permissible error for testing convergence. To calculate this value, use:

   $$\text{Error} = (Q \cdot \Delta t)/(10 \cdot S \cdot \Delta x \cdot \Delta y)$$

   where

   Q = well discharge summed over all nodes

   Δt = time increment

   S = storage coefficient

   Δx = geometric mean of largest and smallest x grid spacing

   Δy = geometric mean of largest and smallest y grid spacing.

   Units must be consistent to give error in units of length.

4. Number of columns—must be ≤ 20.

5. Number of rows—must be ≤ 20.

6. Transmissivity, (v/t/L) or (L^2/t)—The volume of water transported through unit width of aquifer, per unit time, under unit hydraulic gradient. The program automatically compensates for variable grid spacings. Same value is used for both x and y directions.

7. Storage, (ratio) or (v/L^3)—The storage coefficient with units depending on the volume measurement system. If volume is measured as L^3, then the ratio storage coefficient is used. If volume is measured as v (liters, gal) then the storage coefficient must be multiplied by the conversion factor for v to L^3. For example, 7.48 gal/ft^3 or 1000 liters/m^3. The effects of grid spacing are taken into account by the model.

8. Heads (L)—The elevation of the piezometric surface for the confined aquifer relative to some arbitrary datum.

9. Pumpage, (v/t) or (L^3/t)—Discharge from (+) or recharge to (-) a node. The rate is held constant throughout all time steps.

10. Grid spacing (L)—Default distance between nodes if all distances are equal.

11. Vertical conductivity, (v/t/L^3) or (1/t)—Volume of water transported through unit area of confining bed, per unit time, under unit head differential divided by the thickness of the confining bed. The model

takes care of determining the volume of leakage by adjusting for the grid spacing.

12. Source bed heads (L)- The elevation of water in the source bed, for leaky conditions, relative to the same datum as the piezometric surface.

The second stage of input to the model allows modification of the default parameters. The possible changes are listed on the screen, and the selection made by number. When no further changes are desired, exit by typing zero. Modifications to hydrologic parameters can be made either to a range of nodes, or to a series of individual nodes. By changing hydrologic parameter values for certain nodes, recharge boundaries, constant head boundaries, or highly transmissive fault zones can be simulated.

The final alteration that can be made is to change the grid spacing. This is done by entering the distance between adjacent nodes, not the width of the nodal areas. The program will then adjust the hydrologic parameters for the different grid size. More detail can be obtained by placing smaller grids near pumping wells and other areas where heads are changing rapidly.

For extensive hydrologic variables (storage, vertical conductivity), the nodal areas are calculated using arithmetic means. For intensive hydrologic variables (transmissivity), the adjusted nodal values are calculated using harmonic means.[4]

For equidimensional grids, the number of nodes increases as the square of the number of rows (or columns), and so the time required for simulation runs increases greatly with increasing grid size. A simulation of a 19 x 19 grid, for verification purposes, required about 4 h for 10 time steps.

Appendix A is an example of the output from a short simulation run of a 5 x 5 grid. The first page is a printout of the default parameters. If variable grid spacings or pumping wells are added, these are also printed out. Nonleaky conditions can be simulated by setting the vertical conductivity to zero. A listing of the hydrologic parameters for the nodes, corrected for grid spacing, can be obtained as an option. The remaining output consists of head values at the nodes for each time step.

Appendix B contains a listing of the program.

REFERENCES

1. T. A. Prickett and C. G. Lonnquist, *Selected Digital Computer Techniques for Ground-Water Resource Evaluation*, Illinois State Water Survey Bulletin 55, Urbana, Illinois, 1971.

2. J. Bear, *Dynamics of Fluids in Porous Media*, New York: American Elsevier Publishing Co., 1972.

3. S. W. Lohman, *Ground-Water Hydraulics*, U.S. Geological Survey Professional Paper 708, 1972.

4. P. C. Trescott, G. F. Pinder, S. P. Larson, *Finite-Difference Model for Aquifer Simulation in Two Dimensions with Results of Numerical Experiments*, Techniques of Water-Resources Investigations of the U.S. Geological Survey, Book 7, Chapter C1, 1976.

