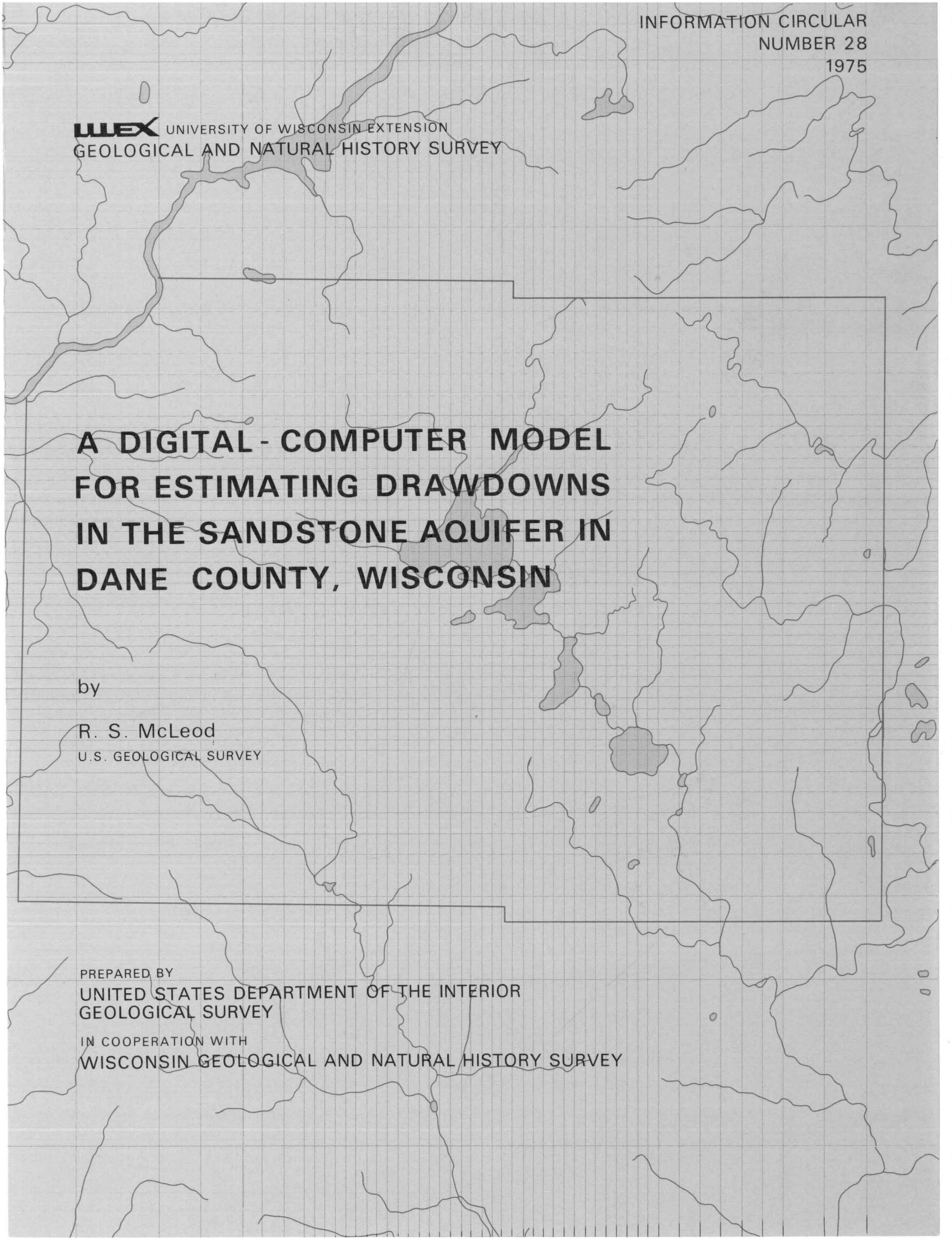


INFORMATION CIRCULAR
NUMBER 28
1975

UWEX UNIVERSITY OF WISCONSIN EXTENSION
GEOLOGICAL AND NATURAL HISTORY SURVEY

A DIGITAL - COMPUTER MODEL FOR ESTIMATING DRAWDOWNS IN THE SANDSTONE AQUIFER IN DANE COUNTY, WISCONSIN

by

R. S. McLeod
U.S. GEOLOGICAL SURVEY

PREPARED BY
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
IN COOPERATION WITH
WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY

INFORMATION CIRCULAR
NUMBER 28

A DIGITAL-COMPUTER MODEL FOR ESTIMATING DRAWDOWNS IN THE SANDSTONE AQUIFER IN DANE COUNTY, WISCONSIN

by

R. S. McLeod
U.S. GEOLOGICAL SURVEY

This report is a product of the Geological and Natural History Survey Water Resources Program which includes: systematic collection, analysis, and cataloguing of basic water data; impartial research and investigation of Wisconsin's water resources and water problems; publication of technical and popular reports and maps; and public service and information. Most of the work of the Survey's Water Resources Program is accomplished through state-federal cooperative cost sharing with the U.S. Geological Survey, Water Resources Division.

**UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
and
UNIVERSITY OF WISCONSIN—EXTENSION
GEOLOGICAL AND NATURAL HISTORY SURVEY
M. E. Ostrom, Director and State Geologist
Madison, Wisconsin
June, 1975**

Available from University of Wisconsin—Extension, Geological and Natural History Survey, 1815 University Avenue, Madison, Wisconsin 53706.

CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

The following factors may be used to convert the English units published herein to the International System of Units (SI).

Multiply English units	By	To obtain SI units
million gallons per day (M gal/day)	0.04381	cubic metres per second (m^3/s)
square miles (mi^2)	2.590	square kilometres (km^2)
feet (ft)	.3048	metres (m)

ABSTRACT

A digital-computer program was developed to compute nonsteady and steady-state hydrologic changes caused by pumping from a confined aquifer. The program computes head changes in the confined aquifer and the rate and volume of water withdrawn from aquifer boundaries.

The program was used to model the sandstone aquifer underlying Dane County, Wisconsin. The aquifer was modeled as a confined aquifer recharged by leakage from the overlying upper aquifer. The physical properties of the aquifer system needed for the model were approximated using aquifer-test data and by matching drawdowns resulting from aquifer development through 1970 with drawdowns computed by the model.

The sandstone aquifer should be able to supply the water needs of Dane County well beyond 1990. Maximum regional drawdowns of approximately 40 feet (12 m) between 1970 and 1990 were computed by the model. This amount of additional drawdown would not seriously deplete the ground-water supply.

INTRODUCTION

The sandstone aquifer is the source of water supply for most municipalities and industries in Dane County, Wisconsin. The first major use of this ground-water reservoir was in 1882, when the city of Madison began its public water-supply system. The total capacity of the system in 1882 was less than 1 M gal/day (3,785 m^3/day) (Weidman and Schultz, 1915, p. 293). By comparison, the average daily pumpage from the sandstone aquifer in 1970 by all users in the county was 40.2 M gal/day (1,522 x 10^5 m^3/day), with Madison averaging 29.0 M gal/day (1,098 x 10^5 m^3/day), approximately 72 percent of the total. Projected pumpage trends indicate that total pumpage will increase to 66 M gal/day (2,498 x 10^5 m^3/day) by 1990, with Madison pumping approximately 75 percent of the total.

Progressive declines of ground-water levels in the sandstone aquifer have accompanied increasing ground-water withdrawals. Although these declines are not serious, proper planning for the future development of the sandstone aquifer will minimize the impact of withdrawals and insure proper management of the total water resources of the county.

Purpose and Scope

The purpose of this report is to present a digital-computer program that can be used to solve two-dimensional, confined ground-water flow problems and to apply the program to the sandstone aquifer in Dane County.

The report describes how the program was developed, using algebraic finite-difference equations to approximate the equation for ground-water flow in a continuous system, and how these equations can be solved on a high-speed digital computer. The digital-computer program is a modification of one developed by Pinder (1970). The report also describes how the program was applied to the sandstone aquifer in Dane County to predict drawdowns in the aquifer through the year 1990 under proposed ground-water development plans.

Location and Extent of the Study Area

The study area is Dane County, an area of 1,233 square miles (3,192 km^2) in south-central Wisconsin (fig. 1). The sandstone aquifer in the county was modeled with particular attention given to a 16- by 17-square-mile area (25.7 x 27.4 km^2), roughly centered on Madison, where development of the aquifer has been greatest.

Previous Investigations

Studies that have described the geology and hydrology of all or parts of Dane County are summarized by Uttormark and others (1969). The work of Cline (1965) provided background information for this report. He described the occurrence, movement, and availability of ground water in Dane County and the relationship between ground water and surface water in the area. Cline also described the geology of Dane County.

More recently, an electric-analog model study of the Madison area was made by the U.S. Geological Survey in cooperation with the city of Madison and the University of Wisconsin-Extension, Geological and Natural History Survey (J.B. Gonthier, written commun., 1971).

Acknowledgment

The cooperation of the Madison Water Utility over the years in well testing is gratefully acknowledged. Without the information thus provided, this study may not have been possible.

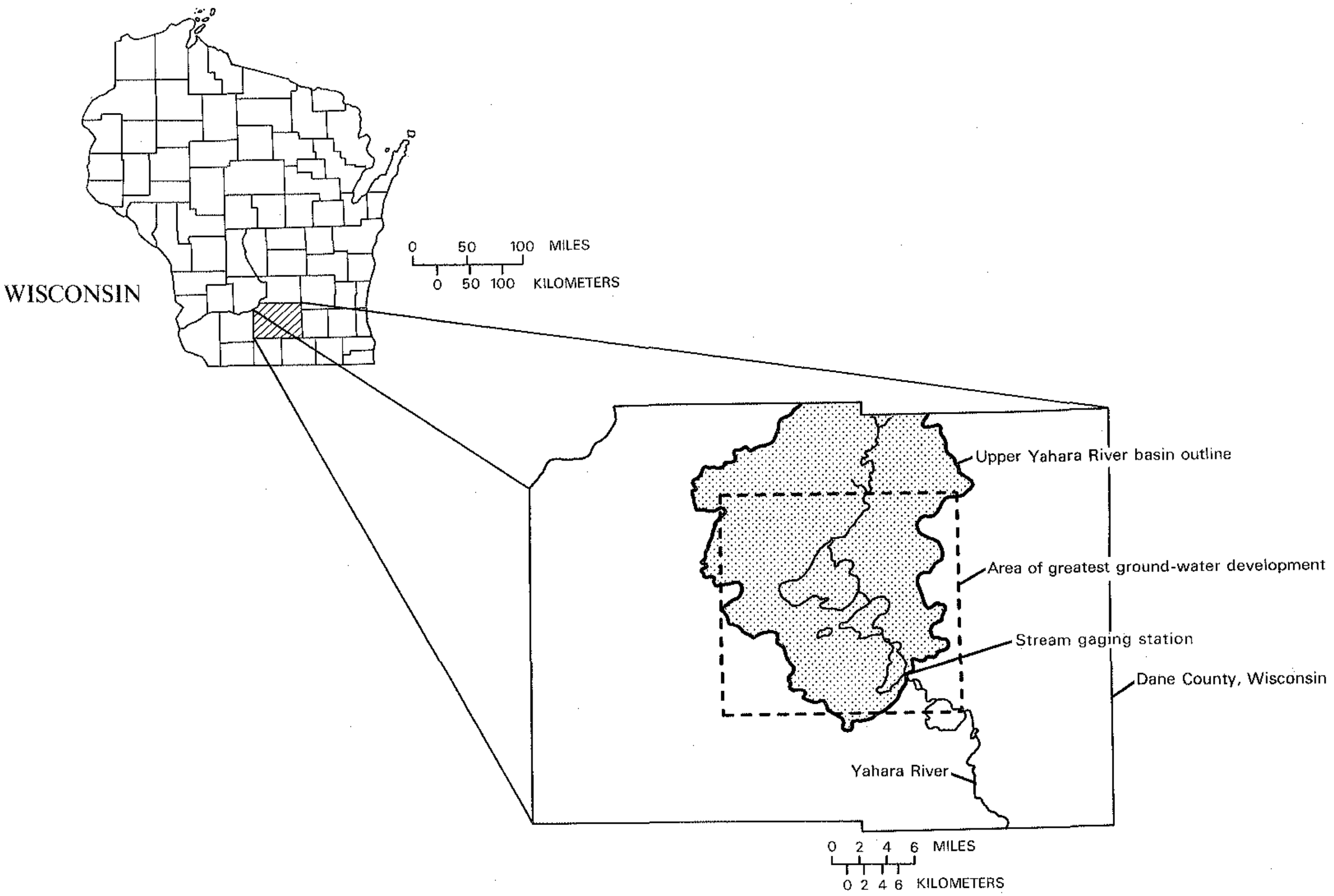


Figure 1. Location and extent of study area.

DEVELOPMENT OF A DIGITAL-COMPUTER PROGRAM FOR SOLVING CONFINED GROUND-WATER FLOW PROBLEMS

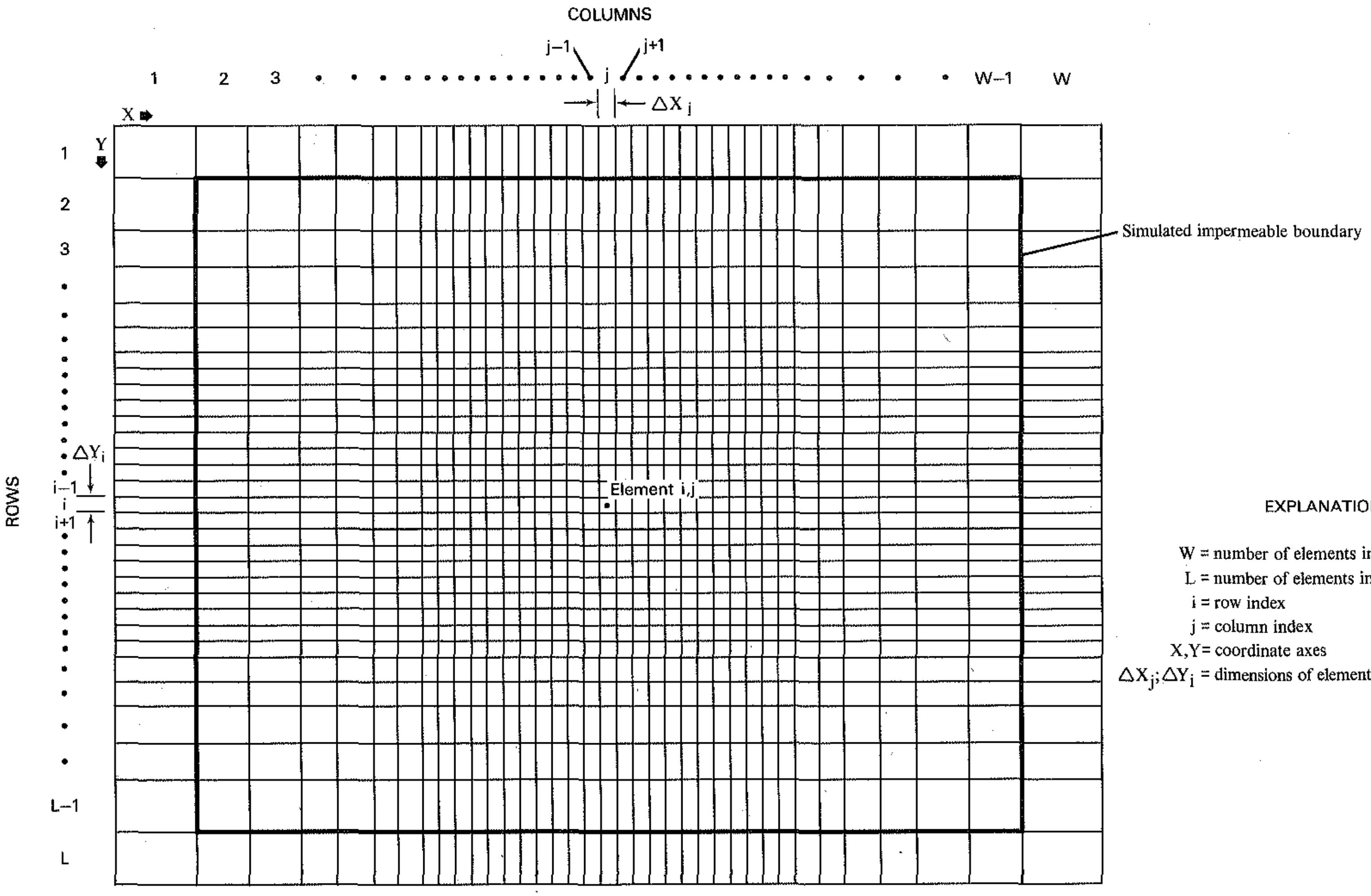
Finite-difference methods are used to calculate approximate solutions to the partial-differential equation describing areal head changes in a continuous confined aquifer that result from pumping. First, a rectangular grid network (fig. 2) is superimposed over a plan view of the aquifer to divide it into finite elements. Second, finite-difference equations for describing head changes in each element caused by pumping are formulated to approximate changes in the continuous aquifer. Third, a digital-computer program is written to solve these equations.

Development of Finite-Difference Equations

Finite-difference equations for estimating head changes and changes in flow across aquifer boundaries that result from pumping a confined aquifer are developed for the aquifer system (fig. 3a), which includes two aquifers. Essential elements of the system include a confined aquifer overlain by confining beds of moderate hydraulic conductivity and underlain by impermeable bedrock and an unconfined aquifer overlying the confining beds. Initially, the potentiometric surface in the confined aquifer may be different from the water table in the unconfined aquifer, and water may be moving through the confining beds.

Simplifying assumptions are made concerning water movement in this aquifer system in order to develop equations that could be solved easily. These assumptions are:

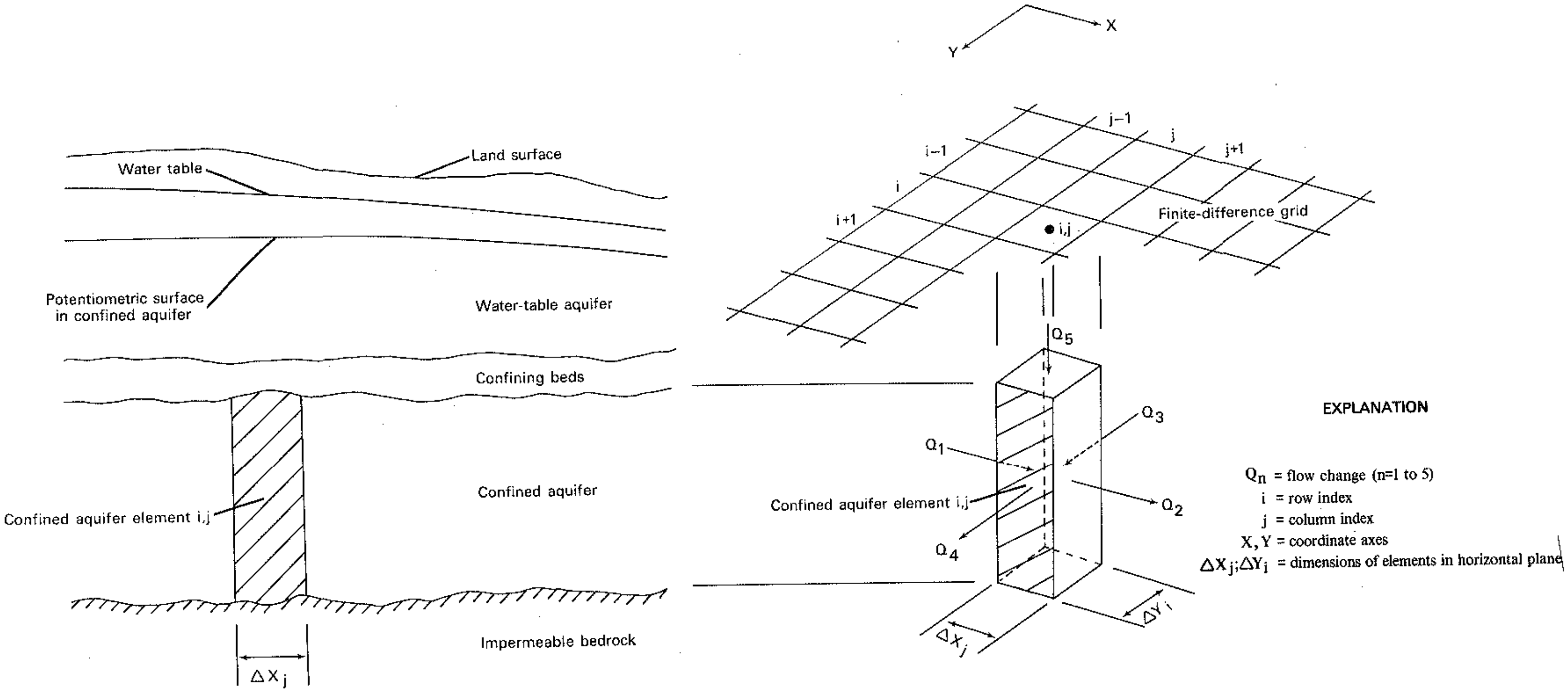
1. Flow in the confined aquifer is horizontal, even though leakage may occur through the confining beds. This assumption is justified if the horizontal extent of the aquifer system is much greater than the thickness of the aquifer.



EXPLANATION

W = number of elements in a row
L = number of elements in a column
i = row index
j = column index
X,Y = coordinate axes
$\Delta X_j;\Delta Y_i$ = dimensions of elements in horizontal plane

Figure 2. Sample finite-difference grid.



A. Schematic representation of a continuous aquifer system

B. Finite element of the confined aquifer

Figure 3. Relation between a continuous aquifer system and a finite element of the confined aquifer.

2. Flow through the confining beds is vertical. This assumption is valid if the hydraulic conductivities of the confined and unconfined aquifers are much greater than the hydraulic conductivity of the confining beds.

3. The water table of the unconfined aquifer remains constant at all times. This assumption is justified if the water table can be maintained at a nearly constant level by rainfall and infiltration from surface-water bodies in spite of flow changes in the aquifer system caused by pumping or recharging the confined aquifer.

Flow changes into or out of confined-aquifer elements caused by pumping are designated Q_1, Q_2, Q_3, Q_4, and Q_5 (fig. 3b). The Q_1, Q_2, Q_3, and Q_4 terms represent flow changes between elements. The Q_5 term represents a change in flow across the contact surface between a confined-aquifer element and the confining beds. These flow changes are approximated (Pinder, 1970) as:

$$\begin{aligned} Q_1 &= -T'_{i,j-\frac{1}{2}}\left(s_{i,j,k} - s_{i,j-1,k}\right)\Delta Y_i; \\ Q_2 &= -T'_{i,j+\frac{1}{2}}\left(s_{i,j+1,k} - s_{i,j,k}\right)\Delta Y_i; \\ Q_3 &= -T'_{i-\frac{1}{2},j}\left(s_{i,j,k} - s_{i-1,j,k}\right)\Delta X_j; \qquad (1) \\ Q_4 &= -T'_{i+\frac{1}{2},j}\left(s_{i+1,j,k} - s_{i,j,k}\right)\Delta X_j; \end{aligned}$$

and $Q_5 = -W_{i,j,k}\, s_{i,j,k}\, \Delta X_j\, \Delta Y_i - Q_{i,j}$;

where, for example, $T'_{i+\frac{1}{2},j} = \dfrac{2T_{i,j}\, T_{i+1,j}}{T_{i,j}\, \Delta Y_{i+1} + T_{i+1,j}\, \Delta Y_i}$, which is the

harmonic mean of: $\dfrac{T_{i,j}}{\Delta Y_i}$; $\dfrac{T_{i+1,j}}{\Delta Y_{i+1}}$

and i = row index,

j = column index,

k = time index,

$\Delta X_j \ \Delta Y_i$ = horizontal dimensions of aquifer elements, in units of length;

$T_{i,j}$ = transmissivity values for elements of the confined aquifer defined as the rate at which water is transmitted through a unit width of the confined aquifer element under a unit hydraulic gradient (Lohman and others, 1972, p. 13). Transmissivity may differ with location, but is assumed not to vary with time, in units of length squared per unit time;

$s_{i,j,k}$ = head change in elements of the confined aquifer resulting from additions or withdrawals of water, in units of length. Drawdowns are negative, rises are positive;

$W_{i,j,k}$ = leakage coefficient defined as the rate at which water flows through a unit horizontal area of contact surface between the confining beds and the confined aquifer at the prevailing kinematic viscosity, if the difference between the head in the confined aquifer and the water table is unity (after DeWiest, 1965, p. 274), in units of time to the minus one power;

and $Q_{i,j}$ = pumping rate from confined-aquifer elements, in units of length cubed per unit time. Recharge is negative, discharge is positive.