APPENDIX A

EXAMPLE PROGRAM OUTPUT

APPENDIX A

EXAMPLE PROGRAM OUTPUT

```
            TEST NON-LEAKY AQUIFER MODEL

MODEL DESCRIPTION
      STEPS.....   2
      COLUMNS...   5
      ROWS......   5
      DELTA T...   1
      ERROR.....   .8

DEFAULT PARAMETERS
      TRANSMSSVTY 10000
      STORAGE...   5E-04
      HEADS.....   0
      PUMPAGE...   0
      VERT COND.   0
      SOURCE BED   0
      GRIDS.....   5000

            LOCATIONS OF PUMPING WELLS

   PUMPAGE    COLUMN                           ROW

     25000       1                              1
     25000       1                              2
     25000       1                              3
     25000       1                              4
     25000       1                              5
```

TRANSMISSIVITTY(C,R,1)

ROWS	1	2	3	4
1	10000	10000	10000	10000
2	10000	10000	10000	10000
3	10000	10000	10000	10000
4	10000	10000	10000	10000
5	10000	10000	10000	10000

ROWS	5	6	7	8
1	10000	0	0	0
2	10000	0	0	0
3	10000	0	0	0
4	10000	0	0	0
5	10000	0	0	0

TRANSMISSIVITTY(C,R,2)

ROWS	1	2	3	4
1	10000	10000	10000	10000
2	10000	10000	10000	10000
3	10000	10000	10000	10000
4	10000	10000	10000	10000
5	10000	10000	10000	10000

ROWS	5	6	7	8
1	10000	0	0	0
2	10000	0	0	0
3	10000	0	0	0
4	10000	0	0	0
5	10000	0	0	0

STORAGE FACTORS

ROWS	1	2	3	4
1	12500	12500	12500	12500
2	12500	12500	12500	12500
3	12500	12500	12500	12500
4	12500	12500	12500	12500
5	12500	12500	12500	12500

ROWS	5	6	7	8
1	12500	0	0	0
2	12500	0	0	0
3	12500	0	0	0
4	12500	0	0	0
5	12500	0	0	0

STEP = 1 TIME = 1 # ITER = 3 ERROR = .120917802

COLUMN NUMBERS

ROWS	1	2	3	4
1	-1.31	-.45	-.16	-.05
2	-1.31	-.45	-.16	-.05
3	-1.31	-.45	-.16	-.05
4	-1.31	-.45	-.16	-.05
5	-1.31	-.45	-.16	-.06

STEP = 1 TIME = 1 # ITER = 3 ERROR = .120917802

COLUMN NUMBERS

ROWS	5	6	7	8
1	-.02	0	0	0
2	-.02	0	0	0
3	-.02	0	0	0
4	-.02	0	0	0
5	-.02	0	0	0

STEP = 2 TIME = 2.2 # ITER = 3 ERROR = .0789722348

COLUMN NUMBERS

ROWS	1	2	3	4
1	-2.44	-1.12	-.49	-.22
2	-2.44	-1.12	-.49	-.22
3	-2.44	-1.12	-.49	-.22
4	-2.44	-1.12	-.49	-.22
5	-2.44	-1.12	-.49	-.22

STEP = 2 TIME = 2.2 # ITER = 3 ERROR = .0789722348

COLUMN NUMBERS

ROWS	5	6	7	8
1	-.12	0	0	0
2	-.12	0	0	0
3	-.12	0	0	0
4	-.12	0	0	0
5	-.12	0	0	0

APPENDIX B

PROGRAM LISTING

APPENDIX B

PROGRAM LISTING

```
10  DIM H(20,20),HO(20,20),SF(20,20),Q(20,20),T(20,20,2),B(20),G(20),DL(20
     ,20),WD$(10),X(20),Y(20),DH(20,20),N1(15),R1(20,20),R2(20,20)
20  DIM QC(30),QR(30):NP = 0:D$ =  CHR$ (4):F2$ = "NONE"
30  DATA      "HEADS","TRANS X","TRANS Y","STORAGE","PUMPAGE","GRIDS","VERT
      COND","SOURCE HEAD"
40  FOR I = 1 TO 8: READ WD$(I): NEXT I: DEF  FN MOD(A) =  INT ((A / 2 -  INT
     (A / 2)) * 2. + 0.5)
50  DATA      2,1,.8,5,5,10000,.0005,0,0,5000,0,0
60  FOR I = 1 TO 12: READ N1(I): NEXT I:VN = 1
70  HOME : VTAB 4: HTAB 3: PRINT "==================================": PRINT
      TAB( 3)"PRICKETT AND LONNQUIST TWO-D MODEL": PRINT  TAB( 3)"========
     =========================="
80  VTAB 10: PRINT  TAB( 5)"CONTACT S.A. MIZELL OR L.C. HULL": PRINT  TAB(
     5)"OF THE GEOSCIENCES BRANCH FOR": PRINT  TAB( 5)"FURTHER DETAILS ON
     ITS USE.": VTAB 23: PRINT "PRESS <RTN> TO CONTINUE": GET A$
90  HOME : VTAB 5: PRINT "ENTER TITLE FOR PROBLEM...": PRINT : INPUT "";TI
     TLE$
100  HOME : INVERSE : HTAB 3: PRINT "DATA ENTRY": NORMAL : VTAB 1: HTAB 14
     : PRINT "- ENTER THE FOLLOWING": HTAB 16: PRINT "PARAMETERS AND": HTAB
     16: PRINT "DEFAULT VALUES"
110  PRINT :I = 1: PRINT "NUMBER OF STEPS.. ";N1(1): VTAB 5: HTAB 30: INPUT
     "";N2$: GOSUB 450: PRINT "DELTA TIME..(T) ";N1(2): VTAB 6: HTAB 30: INPUT
     "";N2$: GOSUB 450
120  PRINT "ERROR CHECK..(L)  ";N1(3): VTAB 7: HTAB 30: INPUT "";N2$: GOSUB
     450: PRINT "NUMBER COLUMNS (<=20) ";N1(4): VTAB 8: HTAB 30: INPUT "";
     N2$: GOSUB 450
130  PRINT "NUMBER ROWS (<=20) ";N1(5): VTAB 9: HTAB 30: INPUT "";N2$: GOSUB
     450: PRINT "TRANSMSSVTY..(V/T/L)  ";N1(6): VTAB 10: HTAB 30: INPUT ""
     ;N2$: GOSUB 450
140  PRINT "STORAGE... ";N1(7): VTAB 11: HTAB 30: INPUT "";N2$: GOSUB 450:
      PRINT "HEADS...(L)  ";N1(8): VTAB 12: HTAB 30: INPUT "";N2$: GOSUB 4
     50
150  PRINT "PUMPAGE...(V/T) ";N1(9): VTAB 13: HTAB 30: INPUT "";N2$: GOSUB
     450: PRINT "GRID SPACING..(L)  ";N1(10): VTAB 14: HTAB 30: INPUT "";N
     2$: GOSUB 450
160  PRINT "VERT COND..(V/T/L3) ";N1(11): VTAB 15: HTAB 30: INPUT "";N2$: GOSUB

     450: PRINT "SOURCE HEADS...(L)  ";N1(12): VTAB 16: HTAB 30: INPUT "";
     N2$: GOSUB 450
170  PRINT : PRINT : INPUT "MAKE ANY CHANGES ? (Y/N)..";Y$: IF Y$ = "Y" THEN
     100