The following expression is used to represent the leakage coefficient:

$$W_{i,j,k} = \frac{K'_{i,j}}{b'_{i,j}} \frac{1}{\sqrt{\pi t'_k}} \left[1 + 2 \sum_{n=1}^{\infty} \exp\left(\frac{-n^2}{t'_k} \right) \right] \qquad (2)$$

where: $t'_k = \dfrac{K'_{i,j} \ t_k}{3S'_{s_{i,j}} \ b'^2_{i,j}}$, a dimensionless time parameter;

$K'_{i,j}$ = hydraulic conductivity of the confining beds defined as the rate at which water flows through a unit area, measured at right angles to the direction of flow, under a unit hydraulic gradient and at the prevailing kinematic viscosity (Lohman and others, 1972, p. 4), in units of length per unit time;

$b'_{i,j}$ = saturated thickness of confining beds, in units of length;

$S'_{s_{i,j}}$ = specific storage of confining beds defined as the volume of water released from or taken into storage per unit volume of the confining beds per unit change in head (Lohman and others, 1972, p. 13), in units of length to the minus one power;

and t_k = time since pumping began, in units of time.

An expression similar to this was proposed by Bredehoeft and Pinder (1970) and Pinder (1970).

This form for the leakage coefficient allows inclusion of the effects of storage in the confining beds when estimating flow changes across the contact surface between the confining beds and the confined aquifer elements. Storage in the confining beds is important in determining these changes, if the confining beds are thick or their hydraulic conductivity is small.

Equation set (1) alone does not provide enough information to solve for head changes in an aquifer element. An additional equation is needed. This additional equation is based on flow continuity and requires that the change in volume of water taken into or withdrawn from storage in a confined-aquifer element must equal the volume difference between changes in inflow and outflow during a short increment of time. Stated in quantitative terms:

$$\left(Q_1 - Q_2\right) \Delta t + \left(Q_3 - Q_4\right) \Delta t + Q_5 \Delta t = S_{i,j} \Delta X_j \Delta Y_i \left(s_{i,j,k} - s_{i,j,k-1}\right) \quad (3)$$

where: Δt = time increment for calculation of head changes;

and $S_{i,j}$ = storage coefficient for the confined-aquifer elements defined as the volume of water released from or taken into storage per unit surface area of the element per unit change in head (Lohman and others, 1972, p. 13). The storage coefficient may differ with location but does not vary with time, dimensionless.

Substituting equation set (1) into equation (3) and rearranging terms leads to the following equation, in which the only unknowns are head changes:

$$\frac{T'_{i,j-\frac{1}{2}}}{\Delta X_j}\left(s_{i,j-1,k} - s_{i,j,k}\right) + \frac{T'_{i,j+\frac{1}{2}}}{\Delta X_j}\left(s_{i,j+1,k} - s_{i,j,k}\right)$$

$$+ \frac{T'_{i-\frac{1}{2},j}}{\Delta Y_i}\left(s_{i-1,j,k} - s_{i,j,k}\right) + \frac{T'_{i+\frac{1}{2},j}}{\Delta Y_i}\left(s_{i+1,j,k} - s_{i,j,k}\right) \qquad (4)$$

$$= \frac{S_{i,j}}{\Delta t}\left(s_{i,j,k} - s_{i,j,k-1}\right) + \frac{Q_{i,j}}{\Delta X_j\, \Delta Y_i} + W_{i,j,k}\, s_{i,j,k}.$$

An equation similar to equation (4) is written for each element. This means that N equations are written, where N is the number of elements. A simultaneous solution of these equations gives the approximate distribution of head changes in the confined aquifer resulting from pumping.

Changes in rates and volumes of flow across boundaries of the confined aquifer can be computed using the computed head changes and equation set (1).

A Method for Solving the Finite-Difference Equations

The iterative alternating-direction, implicit method (IADI) was selected to solve the finite-difference equations. It has been used successfully for solving large sets of equations with a digital computer. The method is efficient, and the computer core storage required is minimal.

The IADI method involves the alternate solution for a given time step of equation (4) at elements along each row and then along each column of the grid in figure 2 until convergence is achieved. The solution along rows is accomplished by assuming that all head changes are known during each iteration except those along the row for which a solution is sought. The solution proceeds in this manner from row to row until all rows have been processed. The same procedure is then used for columns until all columns have been processed. The method continues, alternating solutions by rows and then by columns, until the largest discrepancy between row and column computations for the head change in any element is less than a prescribed maximum value.

The method then steps to the next time increment, and the process is repeated.

To facilitate computations along a row, equation (4) is written:

$$A_j \, s_{i,j-1,k}^{\,n} + B_j \, s_{i,j,k}^{\,n} + C_j \, s_{i,j+1,k}^{\,n} = D_j \tag{5a}$$

where: $A_j = \dfrac{T'_{i,j-\frac{1}{2}}}{\Delta X_j}$,

$$B_j = -\left(\frac{T'_{i,j-\frac{1}{2}}}{\Delta X_j} + \frac{T'_{i,j+\frac{1}{2}}}{\Delta X_j} + \frac{S_{i,j}}{\Delta t} + W_{i,j,k} + I_{i,j}\right),$$

$$C_j = \frac{T'_{i,j+\frac{1}{2}}}{\Delta X_j} \quad ,$$

and

$$D_j = -\frac{T'_{i-\frac{1}{2},j}}{\Delta Y_i} s_{i-1,j,k}^{\,n-1} + \left(\frac{T'_{i-\frac{1}{2},j}}{\Delta Y_i} + \frac{T'_{i+\frac{1}{2},j}}{\Delta Y_i} - I_{i,j}\right) s_{i,j,k}^{\,n-1}$$

$$- \frac{T'_{i+\frac{1}{2},j}}{\Delta Y_i} s_{i+1,j,k}^{\,n-1} + \frac{Q_{i,j}}{\Delta X_j \, \Delta Y_i} - \frac{S_{i,j}}{\Delta t} s_{i,j,k-1} .$$

Similarly, for computations down a column, equation (4) is written:

$$A_i \, s_{i-1,j,k}^{\,n+1} + B_i \, s_{i,j,k}^{\,n+1} + C_i \, s_{i+1,j,k}^{\,n+1} = D_i \tag{5b}$$

where: $A_i = \dfrac{T'_{i-\frac{1}{2},j}}{\Delta Y_i}$,

$$B_i = -\left(\frac{T'_{i-\frac{1}{2},j}}{\Delta Y_i} + \frac{T'_{i+\frac{1}{2},j}}{\Delta Y_i} + \frac{S_{i,j}}{\Delta t} + W_{i,j,k} + I_{i,j}\right) \quad ,$$

$$C_i = \frac{T'_{i,j+\frac{1}{2}}}{\Delta Y_i} \quad ,$$

and $$D_i = -\frac{T'_{i,j-\frac{1}{2}}}{\Delta X_j} s_{i,j-1,k}^{\,n} + \left(\frac{T'_{i,j-\frac{1}{2}}}{\Delta X_j} + \frac{T'_{i,j+\frac{1}{2}}}{\Delta X_j} - I_{i,j}\right) s_{i,j,k}^{\,n}$$

$$- \frac{T'_{i,j+\frac{1}{2}}}{\Delta X_j} s_{i,j+1,k}^{\,n} + \frac{Q_{i,j}}{\Delta X_j\ \Delta Y_i} - \frac{S_{i,j}}{\Delta t} s_{i,j,k-1}.$$

In equations (5a) and (5b):

n = cycle of iteration,

and $I_{i,j}$ = iteration terms introduced into the equation to speed convergence, in units of time to the minus one power.

The iteration terms are defined by:

$$I_{i,j} = r_n\left(\frac{T'_{i,j-\frac{1}{2}}}{\Delta X_j} + \frac{T'_{i,j+\frac{1}{2}}}{\Delta X_j} + \frac{T'_{i-\frac{1}{2},j}}{\Delta Y_i} + \frac{T'_{i+\frac{1}{2},j}}{\Delta Y_i}\right)$$

where: r is set of iteration parameters that are used cyclically during the computations. Selection of iteration parameters follow that given by Pinder (1970, p. 12).

Initial head changes must be specified for every element in the finite-difference grid, and boundary conditions must be specified around the edges of the grid. Zero head changes are used as initial conditions in the solution process.

Impermeable boundary conditions are used at the locations outlined on figure 2 by assigning zero transmissivity values to all elements in the first and last rows and columns of the grid. Equation (5a) can be expanded for any interior row ($2 \leq i \leq L-1$) using these boundary conditions into:

$$\begin{array}{cccccc}
B_2\, s_{i,2,k}^{\,n} + & C_2\, s_{i,3,k}^{\,n} & \circ & \circ & \circ & = D_2 \\
A_3\, s_{i,2,k}^{\,n} + & B_3\, s_{i,3,k}^{\,n} + & C_3\, s_{i,4,k}^{\,n} & \circ & \circ & = D_3 \\
\circ & A_4\, s_{i,3,k}^{\,n} + & B_4\, s_{i,4,k}^{\,n} + & C_4\, s_{i,5,k}^{\,n} & \circ & = D_4 \\
\circ & \circ & \circ & \circ & \circ & \circ \\
\circ & \circ & \circ & A_{W-1}\, s_{i,W-2,k}^{\,n} + & B_{W-1}\, s_{i,W-1,k}^{\,n} & = D_{W-1}
\end{array}$$

Similarly, for any interior column ($2 \leq j \leq W-1$), equation (5b) can be expanded into:

$$\begin{array}{llllll}
B_2\, s_{2,j,k}^{n+1} & + C_2\, s_{3,j,k}^{n+1} & \circ & \circ & \circ & = D_2 \\
A_3\, s_{2,j,k}^{n+1} & + B_3\, s_{3,j,k}^{n+1} & + C_3\, s_{4,j,k}^{n+1} & \circ & \circ & = D_3 \\
\circ & A_4\, s_{3,j,k}^{n+1} & + B_4\, s_{4,j,k}^{n+1} & + C_4\, s_{5,j,k}^{n+1} & & = D_4 \\
\circ & \circ & \circ & \circ & \circ & \circ \\
\circ & \circ & \circ & A_{L-1}\, s_{L-2,j,k}^{n+1} & + B_{L-1}\, s_{L-1,j,k}^{n+1} & = D_{L-1}
\end{array}$$

These sets of equations form tri-diagonal matrices. Equations of this type are conveniently solved using the Thomas algorithm (von Rosenberg, 1969, p. 8). This algorithm computes head changes along any row or column using the equation:

$$s_m = G_m - (BE)_m\, s_{m+1} \tag{6}$$

where:

$$(BE)_m = \frac{C_m}{B_m - A_m\,(BE)_{m-1}} ,$$

$$G_m = \frac{D_m - A_m\, G_{m-1}}{B_m - A_m\,(BE)_{m-1}}$$

$m = j$ if the computation is proceeding along a row,

$m = i$ if the computation is proceeding down a column,

and A_m, B_m, C_m, D_m = the coefficients in equation (5).

To compute head changes along a row, BE_j and G_j are first computed for each aquifer element in the row, beginning with $j = 2$ and proceeding until $j = W-1$. Head changes for each element in the row are then computed by substituting values of BE_j and G_j into equation (6) in order of decreasing j values, beginning with $j = W-1$ and proceeding through $j = 2$. A similar procedure is followed for computation by columns.

The alternate processing of all rows and then all columns continues until the largest difference between head changes computed by row and column computations for all aquifer elements is less than a prescribed allowable error.

A Description of the Digital-Computer Program

The program consists of a source deck, a set of parameter cards, and as many as eight aquifer data decks. The mathematical computations are carried out in the source deck using the IADI method just described. Input data needed for the computations are contained on the parameter cards and the aquifer data decks. An assembled program is shown in figure 4.

The program is a modification of a program described by Pinder (1970). The program is written in FORTRAN IV. It will handle rectangular grids that do not exceed 50 rows by 55 columns in grid size, and it requires approximately 45,000 words of storage, at 36 bits per word.

A printout of the information contained on the parameter cards and the aquifer data decks accompanies each computer run.

Optional printouts from the program during a run are (1) an alphameric map of computed head changes in the confined aquifer, (2) a numerical printout of these head changes, (3) a numerical printout of flow changes to the confined aquifer from confining beds and fully penetrating streams, and (4) a mass balance check of the computations. Also optional is punched output of the last computed head changes during a run.

The program permits modeling (1) constant head or barrier-boundary conditions, (2) nonhomogeneous transmissivity and storage coefficients for the confined aquifer, and (3) areal variations in hydraulic conductivity, specific storage, and saturated thickness for the confining beds.

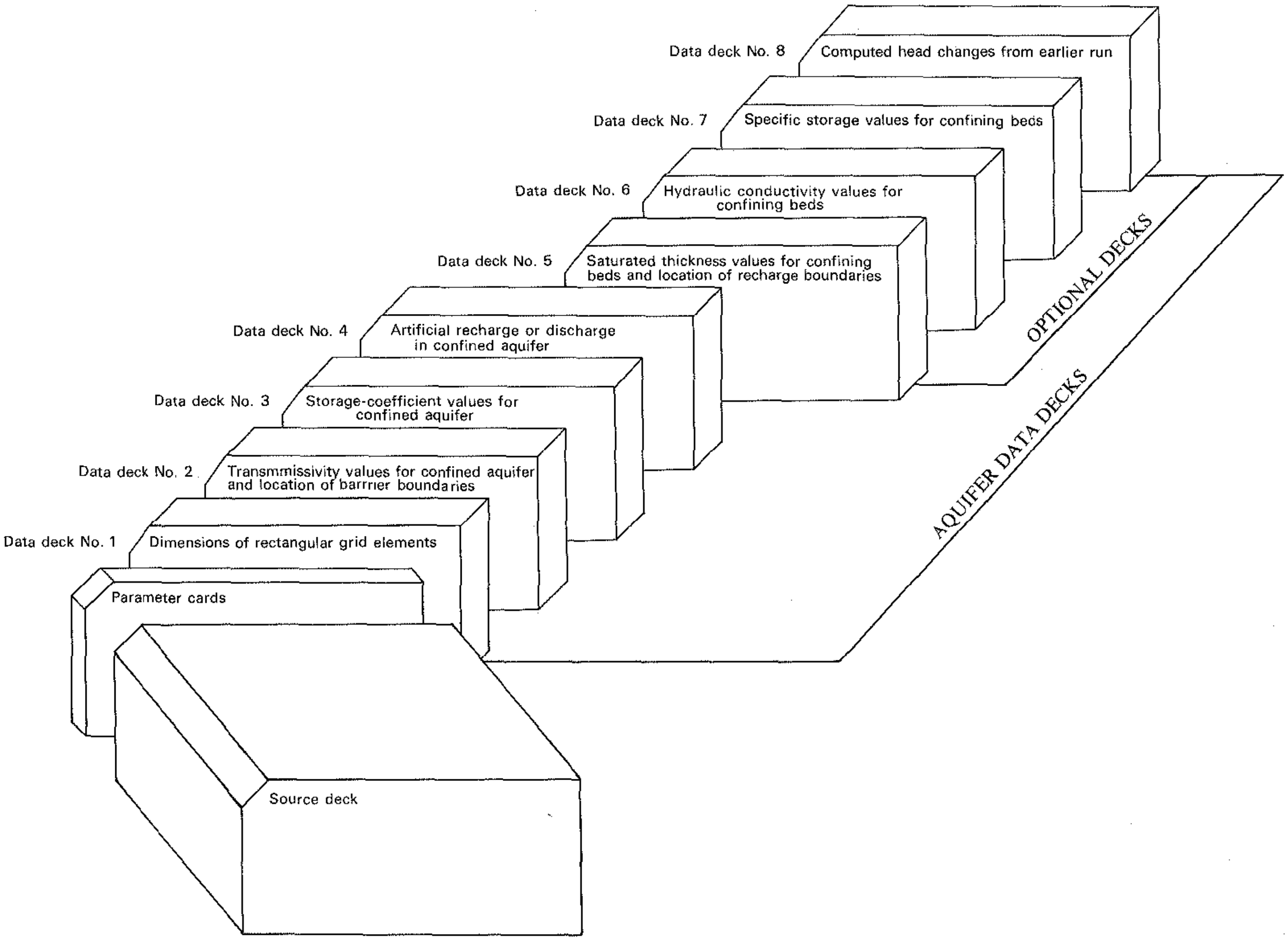


Figure 4. Assembled digital computer program.

EVALUATION OF THE PROGRAM

Analytical solutions of the ground-water flow equations were compared with solutions obtained from the program for a single pumping well. These comparisons demonstrate the versatility and reliability of the program.

Four boundary-condition problems were evaluated. The first evaluation was for an infinite aquifer overlain by impermeable confining beds. The second evaluation considered an infinitely long barrier boundary along one side of the confined aquifer. The third was for a simulated constant-head boundary along one side of the confined aquifer, and the fourth evaluation was for an aquifer of infinite areal extent overlain by confining beds of moderate permeability.

Infinite-Aquifer Conditions

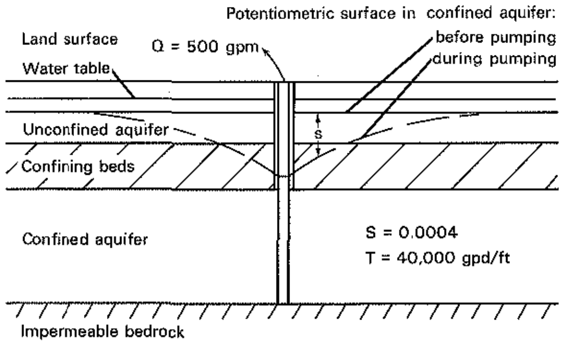
The simplest confined-aquifer system is areally infinite and overlain by impermeable confining beds. The infinite aquifer was computer-simulated by extending the boundary edges of the finite-difference grid to such large distances that the area of interest would not be affected by the boundary edges during the period of analysis.

Computer output for this condition is a drawdown value for each element at the end of each time step. Analytical solutions are computed using the Theis nonequilibrium formula (Hantush, 1964, p. 338).

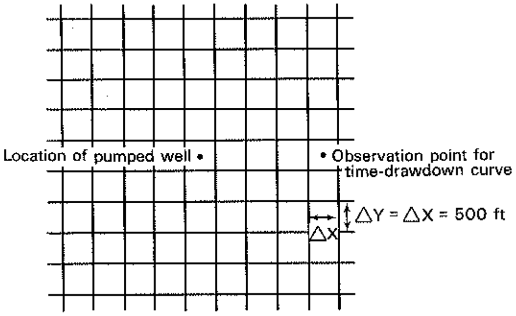
Computer results compared with analytical solutions are shown in figure 5. The agreement between computer results and analytical solutions is good.

Barrier-Boundary Conditions

A barrier boundary is a boundary across which no flow occurs. This condition can be simulated in the program by assigning zero transmissivity values to the appropriate elements in data deck 2 (fig. 4).

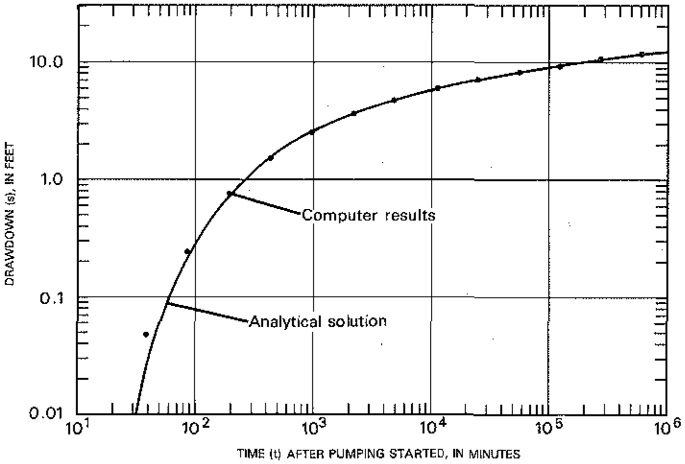


Aqufer system

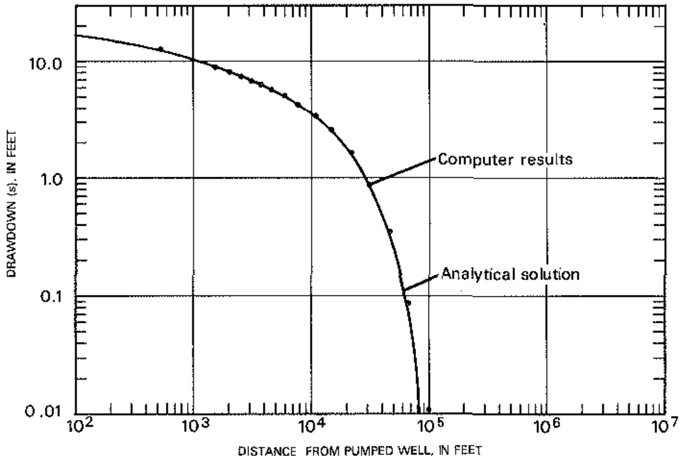


Finite-difference grid in vicinity of well

A. Schematic representation of aquifer system and finite-difference grid



Time-drawdown curve, 2,000 feet from pumping well



Distance-drawdown curve after 40 days of pumping

B. Comparison of computer output with analytical solutions

Figure 5. Comparison of analytical and computer solutions for an infinite aquifer overlain by impermeable confining beds.

Output from the program for this condition is a drawdown value for each element at the end of each time step. Analytical solutions are computed using the Theis nonequilibrium formula and method of images (Hantush, 1964, p. 388).

Examples of computer results compared with analytical solutions are shown in figure 6. The agreement between computer results and the analytical solutions is good.

Constant-Head Boundary Conditions

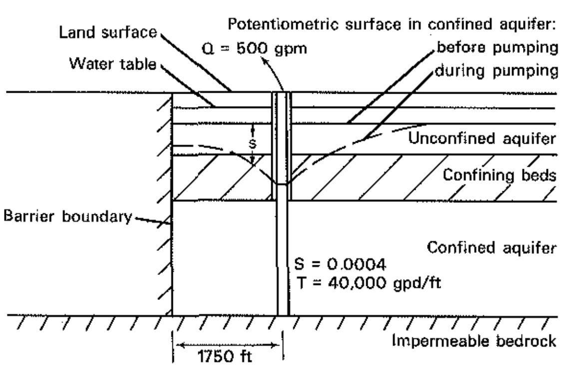
A constant-head boundary is a boundary across which no drawdown occurs, such as a stream that fully penetrates the aquifer. This condition can be simulated in the program by assigning values of -1.0 to elements in data deck 5 (fig. 4) wherever a constant-head boundary occurs. Negative numbers in this data deck are used to indicate constant-head boundaries.

Computer output for this condition includes the rate and volume of water withdrawn from the boundary, the volume of water withdrawn from storage from the confined aquifer, and computed drawdowns in the confined aquifer at the end of each time step. Analytical solutions are computed by methods outlined by Hantush (1964, p. 388).

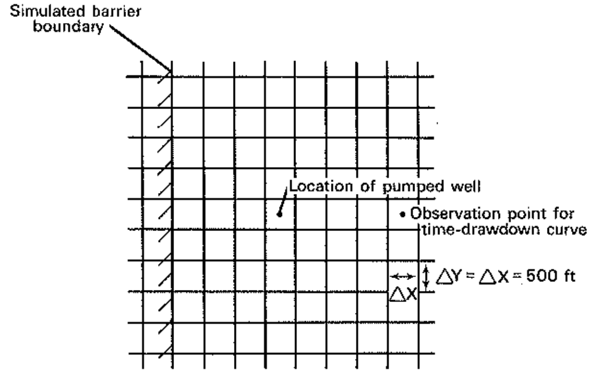
Examples of computer results compared with analytical solutions are shown in figure 7. The agreement between computer results and analytical solutions is good.

Leaky Aquifer Conditions

A leaky aquifer condition exists whenever flow changes occur across the contact surface between the confining beds and the confined aquifer in response to pumping. This condition can be simulated in the program by including aquifer data decks 5, 6, and 7 in the analysis (fig. 4). Data deck 7 may be omitted if the amount of water released from storage in the confining beds is assumed to be insignificant.