180  HOME : VTAB 10: HTAB 8: INVERSE : PRINT "INITIALIZING ARRAYS": NORMAL

190 NC = N1(4):NR = N1(5):XY = N1(10):SS = N1(7):HH = N1(8):QQ = N1(9):DTA
      = N1(2):NS = N1(1):BIG = N1(3):TT = N1(6):RP = N1(11):RH = N1(12)
200  FOR I = 1 TO NC: FOR J = 1 TO NR:T(I,J,1) = N1(6):T(I,J,2) = N1(6):SF
     (I,J) = SS * XY * XY:HO(I,J) = HH:H(I,J) = HH:Q(I,J) = QQ:DL(I,J) = 0
     .0:DH(I,J) = HH:R1(I,J) = RP * XY * XY:R2(I,J) = RH: NEXT J,I
210  FOR I = 1 TO NC + 1:X(I) = N1(10): NEXT I: FOR J = 1 TO NR + 1:Y(J) =
     N1(10): NEXT J
220  HOME : VTAB 2: HTAB 2: PRINT "DO YOU WISH TO CHANGE THE DEFAULT": HTAB
     2: PRINT "VALUES FOR ANY NODES?": PRINT : PRINT : HTAB 4: PRINT "0...
     NO CHANGES": PRINT  TAB( 4)"1...CHANGE HEADS"
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230  PRINT  TAB( 4)"2...CHANGE Y TRANSMSSVITY (T(C,R,1))": PRINT  TAB( 4)"
     3...CHANGE X TRANSMSSVITY (T(C,R,2))"
240  PRINT  TAB( 4)"4...CHANGE STORATIVITY": PRINT  TAB( 4)"5...CHANGE PUM
     PING RATES"
250  PRINT  TAB( 4)"6...CHANGE VERT CONDUCTIVITY": PRINT  TAB( 4)"7...CHAN
     GE SOURCE HEADS"
260  PRINT  TAB( 4)"8...CHANGE BOTH X AND Y TRANS"
270  PRINT : PRINT : HTAB 3: INPUT "ENTER NUMBER OF CHANGE...";A1
280  IF A1 = 0 THEN 650
290  HOME : VTAB 5: HTAB 5: PRINT "CHANGE A RANGE OR SERIES ?": HTAB 10: INPUT
     "(R/S)..";N2$: IF N2$ = "S" THEN 330
300  HOME : PRINT "ENTER NEW VALUES AND LOCATIONS": PRINT  TAB( 6)"<RTN> T
     O END": PRINT : PRINT  TAB( 3)"ENTER VALUE FOR ";WD$(A1): VTAB 6: HTAB
     10: INPUT A3$: IF A3$ = "" THEN 220
310 A2 =  VAL (A3$):R4 = 2
320  PRINT : PRINT  TAB( 3)"ENTER MINIMUM AND MAXIMUM COORDINATES": INPUT
     "      MIN COL ";SC: INPUT "      MIN ROW ";SR: INPUT "      MAX COL ";L
     C: INPUT "      MAX ROW ";LR: GOTO 360
330  HOME : PRINT  TAB( 5)"ENTER 0,, TO END": PRINT "COL, ";"ROW, ";"VALUE
     ": PRINT
340  INPUT LC,LR,A2: IF LC = 0 THEN 220
350 SC = LC:SR = LR:R4 = 1
360  ON A1 GOTO 370,380,380,400,410,420,430,440
370  FOR KC = SC TO LC: FOR KR = SR TO LR:HO(KC,KR) = A2:H(KC,KR) = A2:DH(
     KC,KR) = A2: NEXT KR,KC: ON R4 GOTO 340,300
380 D1 = 1: IF A1 = 3 THEN D1 = 2
390  FOR KC = SC TO LC: FOR KR = SR TO LR:T(KC,KR,D1) = A2: NEXT KR,KC: ON
     R4 GOTO 340,300
400  FOR KC = SC TO LC: FOR KR = SR TO LR:SF(KC,KR) = A2 * XY * XY: NEXT K
     R,KC: ON R4 GOTO 340,300
410  FOR KC = SC TO LC: FOR KR = SR TO LR:Q(KC,KR) = A2:NP = NP + 1:QC(NP)
      = KC:QR(NP) = KR: NEXT KR,KC: ON R4 GOTO 340,300
420  FOR KC = SC TO LC: FOR KR = SR TO LR:R1(KC,KR) = A2 * XY * XY: NEXT K
     R,KC: ON R4 GOTO 340,300
430  FOR KC = SC TO LC: FOR KR = SR TO LR:R2(KC,KR) = A2: NEXT KR,KC: ON R
     4 GOTO 340,300
440  FOR KC = SC TO LC: FOR KR = SR TO LR: FOR KK = 1 TO 2:T(KC,KR,KK) = A
     2: NEXT KK,KR,KC: ON R4 GOTO 340,300
450  IF N2$ <  > "" THEN N1(I) =  VAL (N2$)
460 I = I + 1: RETURN
470  REM  SUBROUTINE TO PRINT OUTPUT ARRAYS
480  PR# 1: PRINT  CHR$ (9);"80N"
490  FOR KT = 1 TO NC STEP 4
500  PRINT "STEP = ";IS;"   TIME = ";TIME;"    # ITER = ";ITER;"    ERROR
     = ";E
510  HTAB 35: PRINT "COLUMN NUMBERS": PRINT
520  PRINT "ROWS",KT,KT + 1,KT + 2,KT + 3: PRINT
530  FOR I = 1 TO NC: FOR J = 1 TO NR: IF  ABS (DH(I,J) - H(I,J)) < .001 THEN
     560
540 T1 =  INT (H(I,J) * 1E04):T2 =  INT (H(I,J) * 100.) * 100.: IF  ABS (T
     1 - T2) > 50.0 THEN T1 = T1 + 100.
550 DH(I,J) =  INT (T1 / 100) / 100.
560  NEXT J,I
570  FOR KI = 1 TO NR
580  PRINT KI,DH(KT,KI),DH(KT + 1,KI),DH(KT + 2,KI),DH(KT + 3,KI)
590  NEXT KI
600  PRINT  CHR$ (12)
610  NEXT KT
620  PR# 0: RETURN
630  REM  END PRINT ROUTINE
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640  REM  RESCALE AQUIFER COEFFICIENTS
650  HOME : VTAB 5: HTAB 2: PRINT "CHANGE GRID SPACINGS ?": PRINT : HTAB 5
     : INPUT "ENTER Y OR N.. ";A2$: IF A2$ = "N" THEN 920
660  HOME : PRINT "THERE ARE NC-1 DISTANCES BETWEEN": PRINT  TAB( 8)"NC CO
     LUMNS": FOR I = 2 TO NC: PRINT I - 1; TAB( 4);X(I): INPUT XX$: GOSUB
     790: NEXT I:X(1) = X(2):X(NC + 1) = X(NC)
670  HOME : PRINT "THERE ARE NR-1 DISTANCES BETWEEN": PRINT  TAB( 8)"NR RO
     WS": FOR J = 2 TO NR: PRINT J - 1; TAB( 4);Y(J): INPUT YY$: GOSUB 810
     : NEXT J:Y(1) = Y(2):Y(NR + 1) = Y(NR)
680  HOME : VTAB 5: HTAB 5: INPUT "MAKE ANY CHANGES ? (Y/N)";Y$: IF Y$ = "
     Y" THEN 660
690  HOME : VTAB 8: HTAB 5: INVERSE : PRINT "SCALING AQUIFER COEFFICIENTS"
     : NORMAL :VN = 2
700  FOR I = 1 TO NC: FOR J = 1 TO NR:DX = (2 * X(I) * X(I + 1)) / (X(I) +
     X(I + 1)):DY = (2 * Y(J) * Y(J + 1)) / (Y(J) + Y(J + 1))
710 AX = (X(I) + X(I + 1)) / 2.:AY = (Y(J) + Y(J + 1)) / 2.
720 SF(I,J) = (SF(I,J) * AX * AY) / (XY * XY):R1(I,J) = (R1(I,J) * AX * AY
     ) / (XY * XY)
730 T(I,J,1) = T(I,J,1) * DX / (Y(J + 1))
740 T(I,J,2) = T(I,J,2) * DY / (X(I + 1))
750  NEXT J,I
760  GOTO 920
770  REM  END RESCALING
780  REM  PRINT COEFFICENT ARRAYS AND HEADINGS
790  IF XX$ <  > "" THEN X(I) =  VAL (XX$)
800  RETURN
810  IF YY$ <  > "" THEN Y(J) =  VAL (YY$)
820  RETURN
830  PR# 1: PRINT  CHR$ (9);"80N": FOR IT = 1 TO 2: PRINT : PRINT "TRANSMI