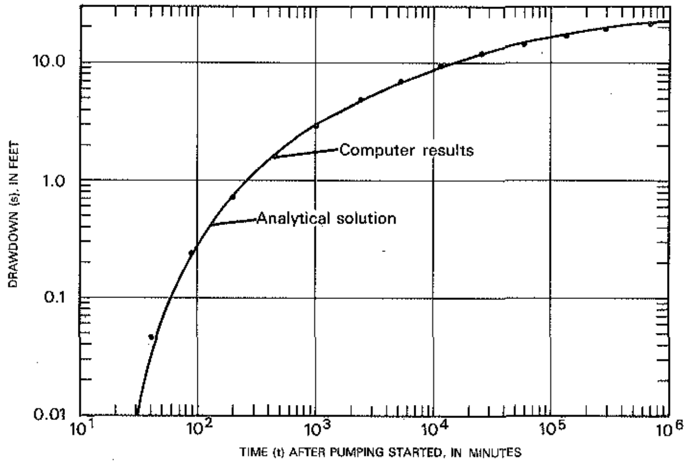


Aquifer system

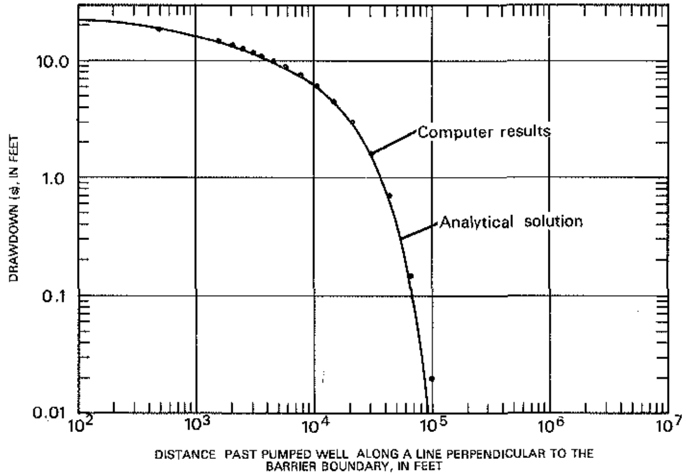


Finite-difference grid in vicinity of well

A. Schematic representation of aquifer system and finite-difference grid



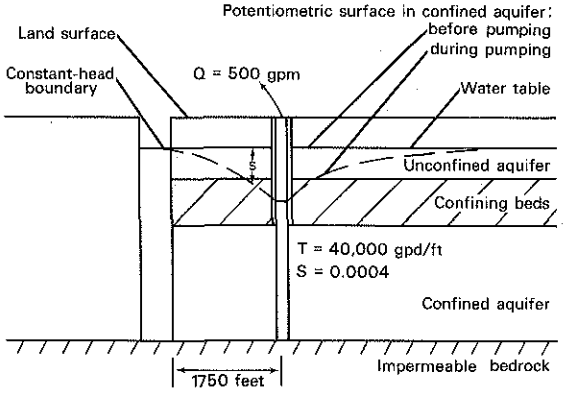
Time-drawdown curve, 2,000 feet from pumped well



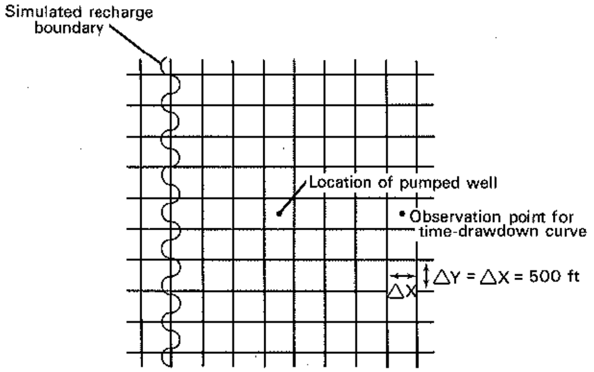
Distance-drawdown curve after 40 days of pumping

B. Comparison of computer output with analytical solutions

Figure 6. Comparison of analytical and computer solutions for barrier-boundary conditions.

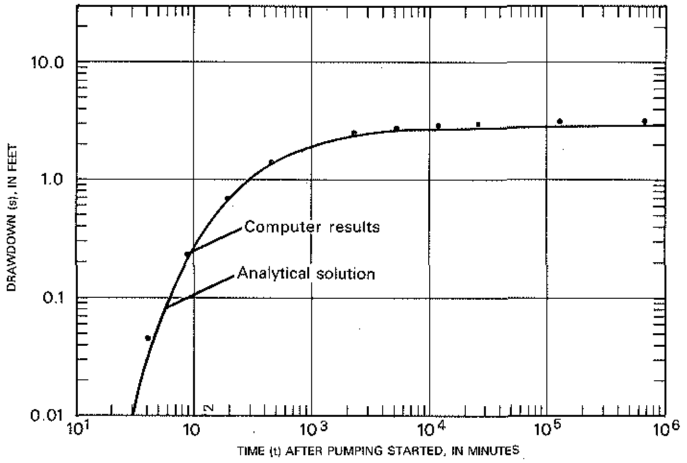


Aquifer system

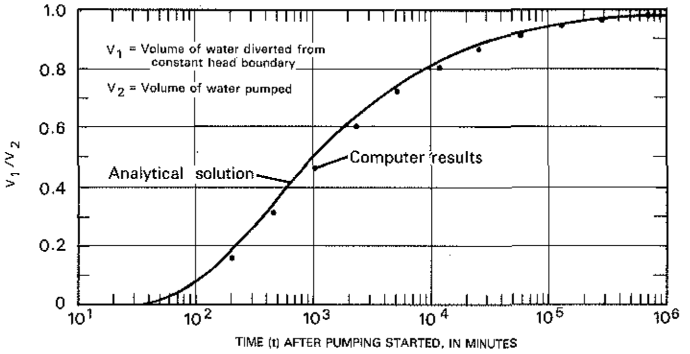


Finite-difference grid in vicinity of well

A. Schematic representation of aquifer system and finite-difference grid



Time-drawdown curve, 2,000 feet past pumped well along a line perpendicular from the recharge boundary



Time-depletion curve for stream 1,750 feet from pumped well

B. Comparison of computer output with analytical solutions

Figure 7. Comparison of analytical and computer solutions for constant-head boundary conditions.

Output from the program for this condition includes the change in rate and volume of flow across the contact surface between the confining beds and the confined aquifer, the volume of water withdrawn from storage in the confined aquifer, and computed drawdowns in the confined aquifer at the end of each time step. Analytical solutions are computed by methods outlined by Hantush (1964, p. 334).

Examples of computer results are compared with analytical solutions in figure 8. The agreement between computer results and the analytical solutions is good.

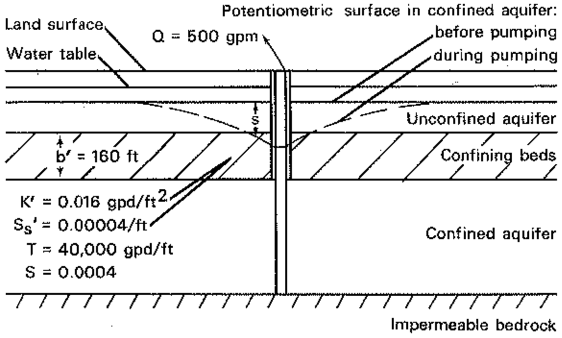
Discussion of the Evaluations

The time-drawdown and distance-drawdown computer solutions are in good agreement with analytical solutions for all the evaluations.

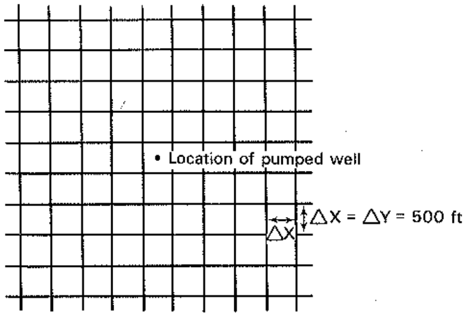
Computer solutions for rates and volumes of flow across aquifer boundaries are less than the analytical solutions during the middle time period in the analyses (figs. 7 and 8). This results partly from the approximation used to compute flow changes and partly from truncation error in the finite-difference equations.

Truncation errors are inherent in the computer solutions because finite-difference methods are used to approximate a continuous system. These errors are greater when either nonhomogeneous conditions are simulated or the grid spacing in the finite-difference grid is not uniform.

The mass-balance check option aids in judging the correctness of the solution. Flow changes in each element are compared with the change in storage within the element at the end of each time step. The difference (residual) is summed for all elements. The largest residual for each time step and a cumulative total for all time steps are printed. The cumulative residual should be less than 1 percent of the total flow changes at each time step for an acceptable solution.

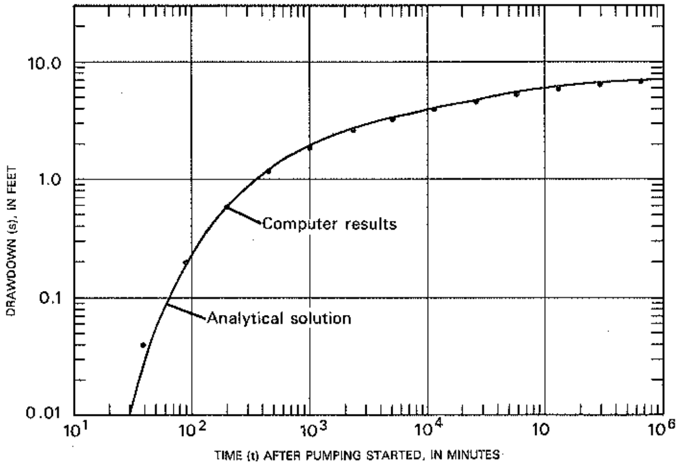


Aquifer system

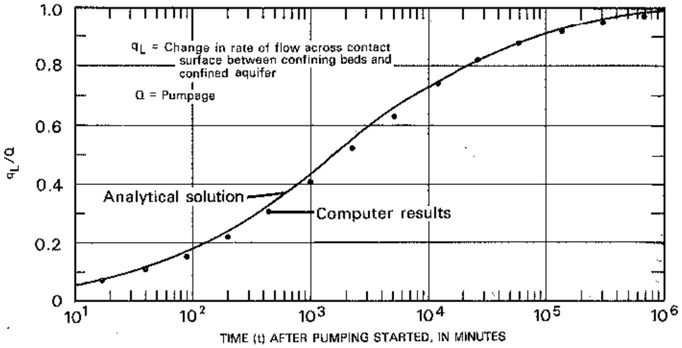


Finite-difference grid in vicinity of well

A. Schematic representation of aquifer system and finite-difference grid



Time-drawdown curve, 2,000 feet from pumped well



Time-leakage curve through leaky confining beds

B. Comparison of model output with analytical solutions

Figure 8. Comparison of analytical and computer solutions for leaky aquifer conditions.

APPLICATION OF THE PROGRAM TO THE SANDSTONE AQUIFER IN DANE COUNTY

The Hydrogeology of Dane County

Dane County is underlain by rocks of Precambrian, Cambrian, Ordovician, and Quaternary age. A stratigraphic column representing the sequence of rocks in the county is given in table 1.

Dense crystalline rock of Precambrian age forms the basement upon which younger geologic units were deposited. The depth below land surface to the Precambrian rock ranges from less than 600 feet (183 m) to more than 1,300 feet (396 m). Crystalline rock thickness is unknown but is very great.

Cambrian formations overlie the Precambrian bedrock and include, in ascending order, Mount Simon, Eau Claire, Galesville, and Franconia Sandstones, and the Trempealeau Formation. These rocks are chiefly sandstone intermixed with layers of shale, siltstone, and dolomite. The combined average thickness of the Cambrian units within the county, as determined from structure contour maps, is about 800 feet (244 m); the greatest thickness, about 1,100 feet (335 m), occurs in the southwest.

Ordovician rocks overlie the Cambrian sandstones and include, in ascending order, the Prairie du Chien Group, St. Peter Sandstone, Platteville and Decorah Formations, and Galena Dolomite. The Prairie du Chien Group and Platteville-Galena unit, (Platteville and Decorah Formations, and Galena Dolomite, undifferentiated), consist mostly of dense dolomite. The St. Peter Sandstone consists mostly of sandstone. In many parts of the county the Ordovician units have been removed by erosion. The thickest deposits within the county, more than 500 feet (152 m), occur in the southwest.

Unconsolidated deposits of Quaternary age overlie bedrock of Cambrian and Ordovician age. These deposits include morainal deposits, outwash, and glacial-lake deposits, and they range in thickness from zero to about 370 feet (113 m).

Table 1.--Generalized stratigraphy and aquifer system.

Era or System	Geologic Unit		Dominant Lithology	Subsurface Hydrologic Unit	Saturated Thickness (ft)
Quaternary	Holocene and Pleistocene Deposits		Clay, silt, sand	Upper aquifer	50-450
Ordovician	Galena Dolomite		Dolomite		
	Decorah Formation		Dolomite		
	Platteville Formation		Dolomite		
	St. Peter Sandstone		Sandstone		
	Prairie du Chien Group		Dolomite		
Cambrian	Trempealeau Formation		Sandstone and Dolomite		
	Franconia Sandstone	Reno Member*	Sandstone		
		Mazomanie* Sandstone Member			
		Ironton Sandstone Member		Sandstone aquifer	450-900
	Galesville Sandstone		Sandstone		
	Eau Claire Sandstone		Sandstone and Shale		
	Mount Simon Sandstone		Sandstone		
Precambrian			Crystalline Rocks	Not an aquifer	

*Not approved by U.S. Geological Survey for formal use.

The glacial deposits are covered in places by thin loess, alluvium, and marsh deposits.

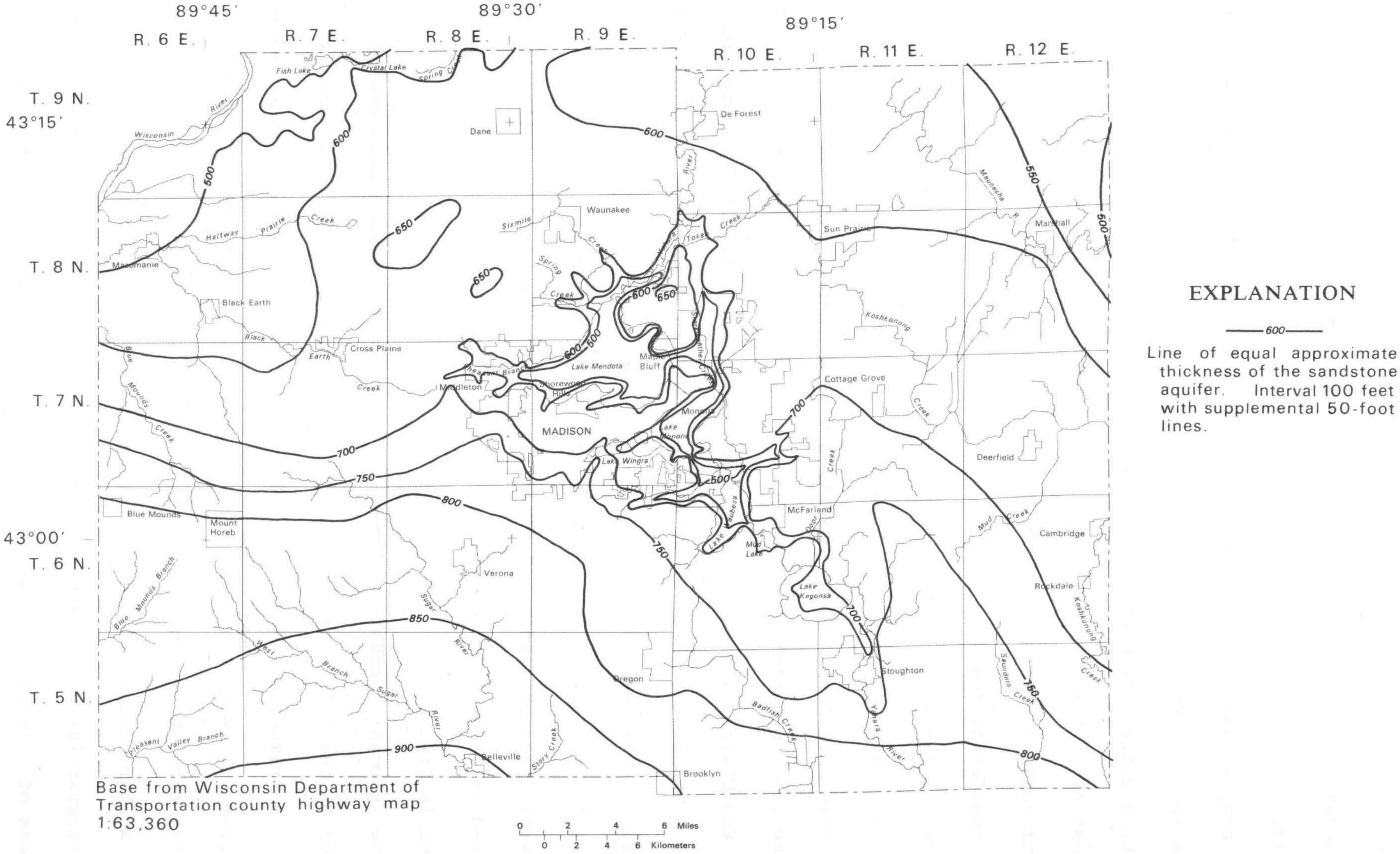
A comprehensive discussion of the geology of Dane County is available in Cline's report (1965).

The aquifer system underlying Dane County is composed of the entire thickness of Cambrian, Ordovician, and Quaternary units. The Precambrian basement rocks are relatively impermeable and are assumed to form the base of the aquifer system.

The aquifer system is subdivided into the sandstone and upper aquifers (table 1). This subdivision is based on well construction practices in the county which, in turn, reflect hydrologic conditions.

The Ironton Sandstone Member of the Franconia Sandstone, plus the Galesville, Eau Claire, and Mount Simon Sandstones, collectively form the sandstone aquifer. These units are saturated everywhere in the county. The aquifer generally is composed of fine-to coarse-grained sandstone. Ground-water movement in the aquifer is primarily through intergranular pore spaces and secondarily through joints and other fractures. The areal variation in saturated thickness of the aquifer, as determined from structure contour maps, is shown in figure 9.

The Mazomanie Sandstone Member and Reno Member (these names are not approved by the U.S. Geological Survey for formal use) of the Franconia Sandstone, the Trempealeau Formation, plus all Ordovician and Quaternary deposits, collectively form the upper aquifer. Water in the upper aquifer probably moves primarily through fractures, joints, and solution channels in dolomitic rocks, intergranular pore spaces in unconsolidated deposits, and fractures, joints, and intergranular pore spaces in sandstone. The areal variation in saturated thickness of this aquifer, as determined from a structure contour map of the base of the aquifer and a water-table map, is shown in figure 10.

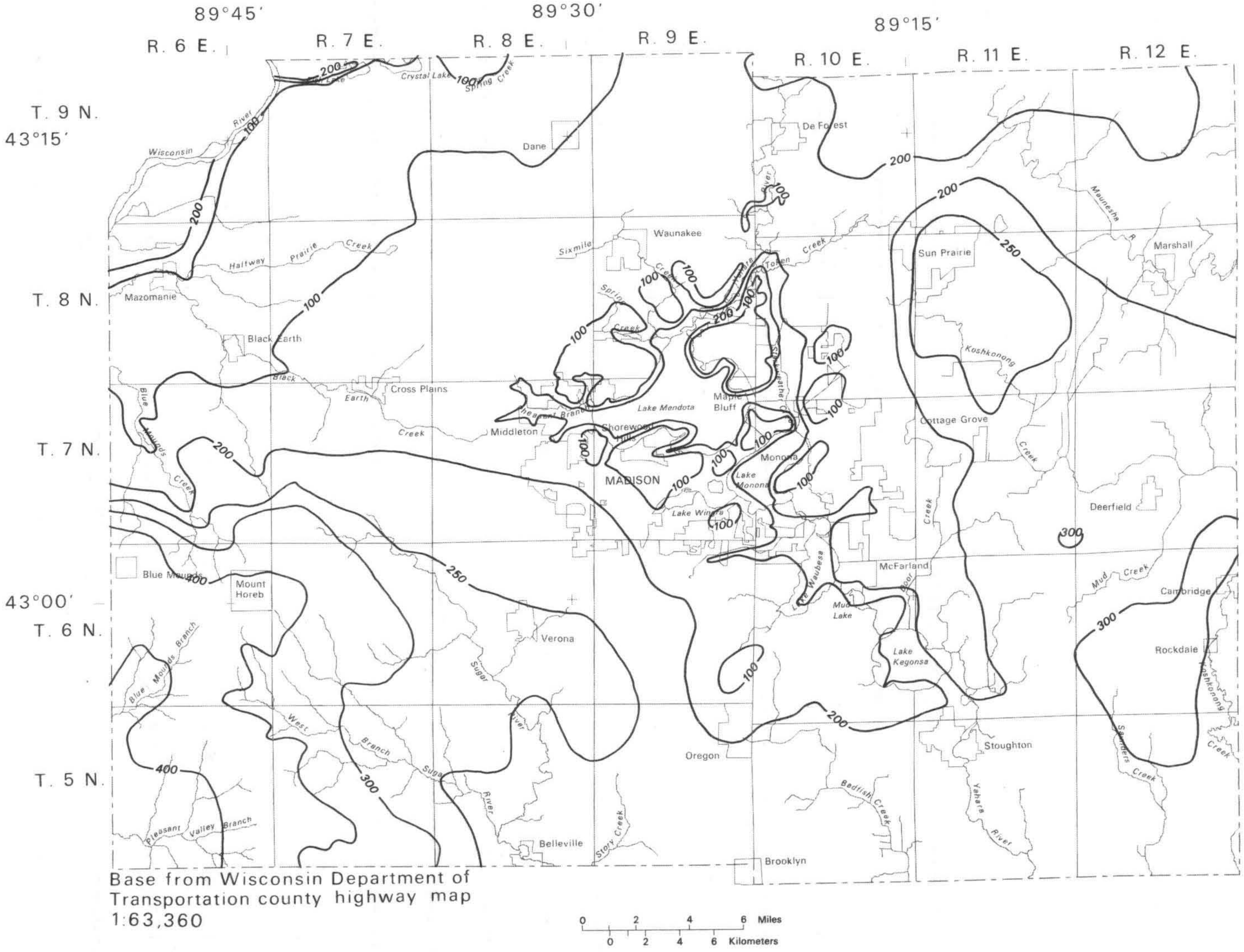


EXPLANATION

——600—— Line of equal approximate thickness of the sandstone aquifer. Interval 100 feet with supplemental 50-foot lines.

Base from Wisconsin Department of Transportation county highway map 1:63,360

Figure 9. Saturated thickness of the sandstone aquifer.



Base from Wisconsin Department of Transportation county highway map 1:63,360

EXPLANATION

—— 100 —— Line of equal approximate saturated thickness before development of the sandstone aquifer. Interval 100 feet with supplemental 50-foot lines.

Figure 10. Saturated thickness of the upper aquifer before development.

The Mazomanie Sandstone and Reno Members of the Franconia, the Trempealeau Formation, and Quaternary deposits form the major part of the saturated thickness of the upper aquifer. These deposits are saturated in part throughout most of the county.

The Prairie du Chien Group and St. Peter Sandstone generally form a small part of the saturated thickness of the upper aquifer. These deposits are generally saturated in part where they are present, but they have been eroded away in many areas. Their saturated thickness is greatest in the southwest part of the county.

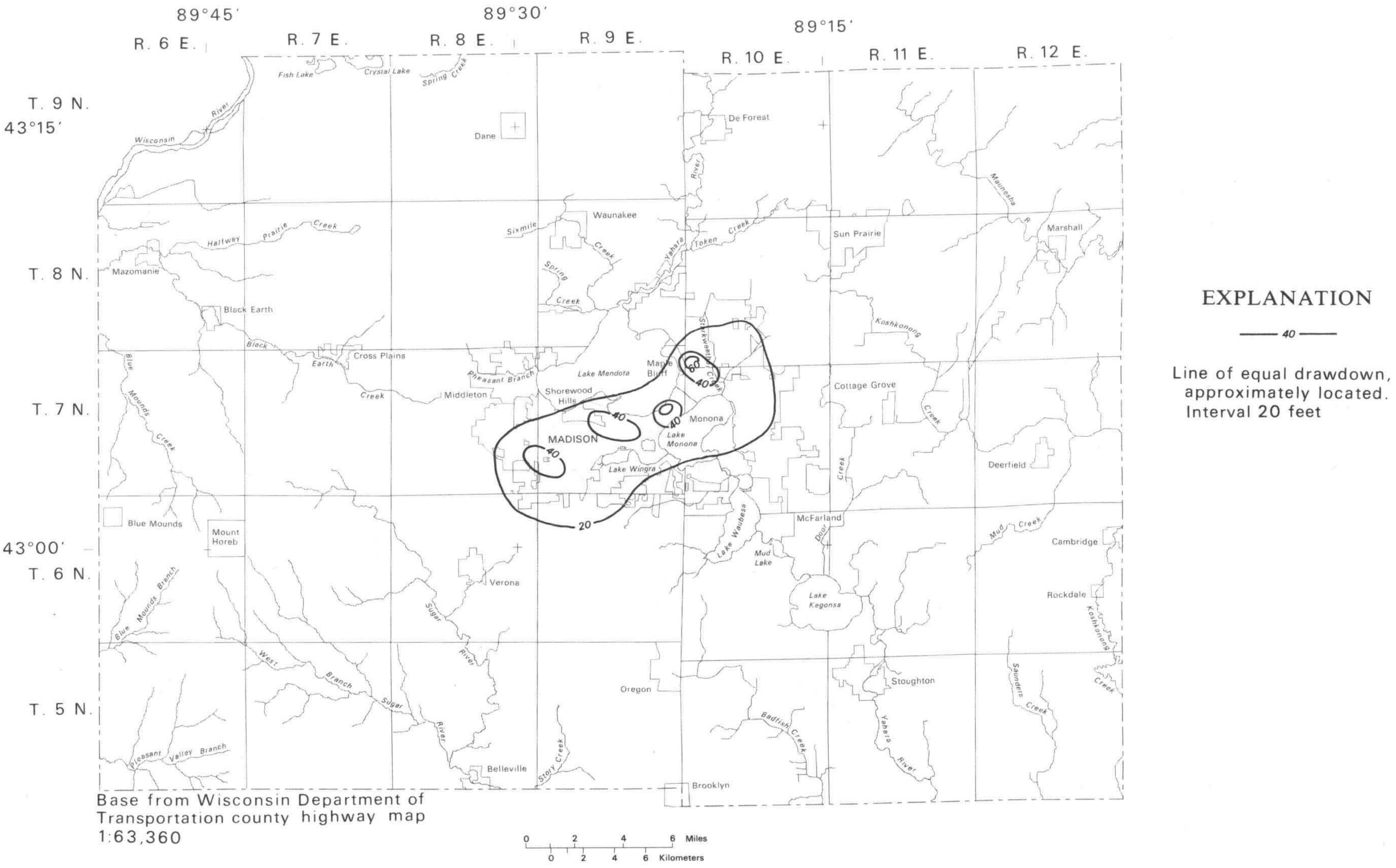
The Platteville-Galena unit does not form a significant part of the saturated thickness of the upper aquifer. The unit has been eroded away throughout much of the county. Where present, it is generally unsaturated.

Many municipal and industrial wells penetrate to Precambrian bedrock and are finished in the sandstone aquifer. Most domestic wells in the county are finished in the upper aquifer.

Hydrologic Changes Caused by Pumping

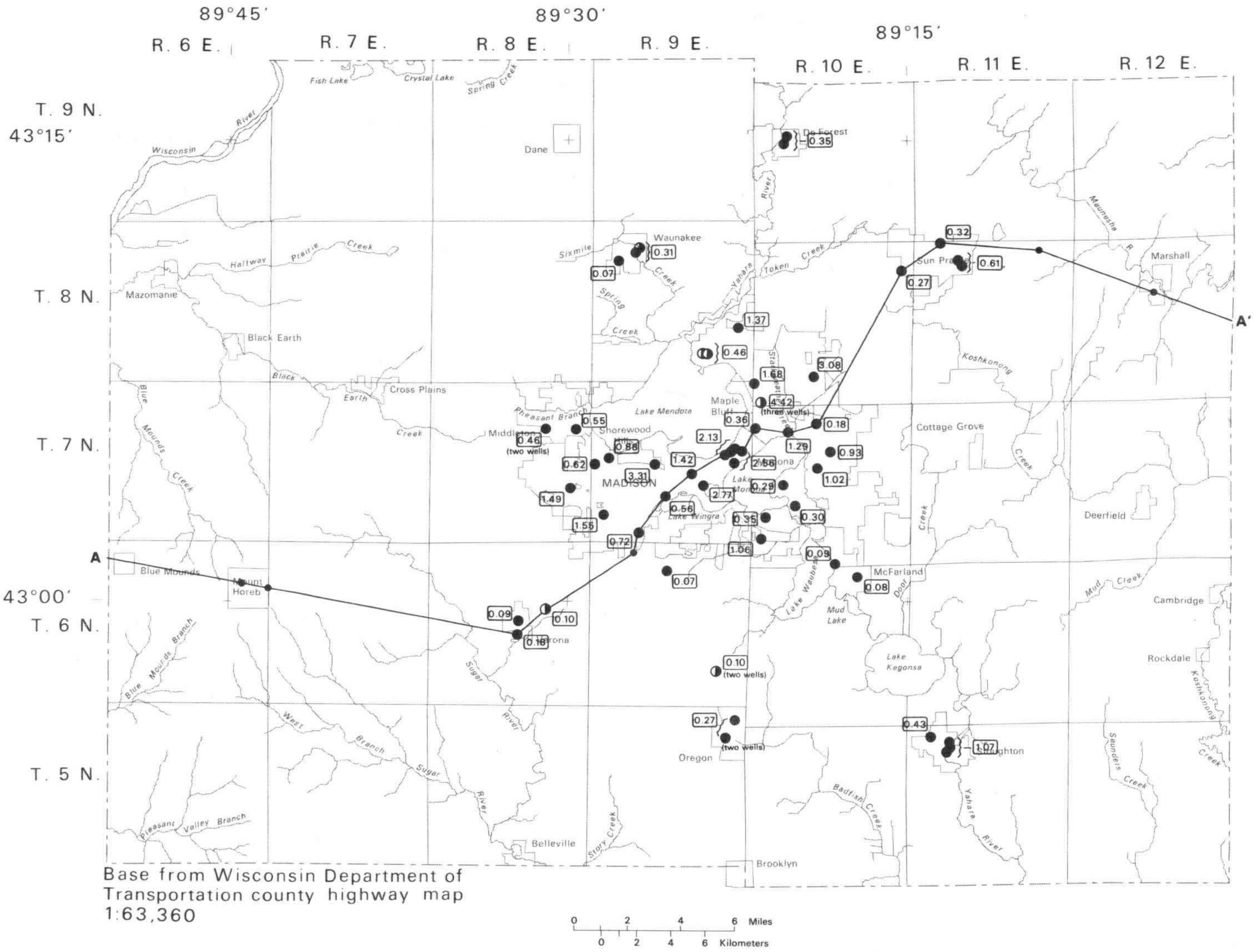
Observed hydrologic changes in the aquifer system caused by pumping from the sandstone aquifer include drawdown of the potentiometric surface in the sandstone aquifer, drawdown of the water table in the upper aquifer away from constant head boundaries, and reductions in base flow to streams. Drawdown of the potentiometric surface by 1970, as determined from water-level measurements in municipal and industrial wells, is shown in figure 11. Largest drawdowns, more than 70 feet (about 21 m), occur along a northeast-southwest line through the Madison area. This trend is due partly to the distribution of pumping (fig. 12) and partly to the hydrogeology of the aquifer system.

Drawdown of the water table by 1970 ranged from 0 to 20 feet (6.10 m) (fig. 13). These drawdowns were estimated from water-level measurements in shallow wells. Largest drawdowns, 10-20 feet (3.05-10 m), occurred in central



Base from Wisconsin Department of Transportation county highway map 1:63,360

Figure 11. Drawdowns in water-levels in the sandstone aquifer by 1970.



Base from Wisconsin Department of Transportation county highway map 1:63,360

EXPLANATION

0.50 Average daily pumpage, in millon gallons per day

1.00 {● Combined pumpage of wells wherever two or more wells are assigned to pump from the same finite-difference grid element

● Water utility well (existing or proposed)

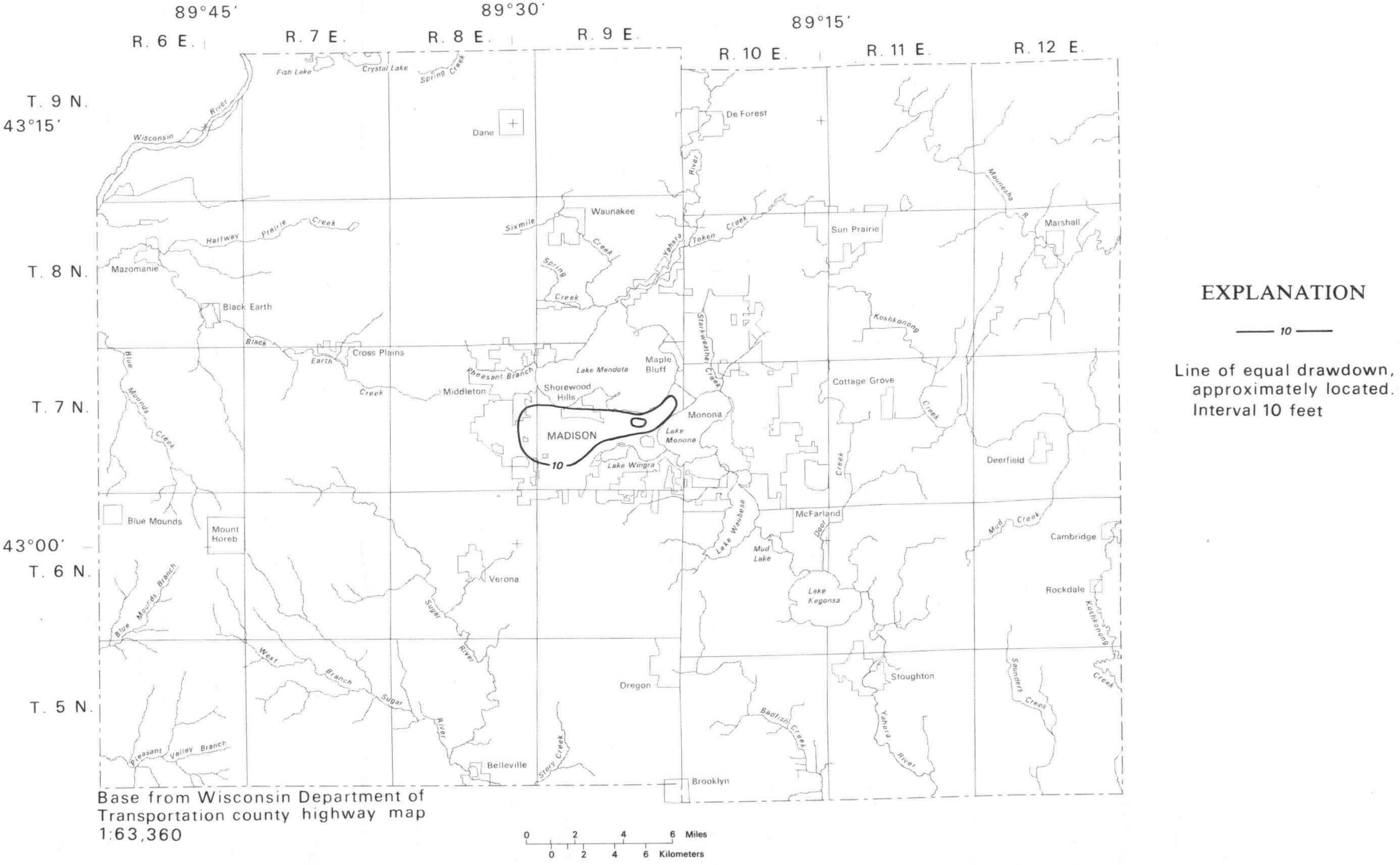
◐ Industrial or public institution well

(two wells) Number of wells represented by well symbol, if more than one well

A — A′ Line of hydrogeologic section shown on Figure 14

• Additional well, used in hydrogeologic section

Figure 12. Pumpage from the sandstone aquifer during 1970.



Base from Wisconsin Department of Transportation county highway map 1:63,360

Figure 13. Drawdowns in the upper aquifer by 1970.

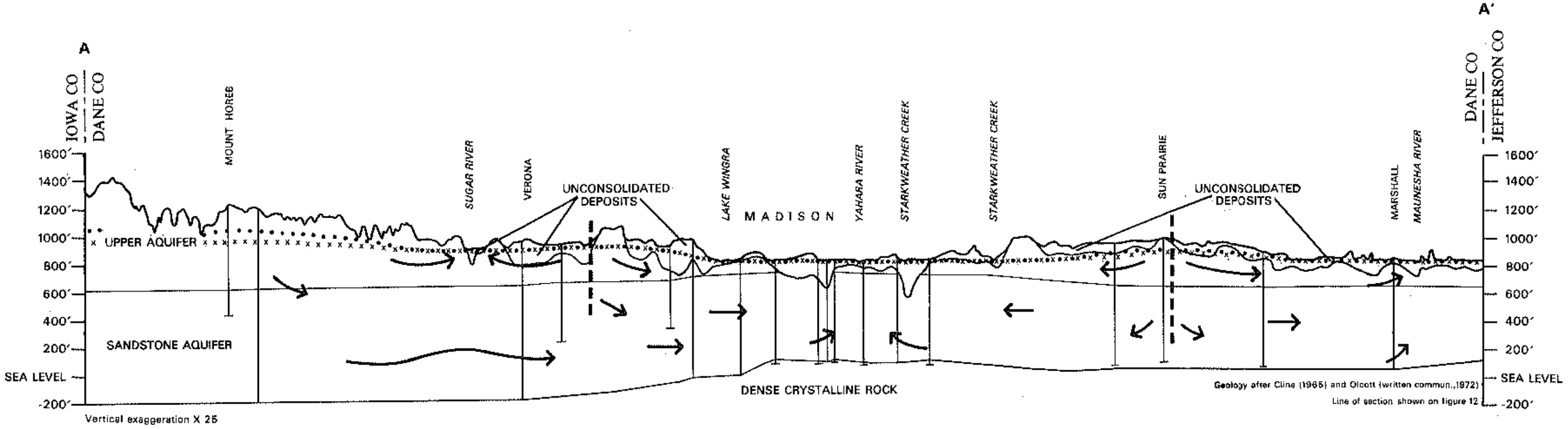
and west Madison. Drawdowns in the water table were generally much smaller than those in the sandstone aquifer at corresponding locations.

Pumping has approximately equaled observed reductions in streamflow past the Upper Yahara River stream-gaging station (fig. 1) (Cline, 1965, p. 61). This indicates that flow in the aquifer system adjusts to maintain an approximate equilibrium between recharge to and discharge from the sandstone aquifer.

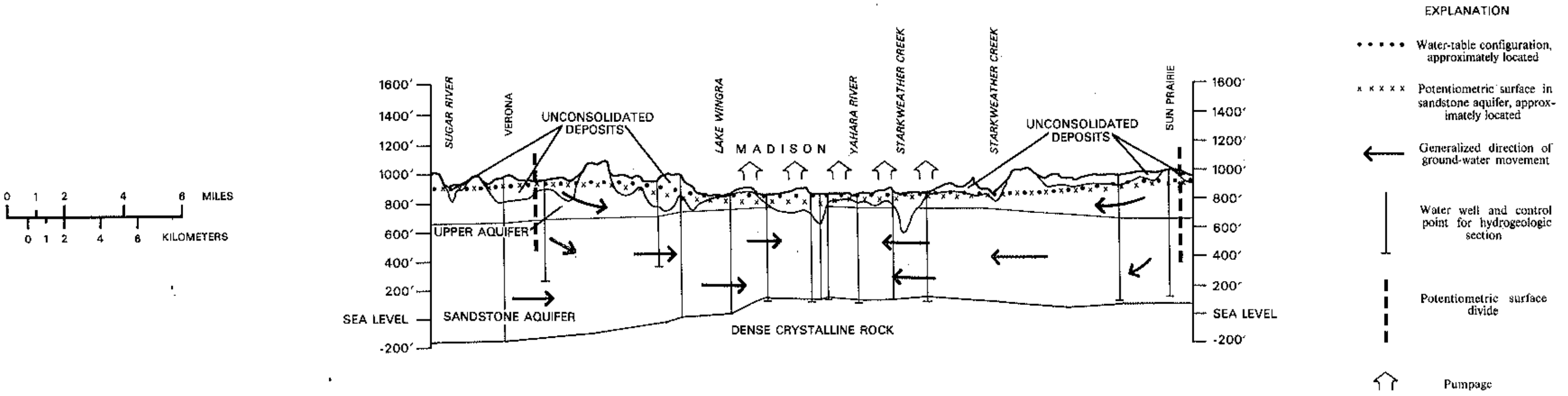
These hydrologic changes are an expression of changes in ground-water movement that have occurred as a result of pumping. Water movement in the aquifer system along section A-A' (fig. 12) before any man-induced changes and during 1970 is illustrated in figure 14. Keeping in mind the vertical exaggeration of the section (approximately 25 to 1), note that water movement in the sandstone aquifer has been predominately horizontal. Exceptions are areas of potentiometric highs and lows. Areas of ground-water recharge are associated with potentiometric highs. Areas of ground-water discharge are associated with potentiometric lows. Vertical water movement predominated in these areas before development (fig. 14a). By 1970, however, some discharge from the sandstone aquifer in the Madison area had been diverted to wells (fig. 14b). Also the west potentiometric surface divide for the Yahara River had shifted southwestward because of pumping. This resulted in the diversion of some ground water to the Yahara River basin that previously discharged into the Sugar River basin.

Modeling the Sandstone Aquifer

The sandstone aquifer was modeled as a confined aquifer overlain by leaky confining beds. Hydrologic changes in the aquifer system indicated that the sandstone aquifer behaved in response to pumping as a confined aquifer that received leakage from the upper aquifer.



A. Generalized ground-water levels and movement before development



B. Generalized ground-water levels and movement by 1970 in area of greatest development

Figure 14. Hydrogeologic section through Dane County.

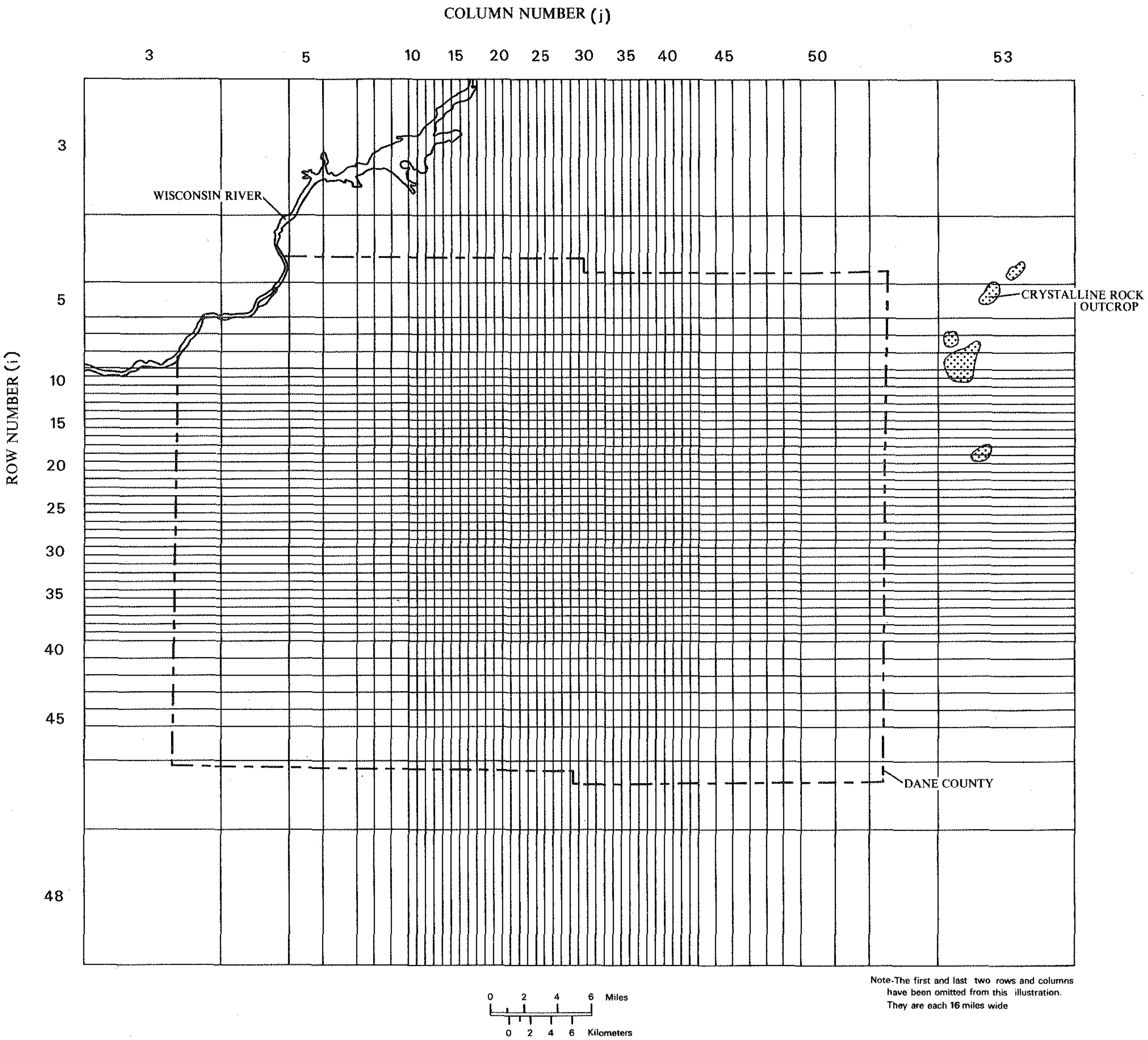
Flow changes in the sandstone aquifer were approximated as horizontal flows for the model. This is a reasonable approximation throughout much of the Madison area (fig. 14b).

Leakage changes to the sandstone aquifer were approximated as vertical flows across the contact surface between the sandstone and upper aquifers. This approximation is partially justifiable because the vertical hydraulic conductivity of the upper aquifer is much less than the horizontal hydraulic conductivity of the sandstone aquifer at corresponding locations.

The water table of the aquifer system was approximated as a constant head boundary for the model. This is a reasonable approximation so long as new drawdowns in the water table are small. The model calibration process incorporates into the model any effects of past drawdowns of the water table on flow changes in the sandstone aquifer.

Two other boundaries also were modeled. One is an outcrop of Precambrian crystalline rock just northeast of Dane County (Alden, 1918, p. 65). The other is the Wisconsin River on the northwest. The crystalline outcrop was modeled as a barrier boundary. The Wisconsin River was modeled as a constant head boundary. The locations of the outcrop and river are shown in figure 15. The sandstone aquifer was assumed to be infinite in areal extent in all other areas.

The maximum number of elements allowed in the program was used for modeling the sandstone aquifer. Grid spacing was made small enough for a reasonable representation of the sandstone aquifer in the Madison area by averaging physical properties within grid elements. The edges of the grid were located far enough from this area to include boundaries that influence flow in the aquifer. The finite-difference grid configuration chosen for the sandstone-aquifer model is shown by figure 15.



Note-The first and last two rows and columns have been omitted from this illustration. They are each 16 miles wide

Figure 15. Finite-difference grid used for modeling the sandstone aquifer.

Approximating Areal Variations in Physical Properties of the Aquifer System

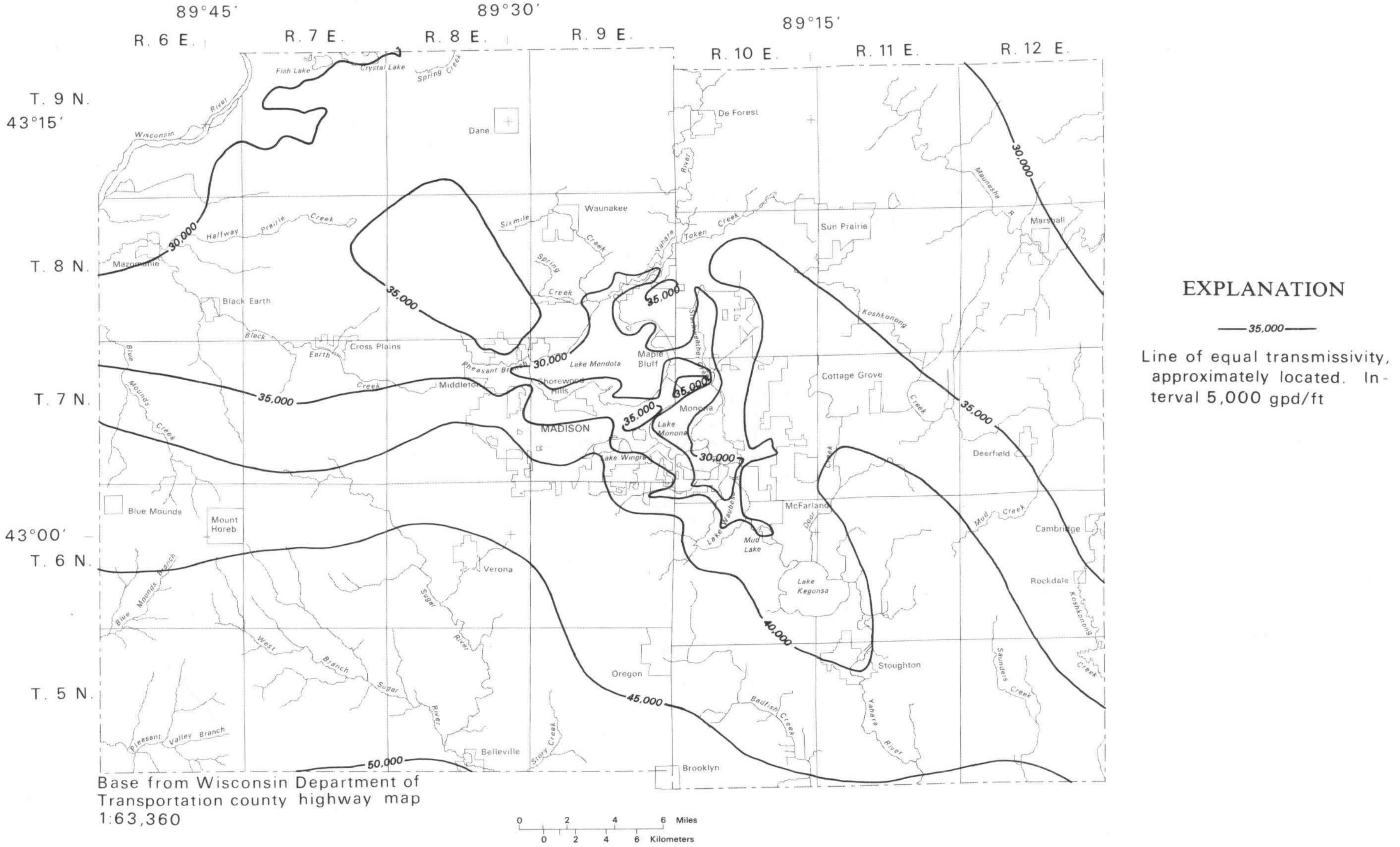
Physical properties of the aquifer system needed for the model are: transmissivity and storage coefficients in the sandstone aquifer, and saturated thickness, vertical hydraulic conductivity, and specific storage in the upper aquifer. These properties are not areally uniform.