     SSIVITTY(C,R,";IT;") ": PRINT
840  FOR KT = 1 TO NC STEP 4: PRINT : PRINT "ROWS",KT,KT + 1,KT + 2,KT + 3
     : PRINT
850  FOR KI = 1 TO NR: PRINT KI,T(KT,KI,IT),T(KT + 1,KI,IT),T(KT + 2,KI,IT
     ),T(KT + 3,KI,IT): NEXT KI,KT,IT
860  PRINT : PRINT "STORAGE FACTORS ": PRINT : FOR KT = 1 TO NC STEP 4: PRINT
     : PRINT "ROWS",KT,KT + 1,KT + 2,KT + 3: PRINT
870  FOR KI = 1 TO NR: PRINT KI,SF(KT,KI),SF(KT + 1,KI),SF(KT + 2,KI),SF(K
     T + 3,KI): NEXT KI,KT
880 SUM = 0.0: FOR I = 1 TO NC: FOR J = 1 TO NR:SUM = SUM + R1(I,J): NEXT
     J,I: IF SUM = 0.0 THEN 910
890  PRINT : PRINT "VERTICLE CONDUCTIVITY ": PRINT : FOR KT = 1 TO NC STEP
     4: PRINT : PRINT "ROWS",KT,KT + 1,KT + 2,KT + 3: PRINT
900  FOR KI = 1 TO NR: PRINT KI,R1(KT,KI),R1(KT + 1,KI),R1(KT + 2,KI),R1(K
     T + 3,KI): NEXT KI,KT
910  PRINT  CHR$ (12): PR# 0: GOTO 930
920  HOME : VTAB 5: HTAB 9: PRINT "PRINT OUT ARRAYS ?": VTAB 7: HTAB 13: INPUT
     "(Y/N)..";N2$: IF N2$ = "Y" THEN 830
930  PR# 1: PRINT  CHR$ (9);"80N": PRINT : PRINT  TAB( 15)TITLE$: PRINT : PRINT

      TAB( 5)"MODEL DESCRIPTION ": PRINT  TAB( 10)"STEPS.....  ";NS: PRINT
      TAB( 10)"COLUMNS...  ";NC: PRINT  TAB( 10)"ROWS......  ";NR: PRINT  TAB(
     10)"DELTA T...  ";DTA
940  PRINT  TAB( 10)"ERROR.....  ";BIG: PRINT : PRINT  TAB( 5)"DEFAULT PAR
     AMETERS": PRINT  TAB( 10)"TRANSMSSVTY ";TT: PRINT  TAB( 10)"STORAGE..
     .  ";SS: PRINT  TAB( 10)"HEADS.....  ";HH: PRINT  TAB( 10)"PUMPAGE...
       ";QQ
950  PRINT  TAB( 10)"VERT COND.  ";RP: PRINT  TAB( 10)"SOURCE BED  ";RH
960  PRINT  TAB( 10)"GRIDS.....  ";XY: IF VN = 1 THEN 1000
970  PRINT : PRINT  TAB( 15)"VARIABLE GRID SPACINGS": PRINT : PRINT  TAB(
     8)"X SPACING"; TAB( 17)"Y SPACING": PRINT
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980 KT = NC: IF NR > NC THEN KT = NR
990  FOR KL = 2 TO KT: PRINT  TAB( 10)X(KL); TAB( 25)Y(KL): NEXT KL
1000  PRINT : PRINT  TAB( 15)"LOCATIONS OF PUMPING WELLS": PRINT : PRINT  TAB(
     8)"PUMPAGE", TAB( 18)"COLUMN", TAB( 25)"ROW": PRINT
1010  FOR I = 1 TO NP: PRINT  TAB( 10)Q(QC(I),QR(I)), TAB( 20)QC(I), TAB(
     27)QR(I): NEXT I
1020  PRINT  CHR$ (12): PR# 0
1030  IF NS > 14 THEN 1040
1032 X4 = 1:BH = 1: GOTO 1090
1040  IF NS > 21 THEN 1050
1042 X4 = 1:BH = 6: GOTO 1090
1050 X4 = 2:BH = 6: GOTO 1090
1060  REM
1070  REM  AQUIFER MODEL
1080  REM
1090 TIME = 0: FOR IS = 1 TO NS:TIME = TIME + DTA
1100  FOR I = 1 TO NC: FOR J = 1 TO NR:D = H(I,J) - HO(I,J):HO(I,J) = H(I,
     J):F = 1.0
1110  IF DL(I,J) = 0.0 THEN 1150
1120  IF IS > 2 THEN F = D / DL(I,J)