The areal variation of transmissivity in the sandstone aquifer (fig. 16) was determined by a method outlined by Jenkins (1963). Briefly, the method involved a graphical multiple-regression analysis to estimate an average hydraulic conductivity for the sandstone aquifer from well-log and aquifer-test data. The hydraulic-conductivity estimate was then used with the saturated thickness map of the sandstone aquifer (fig. 9) to determine areal variations in transmissivity for the aquifer.

The areal variation in storage coefficient (fig. 17) of the sandstone aquifer was determined using aquifer-test data and the saturated thickness map. Storage-coefficient values determined from pumping tests were correlated with the average thicknesses of the sandstone aquifer in the vicinity of the tests. This correlation was then used with the thickness map to determine the areal variation in storage coefficient.

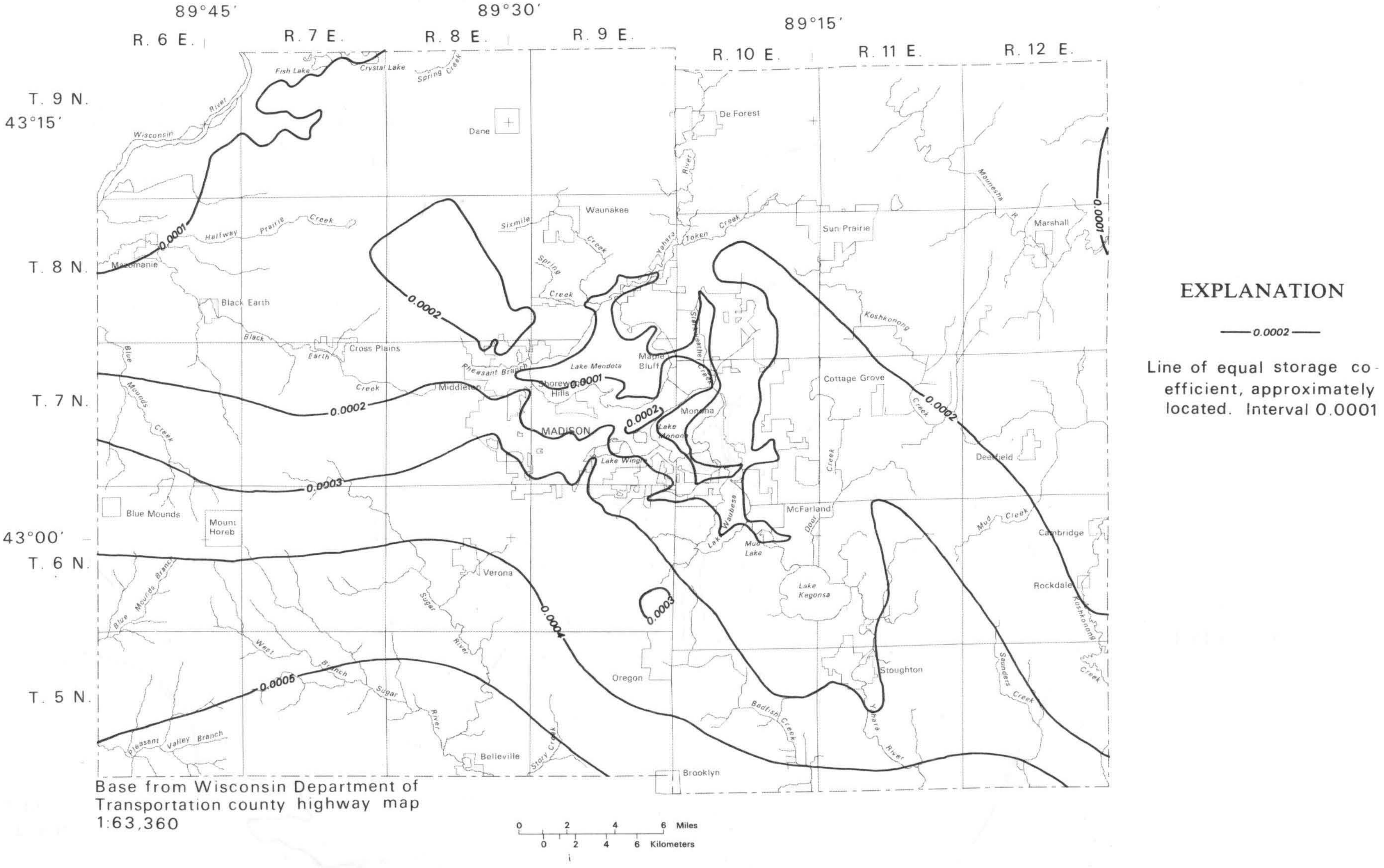
The areal variation in saturated thickness of the upper aquifer was determined earlier (fig. 10).

Areal variations in vertical hydraulic conductivity and specific storage for the upper aquifer (fig. 18) are based on areal differences in geology. One set of average values for vertical hydraulic conductivity and specific storage was estimated for areas where the upper aquifer was composed entirely of unconsolidated deposits. Such areas exist in the deeply buried preglacial Yahara and Wisconsin River valleys. Another set of average values was estimated for remaining areas of the aquifer. These values are derived from aquifer-test data and the results of the model calibration.



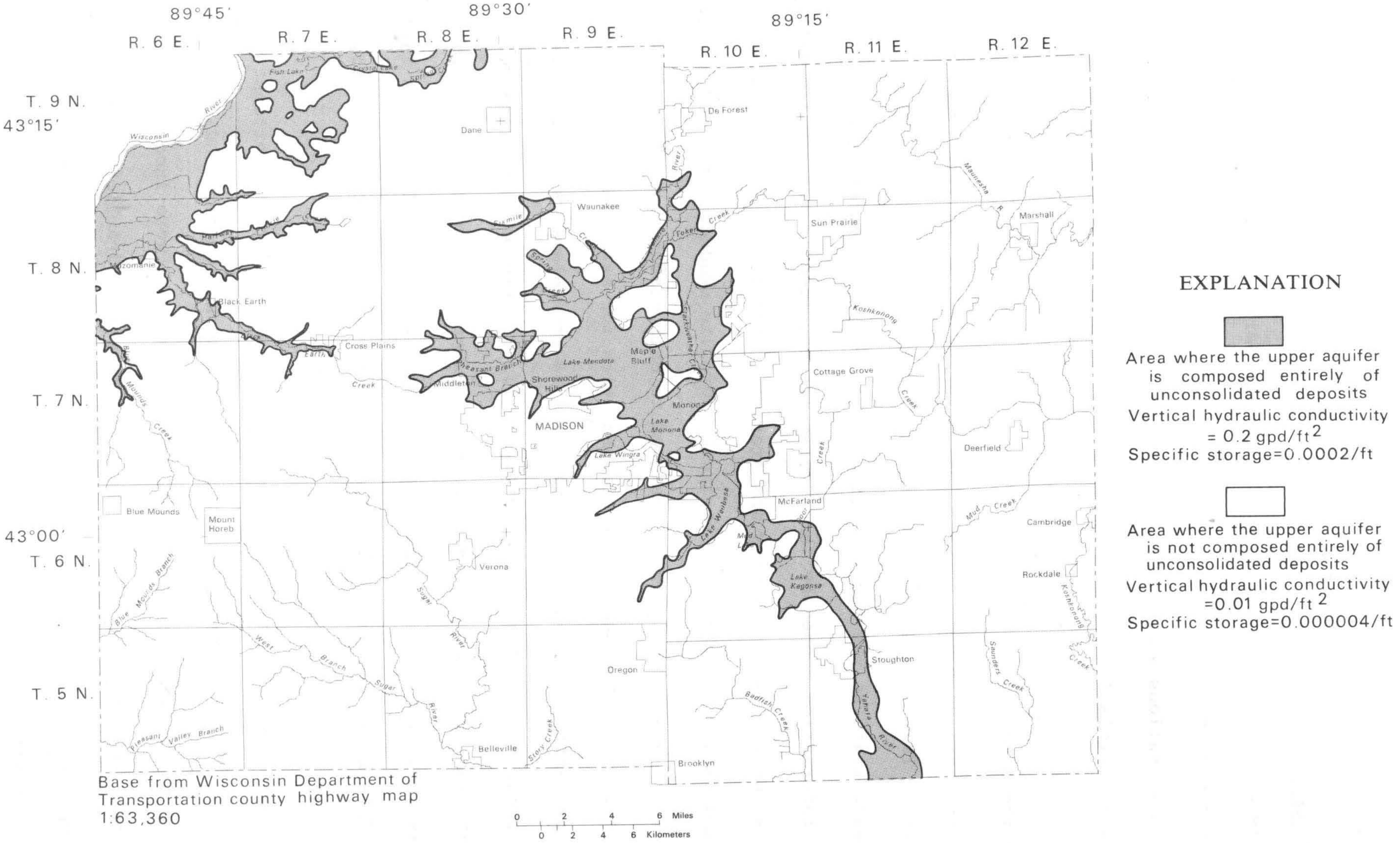
Base from Wisconsin Department of Transportation county highway map 1:63,360

Figure 16. Transmissivity in the sandstone aquifer.



Base from Wisconsin Department of
Transportation county highway map
1:63,360

Figure 17. Storage coefficient in the sandstone aquifer.



Base from Wisconsin Department of Transportation county highway map 1:63,360

EXPLANATION

▨ Area where the upper aquifer is composed entirely of unconsolidated deposits

Vertical hydraulic conductivity = 0.2 gpd/ft^2

Specific storage=0.0002/ft

☐ Area where the upper aquifer is not composed entirely of unconsolidated deposits

Vertical hydraulic conductivity =0.01 gpd/ft^2

Specific storage=0.000004/ft

Figure 18. Vertical hydraulic conductivity and specific storage in the upper aquifer.

Calibrating the Model

A steady-state analysis with 1970 average daily pumpage data was used to calibrate the model.

Two observations suggest that this type of analysis would be appropriate. First, water levels in wells stabilize after relatively short periods of pumping. Second, streamflow in the upper Yahara River basin has been declining at about the same rate as pumping from the sandstone aquifer has been increasing.

Aquifer-test data also suggest that a steady-state analysis would be appropriate. This data showed that the time required for pumping wells to reach steady state at the test locations would be approximately one year.

The information needed by the program was recorded in the aquifer data decks. Values for transmissivity and storage coefficient of the sandstone aquifer and saturated thickness, vertical hydraulic conductivity, and specific storage of the upper aquifer were assigned to each element of the finite-difference grid for the model in accordance with the estimated areal variations in these properties. Pumpages were assigned to grid elements in accordance with the areal distribution shown in figure 12. If two or more wells fell within the same grid element, their combined pumpage was assigned to that element.

Wells whose 1990 pumpage from the sandstone aquifer would be less than 0.1 M gal/day (378 m^3/s) are not included in the analysis. They could not significantly affect the computations.

Drawdowns computed by the program in the first calibration attempt were greater than 1970 drawdowns observed in the sandstone aquifer, indicating that one or more of the aquifer properties used in the model were incorrect. It was assumed that the error lay in the values of vertical hydraulic conductivity used to represent the upper aquifer. The storage properties of the aquifer system do not affect the computations in a steady-state analysis. Also, the control available for determining the transmissivity of the sandstone aquifer was relatively good compared to the control available for estimating the vertical hydraulic conductivities for the upper aquifer.

Computed drawdowns were very sensitive to changes in the value of vertical hydraulic conductivity used for the unconsolidated deposits and moderately sensitive to changes in the value of vertical hydraulic conductivity used for the rest of the upper aquifer. The vertical hydraulic conductivity value used for the unconsolidated deposits was altered in the model until computed and observed drawdowns were in general agreement. Final adjustments were made by altering the vertical hydraulic conductivity value used in the model to represent the rest of the upper aquifer.

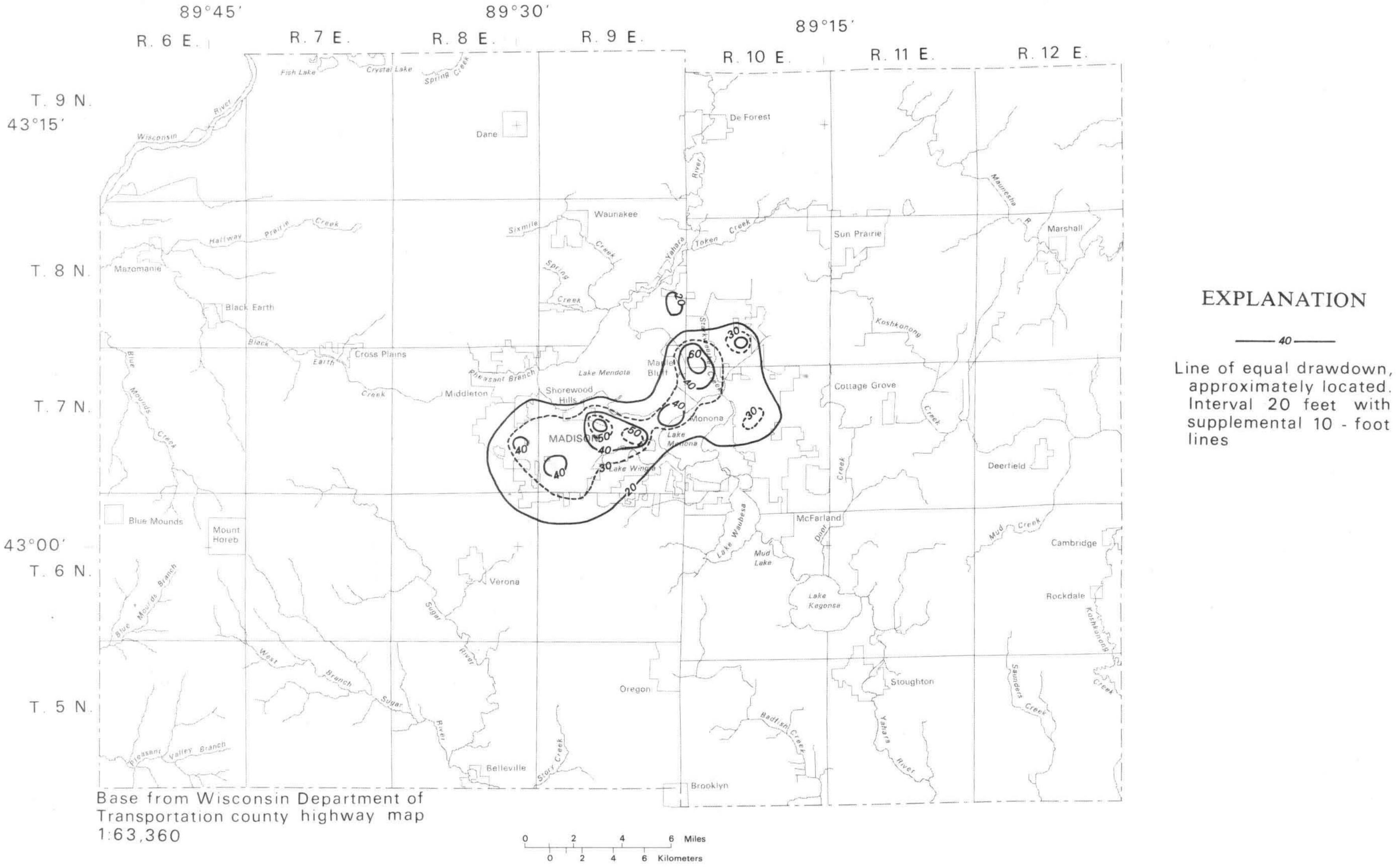
Comparison of model results (fig. 19) with observed drawdowns (fig. 11) shows some differences in local areas. These differences may reflect inadequate drawdown information in these areas rather than an inadequacy in the model. In general, drawdowns in the model reproduced observed drawdowns in the aquifer very well.

Computing Future Drawdowns

Rates and locations of future pumping from the sandstone aquifer had to be determined to compute 1980 and 1990 drawdowns. Pumping rates were determined by the author using an arithmetic projection of the past pumping trend for each user to the year 1990. Each user's long-range ground-water development plan then was used to distribute the projected pumpages. For those users having no long-range plan, projected pumpages were distributed among wells in use in 1970. The rates and locations of pumping from the sandstone aquifer by 1980 and 1990, using the above methods, are shown in figures 20 and 21, respectively. A summary of the projected pumpages for each user is given in table 2 along with the 1970 values.

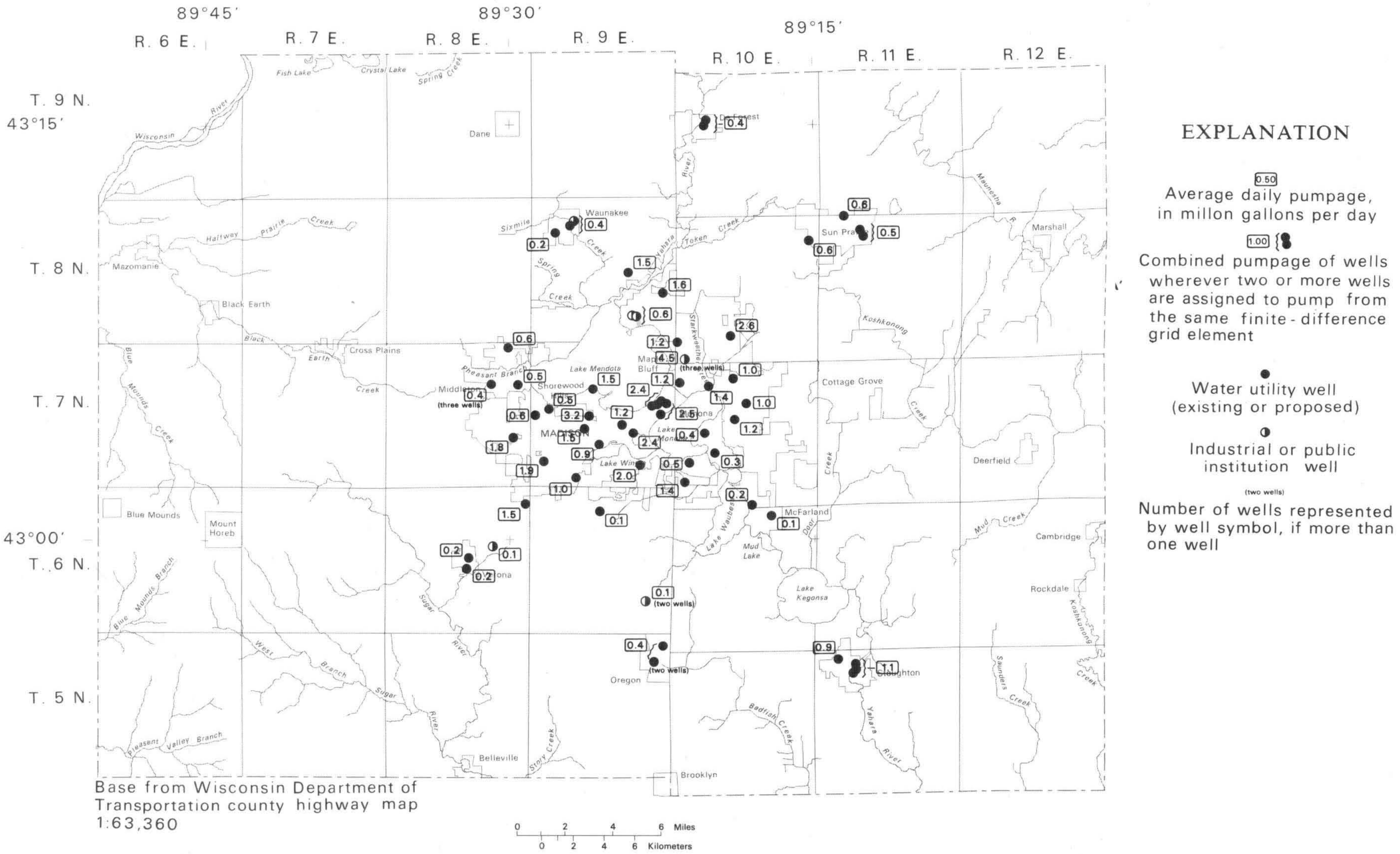
Table 2.--Reported and project pumpages from the sandstone aquifer.

User	Reported pumpage (M gal/day)	Projected pumpage (M gal/day)	
	1970	1980	1990
Dane County Home, Verona	0.10	0.1	0.1
DeForest, village of	.35	.4	.5
Madison Water Utility.	28.98	39.0	49.5
McFarland, village of.	.17	.3	.4
Mendota State Hospital, Madison. . . .	.46	.6	.7
Middleton, city of	1.01	1.5	1.7
Monona, village of	.94	1.2	1.6
Oconomowoc Canning Company, Waunakee .	.13	.2	.2
Oregon School for Girls.	.10	.1	.1
Oregon, village of	.27	.4	.6
Oscar Mayer and Company, Madison. . . .	4.42	4.5	4.8
Stoughton, city of	1.50	2.0	2.6
Sun Prairie, village of.	1.20	1.7	2.2
Town of Fitchburg.	.07	.1	.1
Verona, village of	.27	.4	.6
Waunakee, village of	.25	.4	.5
Total	40.22	52.9	66.2



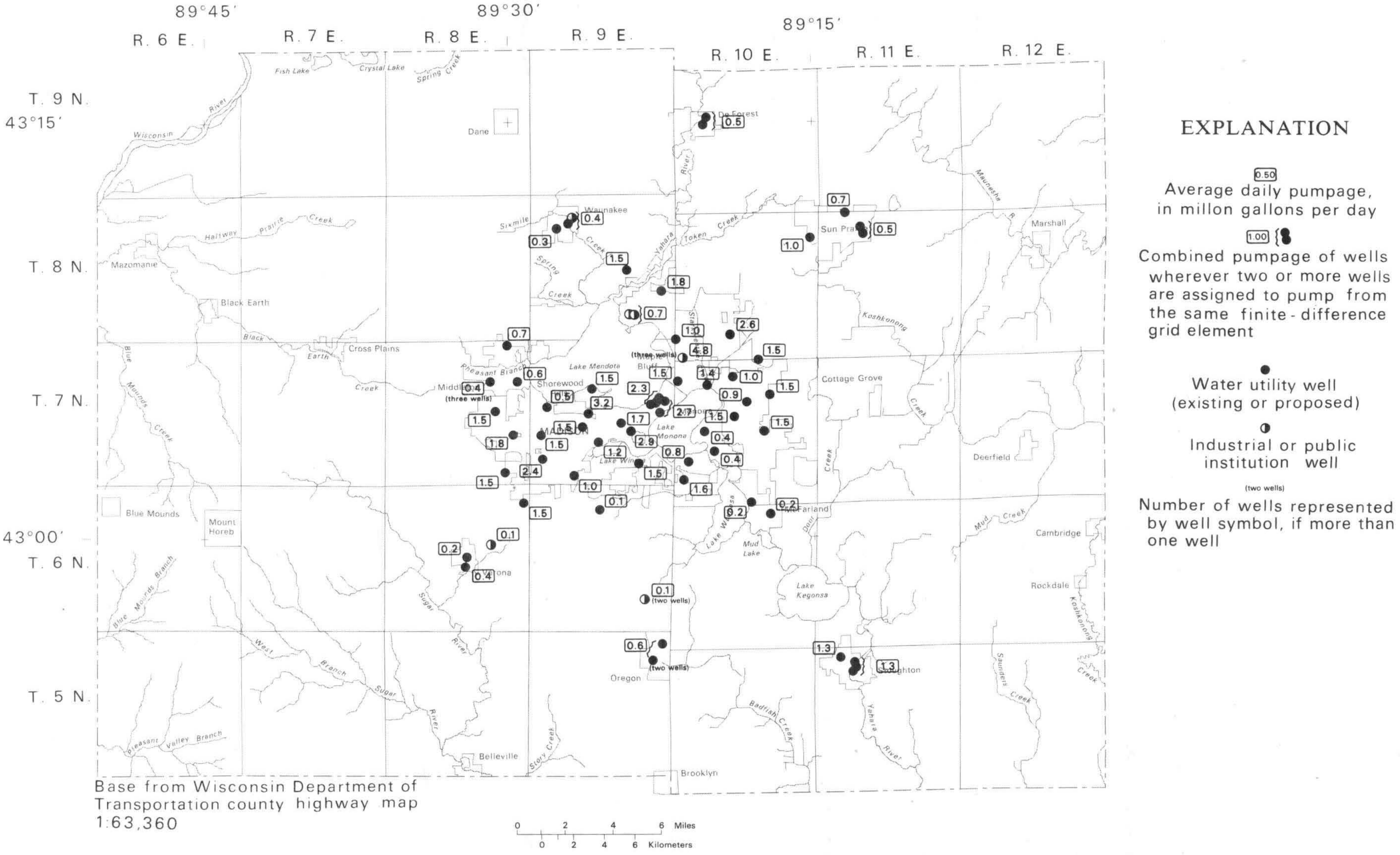
Base from Wisconsin Department of Transportation county highway map 1:63,360

Figure 19. Computed drawdowns in the sandstone aquifer by 1970.