1130  IF F > 5 THEN F = 5
1140  IF F < 0 THEN F = 0
1150 DL(I,J) = D:H(I,J) = H(I,J) + D * F: NEXT J: NEXT I
1160  HOME : PRINT "STEP = ";IS;"   TIME = ";TIME: PRINT : PRINT "ITER   E
     RROR         LIMIT": PRINT
1170 ITER = 0
1180 E = 0.0
1190 ITER = ITER + 1
1200  REM  COLUMN CALCULATIONS
1210  FOR II = 1 TO NC:I = II: IF  FN MOD(IS + ITER) = 1 THEN I = NC - I +
     1
1220  FOR J = 1 TO NR:BB = SF(I,J) / DTA + R1(I,J):DD = HO(I,J) * SF(I,J) /
     DTA - Q(I,J) + R1(I,J) * R2(I,J):AA = 0.0:CC = 0.0
1230  IF (J - 1) = 0 THEN 1250
1240 AA =  - T(I,J - 1,1):BB = BB + T(I,J - 1,1)
1250  IF (J - NR) = 0 THEN 1270
1260 CC =  - T(I,J,1):BB = BB + T(I,J,1)
1270  IF (I - 1) = 0 THEN 1290
1280 BB = BB + T(I - 1,J,2):DD = DD + H(I - 1,J) * T(I - 1,J,2)
1290  IF (I - NC) = 0 THEN 1310
1300 BB = BB + T(I,J,2):DD = DD + H(I + 1,J) * T(I,J,2)
1310 W = BB - AA * B(J - 1):B(J) = CC / W:G(J) = (DD - AA * G(J - 1)) / W:
     NEXT J
1320 E = E +  ABS (H(I,NR) - G(NR)):H(I,NR) = G(NR):N = NR - 1
1330 HA = G(N) - B(N) * H(I,N + 1):E = E +  ABS (HA - H(I,N)):H(I,N) = HA:
     N = N - 1
1340  IF N > 0 THEN 1330
1350  NEXT II
1360  REM  ROW CALCULATIONS
1370  FOR JJ = 1 TO NR:J = JJ: IF  FN MOD(IS + ITER) = 1 THEN J = NR - J +
     1
1380  FOR I = 1 TO NC:BB = SF(I,J) / DTA + R1(I,J):DD = HO(I,J) * SF(I,J) /
     DTA - Q(I,J) + R1(I,J) * R2(I,J):AA = 0.0:CC = 0.0
1390  IF (J - 1) = 0 THEN 1410
1400 BB = BB + T(I,J - 1,1):DD = DD + H(I,J - 1) * T(I,J - 1,1)
1410  IF (J - NR) = 0 THEN 1430
1420 DD = DD + H(I,J + 1) * T(I,J,1):BB = BB + T(I,J,1)
1430  IF (I - 1) = 0 THEN 1450
1440 BB = BB + T(I - 1,J,2):AA =  - T(I - 1,J,2)
1450  IF (I - NC) = 0 THEN 1470
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```
1460 BB = BB + T(I,J,2):CC =  - T(I,J,2)
1470 W = BB - AA * B(I - 1):B(I) = CC / W:G(I) = (DD - AA * G(I - 1)) / W:
      NEXT I
1480 E = E +  ABS (H(NC,J) - G(NC)):H(NC,J) = G(NC):N = NC - 1
1490 HA = G(N) - B(N) * H(N + 1,J):E = E +  ABS (H(N,J) - HA):H(N,J) = HA:
     N = N - 1
1500  IF N > 0 THEN 1490
1510  NEXT JJ: PRINT ITER;"    ";E;"          ";BIG: IF ITER > 25 THEN 1590
1520  IF E > BIG THEN 1180
1530  IF ITER < 3 THEN 1180
1540  IF IS < BH THEN 1560
1550  IF  INT (IS / X4) * X4 = IS THEN  GOSUB 480
1560 DTA = DTA * 1.2: NEXT IS
1570 IS = NS: IF X4 <  > 1 THEN  GOSUB 480
1580  GOTO 1610
1590  PRINT : PRINT  TAB( 5)"NO CONVERGENCE IN 25 ITERATIONS"
1600  PRINT  TAB( 8)"ERROR = ";E;"  LIMIT = ";BIG
1610  END
```

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