Base from Wisconsin Department of Transportation county highway map 1:63,360

Figure 20. Estimated pumpage from the sandstone aquifer by 1980.



Base from Wisconsin Department of Transportation county highway map 1:63,360

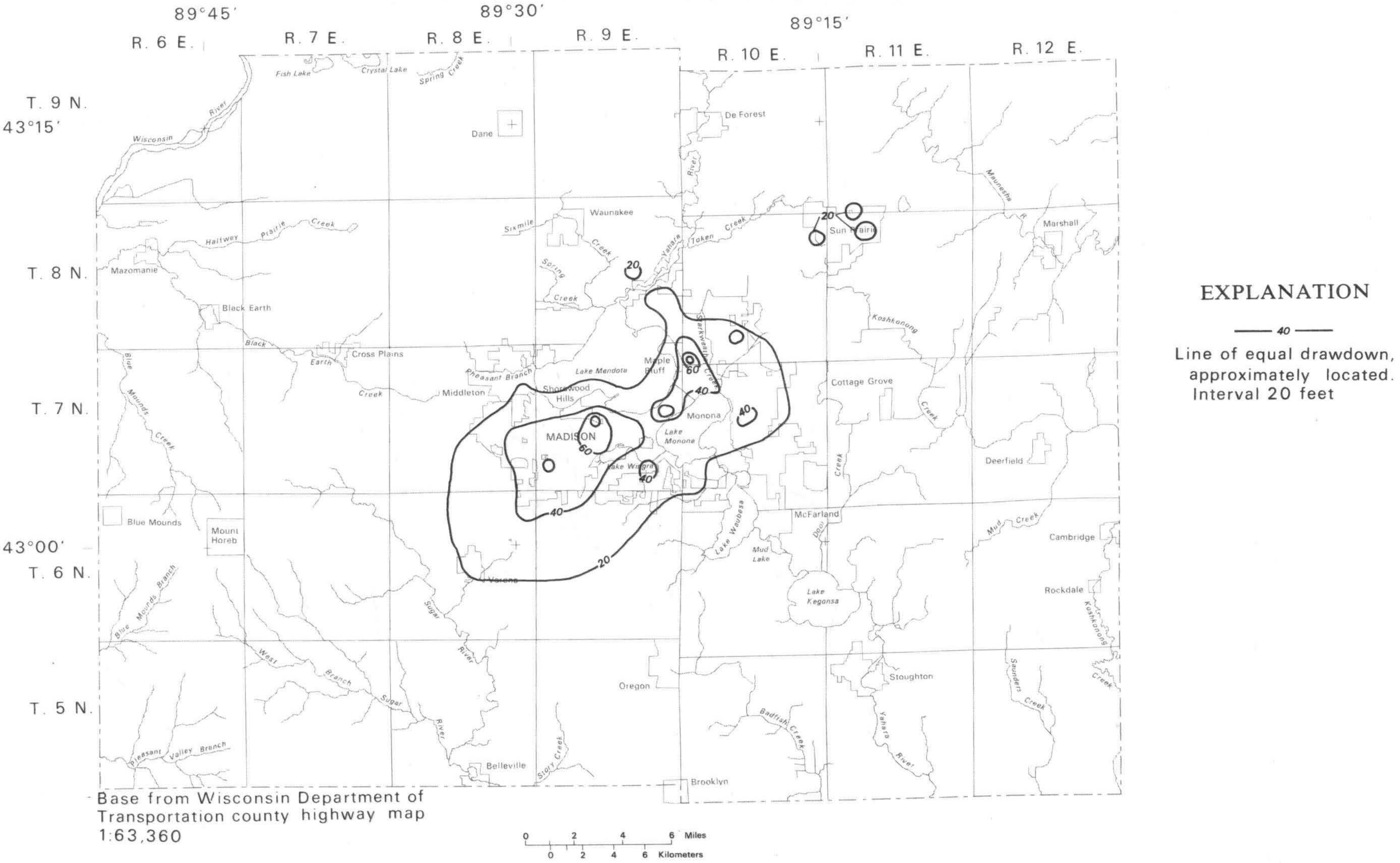
Figure 21. Estimated pumpage from the sandstone aquifer by 1990.

Regional steady-state drawdowns in the sandstone aquifer for 1980 and 1990 were computed by running the model twice, once using pumpages for 1980 and once using pumpages for 1990. The computed 1980 and 1990 drawdowns are shown in figures 22 and 23, respectively.

Computed 1980 and 1990 drawdowns reflect the same general northeast-southwest trend as 1970 drawdowns. Maximum drawdowns continued to occur to the east and south of Lake Mendota and on the southwest side of Madison. Drawdowns in these areas by 1990 ranged from 40 to 80 feet (12.2 to 24.4 m). This would represent an increase over 1970 drawdowns of 10-20 feet (3.0 to 6.1 m) to the east and south of Lake Mendota and 20-40 feet (6.1 to 12.2 m) on the southwest side of Madison. (Compare figs. 19 and 22.)

These drawdowns could eliminate the potentiometric divide between the Yahara and Sugar River basins in the area of the hydrologic section (fig. 14) by 1990. This would result in the capture of additional ground water by the Yahara River that normally discharged from the sandstone aquifer to the Sugar River. Additional ground water also would be captured from the Maunesha River by 1990 because of a northwest migration of the potentiometric divide between the Yahara and Maunesha Rivers.

The estimated 1980 and 1990 pumpages represent only one of many possible courses that development of the sandstone aquifer may take in future years. These estimates represent, however, one of the more likely courses to be followed if current development trends continue.



Base from Wisconsin Department of Transportation county highway map 1:63,360

EXPLANATION

—— 40 —— Line of equal drawdown, approximately located. Interval 20 feet

Figure 22. Computed drawdowns in the sandstone aquifer by 1980.

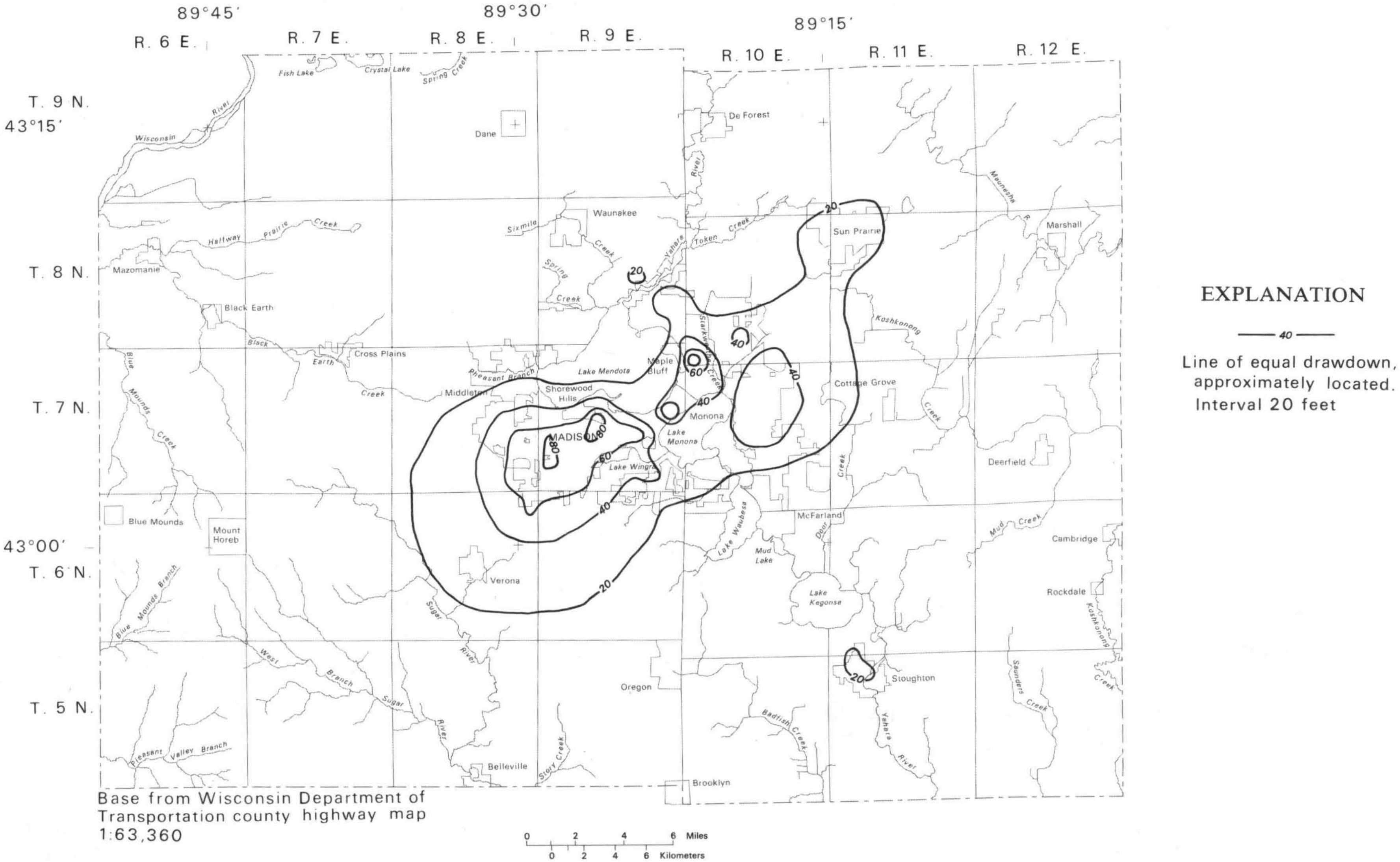


Figure 23. Computed drawdowns in the sandstone aquifer by 1990.

SUMMARY AND CONCLUSIONS

A digital-computer program was developed to solve confined ground-water flow problems. The program uses the iterative alternating-direction, implicit technique for solving a set of finite-difference approximations to the partial-differential equation governing two-dimensional flow in a confined aquifer. The program computes head changes in the confined aquifer. It also computes changes in the rate and volume of water withdrawn from constant-head boundaries and leaky confining beds.

The program was used to model the sandstone aquifer underlying Dane County, Wis., as a confined aquifer overlain by leaky confining beds. Observed drawdowns in the aquifer system indicated that flow in the system could be approximated by horizontal flow in the sandstone aquifer, supplemented by leakage from the upper aquifer. The physical properties of the aquifer system needed for the model were approximated by aquifer-test data and by matching measured 1970 drawdowns with 1970 drawdowns computed by the model.

The model was used to compute 1980 and 1990 drawdowns in the aquifer. The 1980 and 1990 pumping rates were estimated by an arithmetic projection of the past pumping trend of each ground-water user to 1990. These pumping rates were distributed in the model according to the likely course that aquifer development would take if current development trends continue.

The sandstone aquifer should be able to supply the water needs of the county well beyond the projected 1990 demands. Drawdowns of 40 feet or less could be expected between 1970 and 1990 if the estimated development trend is accurate. This amount of additional drawdown would not seriously deplete the ground-water supply. However, pump settings in some wells in the Madison area may have to be lowered if the wells are to meet their estimated 1990 pumpage rates.

The confined-aquifer model can be used to guide future ground-water development of the sandstone aquifer. The hydrologic consequences of alternate development plans can be computed by the model, thus aiding efficient development of the aquifer.

REFERENCES CITED

Alden, W.C., 1918, The Quaternary geology of southeastern Wisconsin: U.S. Geol. Survey Prof. Paper 106, 355 p.

Bredehoeft, J.D., and Pinder, G.F., 1970, Digital analysis of areal flow in multiaquifer ground water systems: A quasi three-dimensional model: Water Resources Research, v. 6, no. 3, p. 883-888.

Cline, D.R., 1965, Geology and ground-water resources of Dane County, Wisconsin: U.S. Geol. Survey Water-Supply Paper 1779-U, 64 p.

DeWiest, R.J.M., 1965, Geohydrology: New York, John Wiley and Sons, 366 p.

Hantush, M.S., 1964, Hydraulics of wells, in Advances in hydroscience, v. 1: New York, Academic Press, p. 281-432.

Jenkins, C.T., 1963, Graphical multiple-regression analysis of aquifer tests: U.S. Geol. Survey Prof. Paper 475-C, p. C198-C201.

Lohman, S.W., and others, 1972, Definitions of selected ground-water terms--revisions and conceptual refinements: U.S. Geol. Survey Water-Supply Paper 1988, 21 p.

Pinder, G.F., 1970, An iterative digital model for aquifer evaluation: U.S. Geol. Survey open-file report, 44 p.

Uttormark, P.D., Nunnelee, L.J., and Utter, L.C., 1969, Selected water resources index for Wisconsin: Wisconsin Univ., Water Resources Center, 202 p.

von Rosenberg, D.U., 1969, Methods for the numerical solution of partial differential equations: New York, Am. Elsvier Pub. Co., 128 p.

Weidman, Samuel, and Schultz, A.R., 1915, The underground and surface water supplies of Wisconsin: Wisconsin Geol. and Nat. History Survey Bull. 35, 664 p.

APPENDIX

Preparation of Input Data

Input data for the digital-computer program are on the parameter cards and the aquifer data decks. The parameter cards contain data used to control computations and printouts from the program. The aquifer data decks contain data on the size of grid elements used in the model, physical properties of the aquifer system modeled, and pumping rates from the aquifer system.

The inconsistent gallon-foot-day system of units is used with the program. The user must be careful to conform to this measurement system when coding parameter cards and aquifer data decks.

Twelve parameter cards must be coded for the model. Table 3 outlines the input data required on the parameter cards and the coding used to prepare the cards. Table 4 aids in determining input data for the parameter cards. Table 4 is based on the formula:

$$\text{SUM} = \text{DELT}\ (1.5^1 + 1.5^2 + 1.5^3 + \ldots\ldots\ldots + 1.5^{KT}) \qquad (7)$$

where: SUM = period of time through which the computations have advanced,

KT = the number of time steps through which the computations have advanced, and

DELT = length of initial time step.

Examples of coded parameter cards are shown by figure 24.

A maximum of eight aquifer data decks can be coded for the program; a minimum of four decks must be coded (fig. 4). Table 5 outlines the input data contained in the aquifer data decks and the coding used to prepare the decks.

Table 3.--Preparation of parameter data cards.

Input Parameter	Card no.	Column nos.	Format Specification	Program variable name	Remarks
Program title	1	1-80	A [1]	HEADNG	Up to 131 spaces may be used in a program title. The title is printed as one line of output.
	2	1-51	A		
Length of pumping period.		1-10	F [2]	TMAX	The period of time to be covered for a nonsteady-state analysis is recorded. SUM in equation (7) equals TMAX at the end of the computations. Assign TMAX any value less than DELT for steady-state runs (see coding for parameter card no. 7).
Number of elements in a column of the finite-difference grid.		11-20	I [3]	DIML	The maximum permitted number of elements for columns is 50.
Number of elements in a row of the finite-difference grid.		21-30	I	DIMW	The maximum permitted number of elements for rows is 55.
Maximum permitted number of time steps.		31-40	I	NUMT	The number of time steps to be used for a nonsteady-state analysis. KT in equation (7) equals NUMT at the end of the computations. NUMT and DELT (see parameter card no. 7) must be chosen simultaneously. Assign NUMT a value of one for steady-state runs.

Table 3.-Continued.

Input Parameter	Card no.	Column nos.	Format Specification	Program variable name	Remarks
Maximum permitted number of iterations per time step.	3	41-50	I	ITMAX	Row and column computations should converge to a solution within 100 iterations for most problems. The diagnostic EXCEEDED PERMITTED NUMBER OF ITERATIONS is printed and the run is terminated if the specified value is exceeded. Computed head changes and the variables SUM, CØNET, PUMPT, DELQT, DIFFT, and DELT at that iteration are provided as punched output for a possible later run. Nonconvergence generally results when a mistake in the input data makes a solution impossible.
Number of time steps between printouts.		51-60	I	KTH	KTH can range from 1 to NUMT if KTH = 1, then NUMT printouts will be made. If KTH = NUMT, then only the final result will be printed.
Number of iteration parameters.		61-70	I	LENGTH	Three to seven parameters generally result in reasonable convergence rates.
Closure error for acceptable solution.		71-80	F	ERR	A closure error of 0.001 to 0.01 foot (0.03048 to 0.3048 centimeters) between row and column computations generally gives a good solution.
Conversion factor for system of measurement units.		1-10	F	FUDGE	FUDGE is assigned a value of 7.48. This factor allows for the use of the inconsistent gallon-foot-day system of units with the program.

Table 3.-Continued.

Input Parameter	Card no.	Column nos.	Format Specification	Program variable name	Remarks
Multiplier for transmissivity values coded in aquifer data deck no. 2	4	11-20	F	FACT	Multipliers provided for aquifer data decks 2 through 7 to reduce the number of numerical characters that must be recorded in these decks. Example: Assume pumpages are recorded in aquifer data deck no. 4 in M gal/day. The multiplication factor FACPP must be assigned a value of 1000000.0. Aquifer data decks 5,6, and 7 may be omitted by assigning values of -1.0 to the appropriate multipliers (also see table 5). Assign FACTØR a value of 0.0 if aquifer data deck no. 5 is used only to identify recharge boundaries.
Multiplier for storage coefficient values coded in aquifer data deck no. 3.		21-30	F	FACS	
Multiplier for pumpage values coded in aquifer data deck no. 4.		31-40	F	FACPP	
Multiplier for saturated thickness values coded in aquifer data deck no. 5.		41-50	F	FACTØR	
Multiplier for hydraulic conductivity values coded in aquifer data deck no. 6		51-60	F	FACH	
Multiplier for specific storage values coded in aquifer data deck no. 7		61-70	F	FACSS	

Table 3.-Continued.

Input Parameter	Card no.	Column nos.	Format Specification	Program variable name	Remarks
Numerical interval for alphameric printout of computed head changes.		71-80	F	SPACNG	The interval between numerical values for a coded alphameric printout of computed head changes is specified. Leave this space blank if such a printout is not desired (also see parameter card no. 9).
Numerical interval for alphameric printout of transmissivity values.	5	1-10	F	SPACT	The interval between numerical values for alphameric printouts of the physical properties of the aquifer system that are included as aquifer data decks in the analysis must be specified, otherwise leave the appropriate spaces blank. There will be an alphameric printout for each of the physical properties of the aquifer system that are included in the analysis.
Numerical interval for alphameric printout of storage coefficient values.		11-20	F	SPACS	
Numerical interval for alphameric printout of saturated thickness values.		21-30	F	SPACR	
Numerical interval for alphameric printout of hydraulic conductivity values for confining beds.		31-40	F	SPACV	
Numerical interval for alphameric printout of specific storage values for confining beds.		41-50	F	SPACSS	

Table 3.-Continued.

Input Parameter	Card no.	Column nos.	Format Specification	Program variable name	Remarks
Duration of pumping since start of computations.	6	1-20	E [4]	SUM	Each of these variables is assigned a value of 0.0 for the initial run. New values are provided as punched output for successive runs, if punched output is requested (see parameter card no. 8).
Volume of cone of depression since start of computations.		21-40	E	CØNET	
Volume of water pumped since start of computations.		41-60	E	PUMPT	
Volume of induced leakage since start of computations.		61-80	E	DELQT	
Cumulative residual error in mass balance analysis at start of computations.	7	1-20	E	DIFFT	Assigned a value of 0.0 for the initial run. A new value is provided as punched output for successive runs, if punched output is requested (see parameter card no. 8).
Length of time step at start of computations.		21-40	D [4]	DELT	<u>Nonsteady-state runs</u>: Divide TMAX by the value from column (2) of Table (4) that is opposite the number of time steps (NUMT) chosen for the analysis (column 1) to obtain DELT. Smaller values of DELT give more accurate results. Values of 10^{-4} to 10^{-5} days have been satisfactory for most problems.

Table 3.-Continued.

Input Parameter	Card no.	Column nos.	Format Specification	Program variable name	Remarks
					Cont'd. Steady-state runs: Assign DELT any value that is great enough to assure steady-state conditions in the aquifer. Steady-state conditions can be checked by comparing the computed rate of induced leakage (see parameter card no. 12) with the net pumping rate from the confined aquifer. A new value of DELT is provided as punched output for successive runs, if punched output is requested.
Indicator for punched output of computed head changes.	8	1-5	A	PNCH	Punch the variable name PUNCH on this card if punched output is desired at the end of the run, otherwise leave this card blank. Punched output would include computed head changes and computed values of SUM, C0NET, PUMPT, DELQT, DIFFT, and DELT at the end of the run.
Indicator for alphameric printout of computed head changes.	9	1-7	A	C0NTR	Punch the variable name C0NT0UR on this card if a coded alphameric printout of computed head changes is desired, otherwise leave this card blank.[5/]
Indicator for numerical printout of computed head changes.	10	1-7	A	NUM	Punch the variable name NUMERIC on this card if a numerical printout of computed head changes is desired, otherwise leave this card blank.[5/]

Table 3.-Continued.

Input Parameter	Card no.	Column nos.	Format Specification	Program variable name	Remarks
Indicator for printout of mass balance computations.	11	1-5	A	CHCK	Punch the variable name CHECK on this card if a printout of mass balance computations is desired, otherwise leave this card blank.[5]
Indicator for numerical printout of induced leakage rates from confining beds and fully penetrating streams.	12	1-6	A	FLØW	Punch the variable name LEAKAGE on this card if a numerical printout of induced leakage rates is desired, otherwise leave this card blank.[5]

1. Alphameric characters appearing anywhere in the field specified by the column numbers will be assigned to the program variable name.

2. The number appearing in the field specified by the column numbers will be assigned to the program variable name. A decimal point must be included in the number.

3. The number appearing in the field specified by the column numbers will be assigned to the program variable name. The number must be right justified and cannot include a decimal point.

4. This format is used to record very large or very small numbers in the specified field making use of scientific notation. For example, 0.00011 could be punched as 1.1E-04. The letter D is used in place of an E to specify double precision. The last digit to the right of the E or D must end in the last column of the field.

5. This printout will occur at the interval specified by the program variable KTH.

Table 4.--Table used to compute length of initial time step for nonsteady-state runs.

Number of time steps (KT or NUMT)	$(1.5^1 + 1.5^2 + \ldots + 1.5^{KT})$	Number of time steps (KT or NUMT)	$(1.5^1 + 1.5^2 + \ldots + 1.5^{KT})$
Column 1	Column 2	Column 1	Column 2
1	1.5000 + 00	51	2.8693 + 09
2	3.7500 + 00	52	4.3039 + 09
3	7.1250 + 00	53	6.4559 + 09
4	1.2188 + 01	54	9.6839 + 09
5	1.9781 + 01	55	1.4526 + 10
6	3.1172 + 01	56	2.1789 + 10
7	4.8258 + 01	57	3.2683 + 10
8	7.3887 + 01	58	4.9025 + 10
9	1.1233 + 02	59	7.3537 + 10
10	1.7000 + 02	60	1.1031 + 11
11	2.5649 + 02	61	1.6546 + 11
12	3.8624 + 02	62	2.4819 + 11
13	5.8086 + 02	63	3.7228 + 11
14	8.7279 + 02	64	5.5842 + 11
15	1.3107 + 03	65	8.3763 + 11
16	1.9675 + 03	66	1.2564 + 12
17	2.9528 + 03	67	1.8847 + 12
18	4.4307 + 03	68	2.8270 + 12
19	6.6475 + 03	69	4.2405 + 12
20	9.9728 + 03	70	6.3608 + 12
21	1.4961 + 04	71	9.5411 + 12
22	2.2442 + 04	72	1.4312 + 13
23	3.3665 + 04	73	2.1468 + 13
24	5.0499 + 04	74	3.2201 + 13
25	7.5750 + 04	75	4.8302 + 13
26	1.1363 + 05	76	7.2453 + 13
27	1.7044 + 05	77	1.0868 + 14
28	2.5567 + 05	78	1.6302 + 14
29	3.8350 + 05	79	2.4453 + 14
30	5.7525 + 05	80	3.6679 + 14
31	8.6288 + 05	81	5.5019 + 14
32	1.2943 + 06	82	8.2529 + 14
33	1.9415 + 06	83	1.2379 + 15
34	2.9122 + 06	84	1.8569 + 15
35	4.3683 + 06	85	2.7853 + 15
36	6.5525 + 06	86	4.1780 + 15
37	9.8287 + 06	87	6.2670 + 15
38	1.4743 + 07	88	9.4005 + 15
39	2.2115 + 07	89	1.4101 + 16
40	3.3172 + 07	90	2.1151 + 16
41	4.9758 + 07	91	3.1727 + 16
42	7.4637 + 07	92	4.7590 + 16
43	1.1196 + 08	93	7.1385 + 16
44	1.6793 + 08	94	1.0708 + 17
45	2.5190 + 08	95	1.6062 + 17
46	3.7785 + 08	96	2.4093 + 17
47	5.6677 + 08	97	3.6139 + 17
48	8.5016 + 08	98	5.4208 + 17
49	1.2752 + 09	99	8.1312 + 17
50	1.9129 + 09	100	1.2197 + 18

Table 5.--Preparation of aquifer data decks.

Input Data	Aquifer data deck no.	Maximum no. of cards	Format for editing code	Program variable name	Remarks
Width of rectangular grid elements.	1	7	8F10.4	DELX(J)	Record width of each grid element going from left to right across the grid. There can be a maximum of 55 values.[1]
Length of rectangular grid elements.		7	8F10.4	DELY(I)	Record the length of each grid element going down the grid. There can be a maximum of 50 values.[1]
Transmissivity values and location of barrier boundaries for confined aquifer.	2	150	20F4.0	T(I,J)	Record transmissivity values divided by the multiplier FACT.[2] Transmissivity values of 0.0 are recorded wherever a barrier boundary occurs. Values of 0.0 must be assigned to the first and last rows and columns of the grid to conform to the computational scheme.
Storage coefficient values for confined aquifer.	3	150	20F4.0	S(I,J)	Record storage coefficient values divided by the multiplier FACS.[2]
Artificial recharge or withdrawal rates for confined aquifer.	4	150	20F4.0	PUMP(I,J)	Record recharge and withdrawal rates divided by the multiplier FACPP.[2] Recharge is recorded as negative values, withdrawals are recorded as positive values.
Saturated thickness values for confining beds and location of becharge boundaries for confined aquifer.	5	150	20F4.0	RATE(I,J)	Record saturated thickness values of confining beds divided by the multiplier FACTØR.[2] Record values of -1.0 wherever a recharge boundary occurs. Omit this deck if FACTØR is assigned a value of -1.0 in the parameter cards.

Table 5.-Continued

Input Data	Aquifer data deck no.	Maximum no. of cards	Format for editing	Program variable name	Remarks
Hydraulic conductivity values for confining beds.	6	150	20F4.0	HYCOND (I,J)	Record hydraulic conductivity values for confining beds divided by the multiplier FACH.[2] Omit this deck if FACH is assigned a value of -1.0 in the parameter cards.
Specific storage values for confining beds.	7	150	20F4.0	SS(I,J)	Record specific storage values for confining beds divided by the multiplier FACSS.[2] Omit this deck if FACSS is assigned a value of -1.0 in the parameter cards.
Head changes computed by an earlier run.	8	350	8F10.4	PHI(I,J)	This deck is omitted in the initial run but can be provided as punched output to continue the computations in later runs (see parameter card no. 8).

1. Eight values are recorded per card (columns 1-10, 11-20, ..., 71-80).

2. Twenty values are recorded per card (columns 1-4, 5-8, 9-12, ..., 77-80). Record values left to right along rows beginning with the first row. Begin each row with a new card.

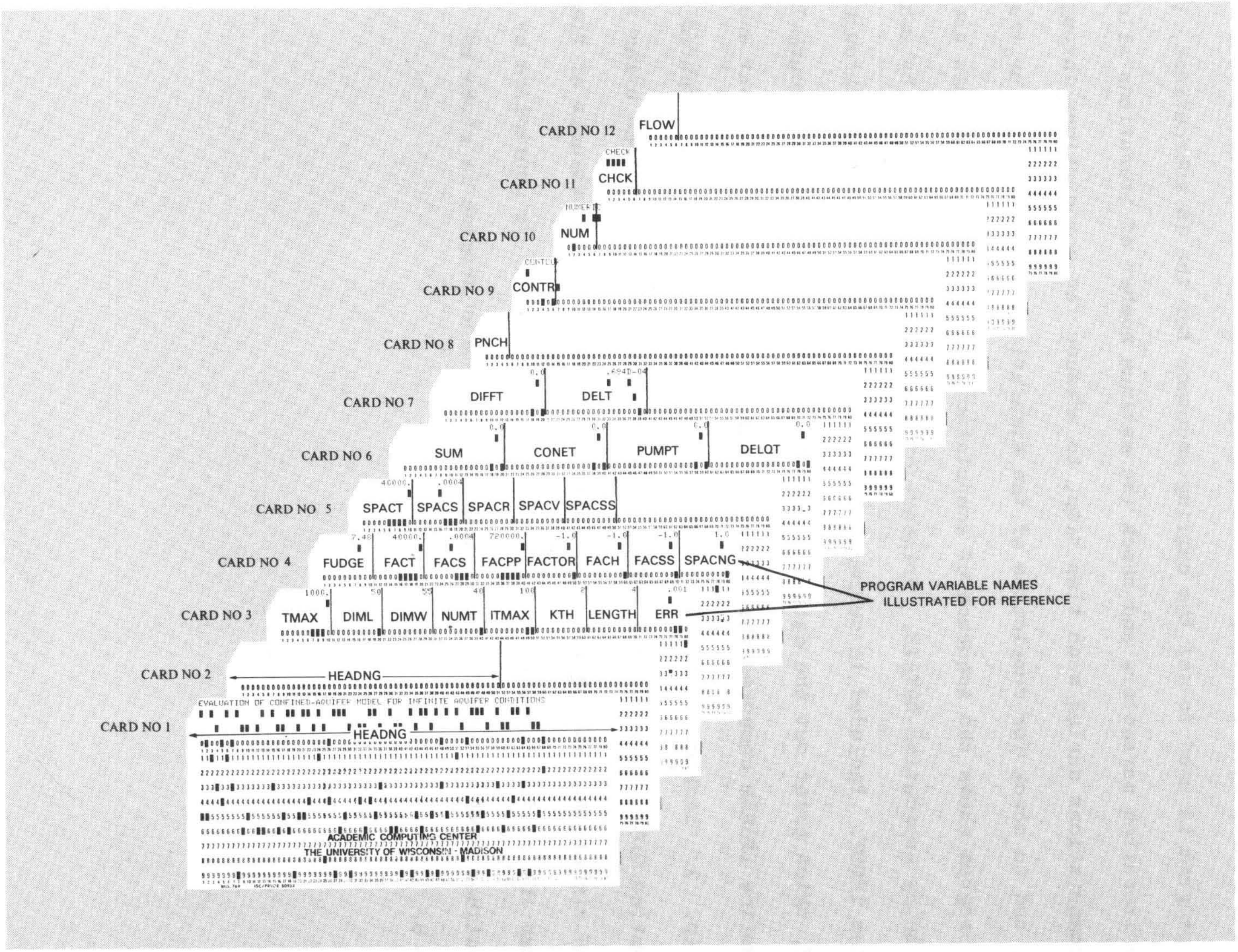


Figure 24. Parameter data cards for the digital computer program.

Description of Source Deck

The source deck consists of a main program and 16 subroutines. The main program is used to set the calling sequence for the 16 subroutines, to cycle iteration parameters and check the maximum number of iterations allowed for computations during each time step, to advance the computations through time, and to check for completion of the simulation. A flow chart for the main program shows the sequence of computations (fig. 25). Input data are read in by subroutine DATAIN. Printout of input data is controlled by subroutine INØUT. Included in subroutine INØUT are subroutines PRNTA through PRNTF, which print out the data included in aquifer data decks 2 through 7. Subroutine IPARAM computes the iteration parameters for equations (5a) and (5b) (p.). Leakage coefficient values for these equations are computed in subroutine CLAY. Subroutines ROW and COLUMN solve these equations using the Thomas algorithm. Subroutine CHECK then computes rates and volumes of flow through the confined aquifer. Printout of the solutions is controlled by subroutines PRNT1 to PRNT3. A listing of the source program is given in Table 6.

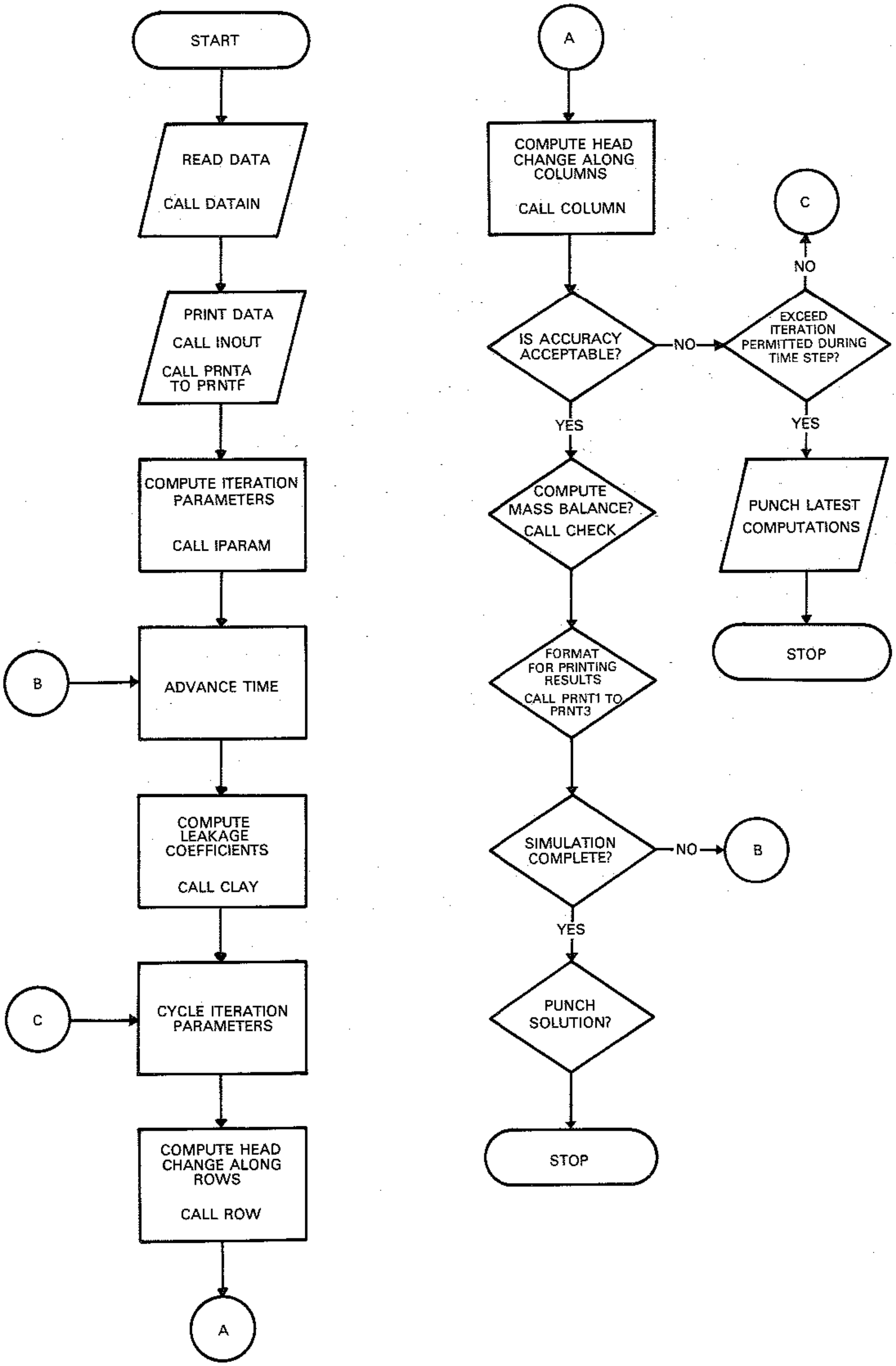


Figure 25. Flow chart for the main program.

Table 6.--Source program listing.

```
C     *********************************************************************
C
C     PURPOSE
C       TO COMPUTE THE DRAWDOWN IN A CONFINED AQUIFER AFTER DESIGNATED
C       PERIODS OF TIME
C
C     METHOD
C       THE ITERATIVE ALTERNATING DIRECTION IMPLICIT PROCEDURE IS USED
C       TO SOLVE THE DIFFERENTIAL EQUATIONS
C
C     PROGRAMMED BY G. F. PINDER - VERSION 5, SEPT. 1, 1970
C     REVISED BY R.S. MCLEOD  MARCH 1, 1972
C
C     .....................................................................
C     .                        TABLE OF CONTENTS                          .
C     .            SUBPROGRAM NO.                  NAME                   .
C     .                  1                         DATAIN                 .
C     .                  2                         INOUT                  .
C     .                  3                         IPARAM                 .
C     .                  4                         CLAY                   .
C     .                  5                         ROW                    .
C     .                  6                         COLUMN                 .
C     .                  7                         CHECK                  .
C     .                  8                         PRNT1                  .
C     .                  9                         PRNT2                  .
C     .                 10                         PRNT3                  .
C     .                 11                         PRNTA                  .
C     .                 12                         PRNTB                  .
C     .                 13                         PRNTC                  .
C     .                 14                         PRNTD                  .
C     .                 15                         PRNTE                  .
C     .                 16                         PRNTF                  .
C     .....................................................................
C
C
C     DESCRIPTION OF INPUT PARAMETERS (GALLON-DAY-FOOT SYSTEM OF UNITS)
C
C     CHCK=INDICATOR FOR MASS BALANCE CHECK OF COMPUTATIONS
C     CONET=VOLUME OF CONE OF DEPRESSION AT START OF COMPUTATIONS
C           (GALLONS)
C     CONTR=INDICATOR FOR ALPHAMERIC PRINTOUT OF COMPUTED DRAWDOWNS
C     DELQT=CUMULATIVE VOLUME OF INDUCED LEAKAGE AT START OF
C           COMPUTATIONS (GALLONS)
C     DELT=LENGTH OF INITIAL TIME STEP (DAYS)
C     DELX=DISTANCE BETWEEN NODES IN THE PROTOTYPE IN THE X DIRECTION
C          (FEET)
C     DELY=DISTANCE BETWEEN NODES IN THE PROTOTYPE IN THE Y DIRECTION
C          (FEET)
C     DIFFT=CUMULATIVE RESIDUAL ERROR AT START OF COMPUTATIONS
C           (GALLONS)
C     DIML=NUMBER OF NODES IN COLUMN OF MATRIX
C     DIMW=NUMBER OF NODES IN ROW OF MATRIX
C     ERR=CLOSURE ERROR FOR ITERATION (FEET)
C     FACH=MULTIPLICATION FACTOR FOR VERTICAL HYDRAULIC CONDUCTIVITY
```

Table 6.-Continued.

```
C              VALUES OF LEAKY CONFINING BEDS
C         FACPP=MULTIPLICATION FACTOR FOR PUMPAGE VALUES
C         FACS=MULTIPLICATION FACTOR FOR STORAGE COEFFICIENT VALUES
C         FACSS=MULTIPLICATION FACTOR FOR SPECIFIC STORAGE VALUES OF
C               LEAKY CONFINING BEDS
C         FACT=MUTIPLICATION FACTOR FOR TRANSMISSIVITY VALUES
C         FACTOR=MULTIPLICATION FACTOR FOR SATURATED THICKNESS VALUES
C                OF LEAKY CONFINING BEDS
C         FLOW=INDICATOR FOR NUMERICAL PRINTOUT OF INDUCED LEAKAGE FROM
C              CONFINING BEDS AND/OR FULLY PENETRATING STREAMS
C         FUDGE=CONVERSION FACTOR BETWEEN GALLONS AND CUBIC FEET
C               (7.48 GALLONS PER CUBIC FOOT)
C         HEADNG=ANY HEADING OF INTEREST TO USER-DO NOT EXCEED
C                131 CHARACTERS
C         HYCOND(I,J)=VERTICAL HYDRAULIC CONDUCTIVITY OF LEAKY
C                     CONFINING BEDS (GPD/SQ.FT.)
C         ITMAX=MAXIMUM PERMITTED NUMBER OF ITERATIONS PER TIME STEP
C         KTH=NUMBER OF TIME STEPS BETWEEN PRINTOUTS
C         LENGTH=NUMBER OF ITERATION PARAMETERS
C         NUM=INDICATOR FOR NUMERICAL PRINTOUT OF DRAWDOWN
C         NUMT=MAXIMUM NUMBER OF TIME STEPS
C         PHI(I,J)=DRAWDOWN (NEGATIVE) OR RISE (POSITIVE) IN POTENTIOMETRIC
C                  SURFACE OF THE AQUIFER AT START OF EACH TIME STEP (FEET)
C         PNCH=INDICATOR FOR PUNCHED OUTPUT OF COMPUTED DRAWDOWNS
C         PUMP(I,J)=PUMPAGE FROM AQUIFER (GPD)-POSITIVE FOR
C                   DISCHARGE WELL,NEGATIVE FOR RECHARGE WELL
C         PUMPT=VOLUME OF WATER PUMPED AT START OF COMPUTATIONS
C               (GALLONS)
C         RATE(I,J)=SATURATED THICKNESS OF LEAKY CONFINING BEDS (FEET)
C         S(I,J)=STORAGE COEFFICIENT (DIMENSIONLESS)
C         SPACNG=SPACING FOR ALPHAMERIC PRINTOUT OF COMPUTED DRAWDOWNS
C         SPACR=SPACING FOR ALPHAMERIC PRINTOUT OF SATURATED THICKNESS
C               VALUES OF LEAKY CONFINING BEDS
C         SPACS=SPACING FOR ALPHAMERIC PRINTOUT OF STORAGE COEFFICIENT
C               VALUES
C         SPACSS=SPACING FOR ALPHAMERIC PRINTOUT OF SPECIFIC STORAGE VALUES
C                OF LEAKY CONFINING BEDS
C         SPACT=SPACING FOR ALPHAMERIC PRINTOUT OF TRANSMISSIVITY VALUES
C         SPACV=SPACING FOR ALPHAMERIC PRINTOUT OF VERTICAL HYDRAULIC
C               CONDUCTIVITY VALUES OF LEAKY CONFINING BEDS
C         SS(I,J)=SPECIFIC STORAGE OF LEAKY CONFINING BEDS (1/FEET)
C         SUM=DURATION OF PUMPING (DAYS)
C         T(I,J)=TRANSMISSIVITY (GPD/FT.)
C         TMAX=MAXIMUM ALLOTTED PERIOD FOR PUMPING (DAYS)
C
C         ..................................................................
          INTEGER DIML,DIMW
          REAL*8 KEEP,IMK
          REAL NUM,MINS
          DIMENSION S(50,55),RATE(50,55),KEEP(50,55),G(55),TEMP(55),BE(55),
         1RHOP(25),CHK(5),T(50,55),PHI(50,55),PUMP(50,55),DELX(55),DELY(50),
         2SYM(39),QCOEF(50,55),HEADNG(33),HYCOND(50,55),SS(50,55),PRNT(55),
         3BLANK(60),DDN(55),DELQ(50,55)
          DOUBLE PRECISION PHI,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,DELT,
```

Table 6.-Continued.

```
     1RHOP,PARAM
      COMMON /INTEGR/ DIML,DIMW,NUMT,LENGTH,ITMAX,INO1,JNO1,KTH
      COMMON /SINGLE/ SUM,DELX,DELY,RATE,S,SPACNG,T,FUDGE,PUMP,FACTOR,
     1ERR,FACS,FACT,TMAX,TEST,CHK,PNCH,CONTR,NUM,QCOEF,SS,TT,HYCOND,
     2HEADNG,FACH,FACSS,FACPP,CHCK,SPACR,SPACT,SPACS,SPACV,SPACSS,FLOW
      COMMON /DOUBLE/ PHI,KEEP,DELT,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,
     1RHOP,PARAM,IMK
      COMMON /CHKWRT/ CONET,PUMPT,DELQT,DIFF,DIFFT,DELQ,DELQR
      COMMON /PRNTOT/ SYM,PRNT,BLANK,DDN
      DIMENSION ASTRIX(50)
      DATA ASTRIX/50*1H*/
C     *******************************************************************
C
C       READ INPUT DATA
C
C     *************
      CALL DATAIN
C     *************
C
C       PRINT INPUT DATA
C
C     *************
      CALL INOUT
C     *************
C
C       COMPUTE ITERATION PARAMETERS
C
C     *************
      CALL IPARAM
C     *************
C
      KT=0
      TEST=0
      JNO1=DIMW-1
      INO1=DIML-1
   10 IF(TEST.EQ.0) GO TO 50
C
C       TEST FOR MAXIMUM PERMITTED NO. OF ITERATIONS PER TIME STEP
C
      IF(KOUNT.LT.ITMAX) GO TO 20
      WRITE (6,170)
      GO TO 60
C
C       CYCLE ITERATION PARAMETERS
C
   20 KOUNT=KOUNT+1
      IF(MOD(KOUNT,LENGTH))30,30,40
   30 NTH=0
   40 NTH=NTH+1
      PARAM=RHOP(NTH)
      TEST=0.
C
C       COMPUTE IMPLICITLY ALONG ROWS
C
```

Table 6.-Continued.

```
C     *************
      CALL ROW
C     *************
C
C         COMPUTE IMPLICITLY ALONG COLUMNS
C
C     *************
      CALL COLUMN
C     *************
C
      GO TO 10
C
C         ADJUST FOR NEW TIME STEP
C
   50 IFINAL=0
      IF((CHCK.EQ.CHK(4).OR.FLOW.EQ.CHK(5)).AND.KT.NE.0) CALL CHECK
      IF(KT.GT.NUMT.OR.SUM.GT.TMAX) IFINAL=1
      IF((MOD(KT,KTH).NE.0.OR.KT.EQ.0).AND.IFINAL.NE.1) GO TO 80
      WRITE (6,180) KT,DELT,SEC,MINS,HRS,SUM,KOUNT,TT
      IF(CONTR.EQ.CHK(2)) CALL PRNT2
      IF(NUM.EQ.CHK(3)) CALL PRNT1
      IF(FLOW.EQ.CHK(5)) CALL PRNT3
      IF(CHCK.EQ.CHK(4)) WRITE (6,120) DIFF,DIFFT,CONET,PUMPT,DELQT
      WRITE (6,130) ASTRIX
      IF(IFINAL.NE.1) GO TO 80
      IF(PNCH.NE.CHK(1)) STOP
   60 DO 70 I=1,DIML
   70 WRITE (1,150) (PHI(I,J),J=1,DIMW)
      WRITE(1,140) SUM,CONET,PUMPT,DELQT,DIFFT,DELT
      STOP
   80 CONTINUE
      KT=KT+1
      KOUNT=0
      DO 90 I=1,DIML
      DO 90 J=1,DIMW
   90 KEEP(I,J)=PHI(I,J)
  100 CONTINUE
  110 DELT=1.5*DELT
      SUM=SUM+DELT
C
C         COMPUTE COEFFICIENT OF VERTICAL LEAKAGE FOR CONFINING BEDS
C
C     *********
      CALL CLAY
C     *********
C
      HRS=SUM*24.
      MINS=HRS*60.
      SEC=MINS*60.
      GO TO 30
C
C     ******************************************************************
C
  120 FORMAT(1H1,///,51X,29HINFORMATION FROM MASS BALANCE//50X,21HMASS B
```

Table 6.-Continued

```
     1ALANCE RESIDUAL1PE11.3/50X,19HCUMULATIVE RESIDUAL1PE11.3/50X,28HVO
     2LUME OF CONE OF DEPRESSION1PE11.3/50X,18HCUMULATIVE PUMPING1PE11.3
     3/50X,26HCUMULATIVE INDUCED LEAKAGE1PE11.3)
 130 FORMAT(1H ,15X,50A2)
 140 FORMAT(4E20.10/E20.10,D20.10)
 150 FORMAT(8E10.3)
 170 FORMAT(1H0,39HEXCEEDED PERMITTED NUMBER OF ITERATIONS)
 180 FORMAT(1H1,55X,17HTIME STEP NUMBER ,I10/49X,26HSIZE OF TIME STEP I
     1N DAYS ,E10.3/40X,48HDURATION OF PUMPING AT THIS PRINTOUT IN SECON
     2DS ,E10.3/80X,8HMINUTES ,E10.3/80X,6HHOURS ,E10.3/80X,5HDAYS ,E10.
     33/56X,17HITERATION NUMBER ,I10/45X,26HMAXIMUM DIMENSIONLESS TIME,1
     4PE10.3)
      END
```

Table 6.-Continued.

```
      SUBROUTINE DATAIN
C     SUBPROGRAM NO. 1
C     ****************************************************************
      INTEGER DIML,DIMW
      REAL*8 KEEP,IMK
      REAL NUM
      DIMENSION S(50,55),RATE(50,55),KEEP(50,55),G(55),TEMP(55),BE(55),
     1RHOP(25),CHK(5),T(50,55),PHI(50,55),PUMP(50,55),DELX(55),DELY(50),
     2SYM(39),QCOEF(50,55),HEADNG(33),HYCOND(50,55),SS(50,55),PRNT(55),
     3BLANK(60),DDN(55),DELQ(50,55)
      DOUBLE PRECISION PHI,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,DELT,
     1RHOP,PARAM
      COMMON /INTEGR/ DIML,DIMW,NUMT,LENGTH,ITMAX,INO1,JNO1,KTH
      COMMON /SINGLE/ SUM,DELX,DELY,RATE,S,SPACNG,T,FUDGE,PUMP,FACTOR,
     1ERR,FACS,FACT,TMAX,TEST,CHK,PNCH,CONTR,NUM,QCOEF,SS,TT,HYCOND,
     2HEADNG,FACH,FACSS,FACPP,CHCK,SPACR,SPACT,SPACS,SPACV,SPACSS,FLOW
      COMMON /DOUBLE/ PHI,KEEP,DELT,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,
     1RHOP,PARAM,IMK
      COMMON /CHKWRT/ CONET,PUMPT,DELQT,DIFF,DIFFT,DELQ,DELQR
      COMMON /PRNTOT/ SYM,PRNT,BLANK,DDN
C     ****************************************************************
C
C     PURPOSE--TO READ INPUT DATA
C
      READ(5,130) HEADNG
      READ(5,140) TMAX,DIML,DIMW,NUMT,ITMAX,KTH,LENGTH,ERR,
     1FUDGE,FACT,FACS,FACPP,FACTOR,FACH,FACSS,SPACNG
      READ(5,200) SPACT,SPACS,SPACR,SPACV,SPACSS
      READ(5,170) SUM,CONET,PUMPT,DELQT,DIFFT,DELT
      READ(5,160) PNCH,CONTR,NUM,CHCK,FLOW
      READ(5,190) (DELX(J),J=1,DIMW)
      READ(5,190) (DELY(I),I=1,DIML)
      DO 10 I=1,DIML
      READ(5,150) (T(I,J),J=1,DIMW)
      DO 10 J=1,DIMW
   10 T(I,J)=T(I,J)*FACT
      DO 20 I=1,DIML
      READ(5,150) (S(I,J),J=1,DIMW)
      DO 20 J=1,DIMW
   20 S(I,J)=S(I,J)*FACS
      DO 30 I=1,DIML
      READ(5,150) (PUMP(I,J),J=1,DIMW)
      DO 30 J=1,DIMW
   30 PUMP(I,J)=PUMP(I,J)*FACPP
      IF(FACTOR.LT.0.0) GO TO 50
      DO 40 I=1,DIML
      READ(5,150) (RATE(I,J),J=1,DIMW)
      DO 40 J=1,DIMW
      IF(RATE(I,J).LT.0.) QCOEF(I,J)=1.0E+07
   40 IF(RATE(I,J).GT.0) RATE(I,J)=RATE(I,J)*FACTOR
   50 IF(FACH.LT.0.0) GO TO 70
      DO 60 I=1,DIML
      READ(5,150) (HYCOND(I,J),J=1,DIMW)
      DO 60 J=1,DIMW
```

Table 6.-Continued.

```
   60 HYCOND(I,J)=HYCOND(I,J)*FACH
   70 IF(FACSS.LT.0.0) GO TO 90
      DO 80 I=1,DIML
      READ(5,150) (SS(I,J),J=1,DIMW)
      DO 80 J=1,DIMW
   80 SS(I,J)=SS(I,J)*FACSS
   90 IF(SUM.EQ.0.) GO TO 120
      DO 110 I=1,DIML
  110 READ(5,180) (PHI(I,J),J=1,DIMW)
  120 RETURN
C
C     ..................................................................
C
  130 FORMAT(20A4/20A4)
  140 FORMAT(F10.2,6I10,F10.2/8F10.2)
  150 FORMAT(20F4.0)
  160 FORMAT(A5/A6/A6/A5/A6)
  170 FORMAT(4E20.10/E20.10,D20.10)
  180 FORMAT(8E10.3)
  190 FORMAT(8F10.0)
  200 FORMAT(5F10.2)
      END
```

Table 6.-Continued.

```
      SUBROUTINE INOUT
C     SUBPROGRAM NO. 2
C     ****************************************************************
      INTEGER DIML,DIMW
      REAL*8 KEEP,IMK
      REAL NUM
      DIMENSION S(50,55),RATE(50,55),KEEP(50,55),G(55),TEMP(55),BE(55),
     1RHOP(25),CHK(5),T(50,55),PHI(50,55),PUMP(50,55),DELX(55),DELY(50),
     2SYM(39),QCOEF(50,55),HEADNG(33),HYCOND(50,55),SS(50,55),PRNT(55),
     3BLANK(60),DDN(55),DELQ(50,55)
      DOUBLE PRECISION PHI,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,DELT,
     1RHOP,PARAM
      COMMON /INTEGR/ DIML,DIMW,NUMT,LENGTH,ITMAX,INO1,JNO1,KTH
      COMMON /SINGLE/ SUM,DELX,DELY,RATE,S,SPACNG,T,FUDGE,PUMP,FACTOR,
     1ERR,FACS,FACT,TMAX,TEST,CHK,PNCH,CONTR,NUM,QCOEF,SS,TT,HYCOND,
     2HEADNG,FACH,FACSS,FACPP,CHCK,SPACR,SPACT,SPACS,SPACV,SPACSS,FLOW
      COMMON /DOUBLE/ PHI,KEEP,DELT,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,
     1RHOP,PARAM,IMK
      COMMON /CHKWRT/ CONET,PUMPT,DELQT,DIFF,DIFFT,DELQ,DELQR
      COMMON /PRNTOT/ SYM,PRNT,BLANK,DDN
C     ****************************************************************
C
C     PURPOSE--TO PRINT OUT INPUT DATA
C
C        PRINT PARAMETER CARD DATA
C
      WRITE(6,160) HEADNG
      WRITE(6,180) DELT,TMAX,NUMT,DIML,DIMW,LENGTH,ERR,FACTOR,FACS,
     1FACT,KTH,ITMAX,FACH,FACSS,FACPP
      IF(CHK(1).EQ.PNCH) WRITE(6,110)
      IF(CHK(2).EQ.CONTR) WRITE(6,130)
      IF(CHK(3).EQ.NUM) WRITE(6,140)
      IF(CHK(4).EQ.CHCK) WRITE(6,150)
      IF(CHK(5).EQ.FLOW) WRITE(6,155)
C
C        PRINT GRID DIMENSIONS
C
      WRITE(6,210) (DELX(J),J=1,DIMW)
      WRITE(6,220) (DELY(I),I=1,DIML)
C
C        PRINT TRANSMISSIVITY VALUES AND LOCATION OF BARRIER BOUNDARIES
C
C     *************
      CALL PRNTA
C     *************
C
C        PRINT STORAGE COEFFICIENT VALUES
C
C     *************
      CALL PRNTB
C     *************
C
C        PRINT PUMPAGE
C
```

Table 6.-Continued.

```
C     *************
      CALL PRNTC
C     *************
C
C        PRINT SATURATED THICKNESS OF LEAKY CONFINING BEDS AND/OR
C              LOCATION OF RECHARGE BOUNDARIES
C
      IF(FACTOR.LT.0.0) GO TO 10
C
C     *************
      CALL PRNTD
C     *************
C
C        PRINT VERTICAL HYDRAULIC CONDUCTIVITY OF CONFINING BEDS
C
   10 IF(FACH.LT.0.0) GO TO 20
C
C     *************
      CALL PRNTE
C     *************
C
C        PRINT SPECIFIC STORAGE OF CONFINING BEDS
C
   20 IF(FACSS.LT.0.0) GO TO 30
C
C     *************
      CALL PRNTF
C     *************
C
   30 CONTINUE
      RETURN
C
C     ***************************************************************
C
  110 FORMAT(1H0,24HPUNCHED OUTPUT REQUESTED)
  130 FORMAT(1H0,26HCONTOURED OUTPUT REQUESTED)
  140 FORMAT(1H0,24HNUMERIC OUTPUT REQUESTED)
  150 FORMAT(1H0,28HMASS BALANCE CHECK REQUESTED)
  155 FORMAT(1H0,32HINDUCED LEAKAGE OUTPUT REQUESTED)
  160 FORMAT(1H1,//1X,32A4,A3//)
  180 FORMAT(1H0,60X,16HINPUT PARAMETERS//37H LENGTH OF INITIAL TIME STE
     1P IN DAYS=,E10.3//45H MAXIMUM PERMITTED PERIOD OF PUMPING IN DAYS=
     2,E10.3//40H MAXIMUM PERMITTED NUMBER OF TIME STEPS=,I4//37H NUMBER
     3 OF NODES IN COLUMN OF MATRIX=,I4//34H NUMBER OF NODES IN ROW OF M
     4ATRIX=,I4//32H NUMBER OF ITERATION PARAMETERS=,I4//28H ERROR CRITE
     5RIA FOR CLOSURE=,F10.3//44H MULTIPLIER FOR THICKNESS OF CONFINING
     6BEDS=,1PE10.3//36H MULTIPLIER FOR STORAGE COEFFICIENT=,E10.3//31H
     7MULTIPLIER FOR TRANSMISSIVITY=,E10.3//40H NUMBER OF TIME STEPS BET
     8WEEN PRINTOUTS=,I4//40H MAXIMUM PERMITTED NUMBER OF ITERATIONS=,I4
     9//57H MULTIPLIER FOR HYDRAULIC CONDUCTIVITY OF CONFINING BEDS=,1PE
     $10.3//51H MULTIPLIER FOR SPECIFIC STORAGE OF CONFINING BEDS=,1PE10
     $.3//24H MULTIPLIER FOR PUMPAGE=,1PE10.3)
  210 FORMAT(1H1,42X,48HGRID SPACING IN PROTOTYPE IN X DIRECTION,IN FEET
     1///(1H0,12E10.3))
  220 FORMAT(1H0,42X,48HGRID SPACING IN PROTOTYPE IN Y DIRECTION,IN FEET
     1///(1H0,12E10.3))
      END
```

Table 6.-Continued.

```
      SUBROUTINE IPARAM
C     SUBPROGRAM NO. 3
C     ••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
      INTEGER DIML,DIMW
      REAL*8 KEEP,IMK
      REAL NUM
      DIMENSION S(50,55),RATE(50,55),KEEP(50,55),G(55),TEMP(55),BE(55),
     1RHOP(25),CHK(5),T(50,55),PHI(50,55),PUMP(50,55),DELX(55),DELY(50),
     2SYM(39),QCOEF(50,55),HEADNG(33),HYCOND(50,55),SS(50,55),PRNT(55),
     3BLANK(60),DDN(55),DELQ(50,55)
      DOUBLE PRECISION PHI,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,DELT,
     1RHOP,PARAM
      COMMON /INTEGR/ DIML,DIMW,NUMT,LENGTH,ITMAX,INO1,JNO1,KTH
      COMMON /SINGLE/ SUM,DELX,DELY,RATE,S,SPACNG,T,FUDGE,PUMP,FACTOR,
     1ERR,FACS,FACT,TMAX,TEST,CHK,PNCH,CONTR,NUM,QCOEF,SS,TT,HYCOND,
     2HEADNG,FACH,FACSS,FACPP,CHCK,SPACR,SPACT,SPACS,SPACV,SPACSS,FLOW
      COMMON /DOUBLE/ PHI,KEEP,DELT,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,
     1RHOP,PARAM,IMK
      COMMON /CHKWRT/ CONET,PUMPT,DELQT,DIFF,DIFFT,DELQ,DELQR
      COMMON /PRNTOT/ SYM,PRNT,BLANK,DDN
C     ••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
C
C     PURPOSE--TO COMPUTE ITERATION PARAMETERS
C
C     COMPUTE HMIN
      HMIN=2.
      XVAL=3.1415**2/(2.*DIMW**2)
      YVAL=3.1415**2/(2.*DIML**2)
      DO 10 I=2,DIML
      DO 10 J=2,DIMW
      IF(T(I,J).EQ.0.) GO TO 10
      XPART=XVAL*(1/(1+DELX(J)**2/DELY(I)**2))
      YPART=YVAL*(1/(1+DELY(I)**2/DELX(J)**2))
      HMIN=AMIN1(HMIN,XPART,YPART)
   10 CONTINUE
      ALPHA=EXP(ALOG(1/HMIN)/(LENGTH-1))
      RHOP(1)=HMIN
      DO 20 NTIME=2,LENGTH
   20 RHOP(NTIME)=RHOP(NTIME-1)*ALPHA
      WRITE (6,30) (RHOP(J),J=1,LENGTH)
      RETURN
C
C     ••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
C
   30 FORMAT (1H1,56X,20HITERATION PARAMETERS///(1H ,10E12.3))
      END
```

```
      SUBROUTINE CLAY
C     SUBPROGRAM NO. 4
C     ******************************************************************
      INTEGER DIML,DIMW
      REAL*8 KEEP,IMK
      REAL NUM
      DIMENSION S(50,55),RATE(50,55),KEEP(50,55),G(55),TEMP(55),BE(55),
     1RHOP(25),CHK(5),T(50,55),PHI(50,55),PUMP(50,55),DELX(55),DELY(50),
     2SYM(39),QCOEF(50,55),HEADNG(33),HYCOND(50,55),SS(50,55),PRNT(55),
     3BLANK(60),DDN(55),DELQ(50,55)
      DOUBLE PRECISION PHI,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,DELT,
     1RHOP,PARAM
      COMMON /INTEGR/ DIML,DIMW,NUMT,LENGTH,ITMAX,INO1,JNO1,KTH
      COMMON /SINGLE/ SUM,DELX,DELY,RATE,S,SPACNG,T,FUDGE,PUMP,FACTOR,
     1ERR,FACS,FACT,TMAX,TEST,CHK,PNCH,CONTR,NUM,QCOEF,SS,TT,HYCOND,
     2HEADNG,FACH,FACSS,FACPP,CHCK,SPACR,SPACT,SPACS,SPACV,SPACSS,FLOW
      COMMON /DOUBLE/ PHI,KEEP,DELT,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,
     1RHOP,PARAM,IMK
      COMMON /CHKWRT/ CONET,PUMPT,DELQT,DIFF,DIFFT,DELQ,DELQR
      COMMON /PRNTOT/ SYM,PRNT,BLANK,DDN
C     ******************************************************************
C
C     THIS SUBROUTINE CALCULATES THE COEFFICIENT OF VERTICAL LEAKAGE
C     FOR THE CONFINING BEDS
C
      PIE=3.1415927
      TT=0.
      DO 50 I=1,DIML
      DO 50 J=1,DIMW
      IF(RATE(I,J).LE.0..OR.T(I,J).EQ.0.) GO TO 50
      IF(HYCOND(I,J).LE.0.0) GO TO 50
      IF(SS(I,J).LE.0.0) GO TO 40
      DIMT=HYCOND(I,J)*SUM/(RATE(I,J)*RATE(I,J)*SS(I,J)* 3.*FUDGE)
      IF(DIMT.GT.TT) TT=DIMT
      SUMN=0.
      DO 20 L=1,200
      PPT=PIE*PIE*DIMT
      IF(DIMT.LT.1.0E-03) PPT=1.0/DIMT
      CK=(2.3-PPT)/(2.*PPT)
      POWER=L*L*PPT
      IF(POWER.LE.174.) GO TO 10
      POWER=150
   10 PEX=EXP(-POWER)
      SUMN=SUMN+PEX
      IF(PEX.GT.0.00009) GO TO 20
      IF(L.GT.CK) GO TO 30
   20 CONTINUE
   30 DENOM=1.0
      IF(DIMT.LT.1.0E-03) DENOM=SQRT(PIE*DIMT)
      Q1=HYCOND(I,J)/(RATE(I,J)*DENOM)
      QCOEF(I,J)=Q1+2.0*Q1*SUMN
      GO TO 50
   40 QCOEF(I,J)=HYCOND(I,J)/RATE(I,J)
   50 CONTINUE
   60 RETURN
      END
```

Table 6.-Continued.

```
      SUBROUTINE ROW
C     SUBPROGRAM NO. 5
C     *******************************************************************
      INTEGER DIML,DIMW
      REAL*8 KEEP,IMK
      REAL NUM
      DIMENSION S(50,55),RATE(50,55),KEEP(50,55),G(55),TEMP(55),BE(55),
     1RHOP(25),CHK(5),T(50,55),PHI(50,55),PUMP(50,55),DELX(55),DELY(50),
     2SYM(39),QCOEF(50,55),HEADNG(33),HYCOND(50,55),SS(50,55),PRNT(55),
     3BLANK(60),DDN(55),DELQ(50,55)
      DOUBLE PRECISION PHI,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,DELT,
     1RHOP,PARAM
      COMMON /INTEGR/ DIML,DIMW,NUMT,LENGTH,ITMAX,INO1,JNO1,KTH
      COMMON /SINGLE/ SUM,DELX,DELY,RATE,S,SPACNG,T,FUDGE,PUMP,FACTOR,
     1ERR,FACS,FACT,TMAX,TEST,CHK,PNCH,CONTR,NUM,QCOEF,SS,TT,HYCOND,
     2HEADNG,FACH,FACSS,FACPP,CHCK,SPACR,SPACT,SPACS,SPACV,SPACSS,FLOW
      COMMON /DOUBLE/ PHI,KEEP,DELT,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,
     1RHOP,PARAM,IMK
      COMMON /CHKWRT/ CONET,PUMPT,DELQT,DIFF,DIFFT,DELQ,DELQR
      COMMON /PRNTOT/ SYM,PRNT,BLANK,DDN
C     *******************************************************************
C
C     PURPOSE-TO CALCULATE IMPLICITLY ALONG ROWS,EXPLICITLY
C              ALONG COLUMNS
C
      DO 10 J=1,DIMW
      BE(J)=0.
      G(J)=0.
   10 TEMP(J)=PHI(1,J)
      DO 70 I=2,DIML
      DO 30 J=2,JNO1
      IF(T(I,J)) 20,30,20
   20 RHO=FUDGE*S(I,J)/DELT
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
     1(J)
      T2=((2.*T(I,J+1)*T(I,J))/(T(I,J)*DELX(J+1)+T(I,J+1)*DELX(J)))/DELX
     1(J)
      T3=((2.*T(I-1,J)*T(I,J))/(T(I,J)*DELY(I-1)+T(I-1,J)*DELY(I)))/DELY
     1(I)
      T4=((2.*T(I+1,J)*T(I,J))/(T(I,J)*DELY(I+1)+T(I+1,J)*DELY(I)))/DELY
     1(I)
      IMK=PARAM*(T1+T2+T3+T4)
C
C     CALCULATE VALUES OF B AND G ARRAYS
C
      B=-T1-T2-RHO-IMK-QCOEF(I,J)
      A=T1
      C=T2
      W=B-A*BE(J-1)
      BE(J)=C/W
```

Table 6.-Continued.

```
      D=-T3*PHI(I-1,J)+(T4+T3-IMK)*PHI(I,J)-T4*PHI(I+1,J)-RHO*KEEP(I,J)+
     1PUMP(I,J)/(DELX(J)*DELY(I))
      G(J)=(D-A*G(J-1))/W
   30 CONTINUE
C
C     CALCULATE HEAD VALUES FOR ROWS OF MATRIX AND PLACE THEM IN
C     TEMPORARY LOCATION TEMP
C
      NO3=DIMW-2
      DO 60 KNO4=1,NO3
      NO4=DIMW-KNO4
      PHI(I-1,NO4)=TEMP(NO4)
      IF(T(I,NO4)) 50,40,50
   40 TEMP(NO4)=PHI(I,NO4)
      GO TO 60
   50 TEMP(NO4)=G(NO4)-BE(NO4)*TEMP(NO4+1)
   60 CONTINUE
   70 CONTINUE
      RETURN
      END
```

Table 6.-Continued.

```
      SUBROUTINE COLUMN
C     SUBPROGRAM NO.6
C     ..................................................................
      INTEGER DIML,DIMW
      REAL*8 KEEP,IMK
      REAL NUM
      DIMENSION S(50,55),RATE(50,55),KEEP(50,55),G(55),TEMP(55),BE(55),
     1RHOP(25),CHK(5),T(50,55),PHI(50,55),PUMP(50,55),DELX(55),DELY(50),
     2SYM(39),QCOEF(50,55),HEADNG(33),HYCOND(50,55),SS(50,55),PRNT(55),
     3BLANK(60),DDN(55),DELQ(50,55)
      DOUBLE PRECISION PHI,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,DELT,
     1RHOP,PARAM
      COMMON /INTEGR/ DIML,DIMW,NUMT,LENGTH,ITMAX,INO1,JNO1,KTH
      COMMON /SINGLE/ SUM,DELX,DELY,RATE,S,SPACNG,T,FUDGE,PUMP,FACTOR,
     1ERR,FACS,FACT,TMAX,TEST,CHK,PNCH,CONTR,NUM,QCOEF,SS,TT,HYCOND,
     2HEADNG,FACH,FACSS,FACPP,CHCK,SPACR,SPACT,SPACS,SPACV,SPACSS,FLOW
      COMMON /DOUBLE/ PHI,KEEP,DELT,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,
     1RHOP,PARAM,IMK
      COMMON /CHKWRT/ CONET,PUMPT,DELQT,DIFF,DIFFT,DELQ,DELQR
      COMMON /PRNTOT/ SYM,PRNT,BLANK,DDN
C     ..................................................................
C
C     PURPOSE--TO CALCULATE IMPLICITLY ALONG COLUMNS, EXPLICITLY ALONG
C     ROWS
C
      DO 10 I=1,DIML
      BE(I)=0.
      G(I)=0.
   10 TEMP(I)=PHI(I,1)
      DO 70 J=2,DIMW
      DO 30 I=2,INO1
      IF(T(I,J)) 20,30,20
   20 RHO=FUDGE*S(I,J)/DELT
C
C     CALCULATE AVERAGE VALUES OF T BETWEEN ADJACENT NODES
C
      T1=((2.*T(I,J-1)*T(I,J))/(T(I,J)*DELX(J-1)+T(I,J-1)*DELX(J)))/DELX
     1(J)
      T2=((2.*T(I,J+1)*T(I,J))/(T(I,J)*DELX(J+1)+T(I,J+1)*DELX(J)))/DELX
     1(J)
      T3=((2.*T(I-1,J)*T(I,J))/(T(I,J)*DELY(I-1)+T(I-1,J)*DELY(I)))/DELY
     1(I)
      T4=((2.*T(I+1,J)*T(I,J))/(T(I,J)*DELY(I+1)+T(I+1,J)*DELY(I)))/DELY
     1(I)
      IMK=PARAM*(T1+T2+T3+T4)
C
C     CALCULATE VALUES OF B AND G ARRAYS
C
      A=T3
      C=T4
      B=-T3-T4-RHO-IMK-QCOEF(I,J)
      W=B-A*BE(I-1)
      BE(I)=C/W
      D=-T1*PHI(I,J-1)+(T1+T2-IMK)*PHI(I,J)-T2*PHI(I,J+1)-RHO*KEEP(I,J)+
```

Table 6.-Continued.

```
     1PUMP(I,J)/(DELX(J)*DELY(I))
      G(I)=(D-A*G(I-1))/W
   30 CONTINUE
C
C     CALCULATE HEAD VALUES FOR COLUMNS OF MATRIX AND PLACE IN TEMPORARY
C     LOCATION TEMP
C
      NO3=DIML-2
      DO 60 KNO4=1,NO3
      NO4=DIML-KNO4
      PHI(NO4,J-1)=TEMP(NO4)
      IF(T(NO4,J)) 50,40,50
   40 TEMP(NO4)=PHI(NO4,J)
      GO TO 60
   50 TEMP(NO4)=G(NO4)-BE(NO4)*TEMP(NO4+1)
      SNGL=TEMP(NO4)-PHI(NO4,J)
      IF(ABS(SNGL).GT.ERR) TEST=1.
   60 CONTINUE
   70 CONTINUE
      RETURN
      END
```

Table 6.-Continued.

```
      SUBROUTINE CHECK
C     SUBPROGRAM NO. 7
C     ******************************************************************
      INTEGER DIML,DIMW
      REAL*8 KEEP,IMK
      REAL NUM
      DIMENSION S(50,55),RATE(50,55),KEEP(50,55),G(55),TEMP(55),BE(55),
     1RHOP(25),CHK(5),T(50,55),PHI(50,55),PUMP(50,55),DELX(55),DELY(50),
     2SYM(39),QCOEF(50,55),HEADNG(33),HYCOND(50,55),SS(50,55),PRNT(55),
     3BLANK(60),DDN(55),DELQ(50,55)
      DOUBLE PRECISION PHI,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,DELT,
     1RHOP,PARAM
      COMMON /INTEGR/ DIML,DIMW,NUMT,LENGTH,ITMAX,INO1,JNO1,KTH
      COMMON /SINGLE/ SUM,DELX,DELY,RATE,S,SPACNG,T,FUDGE,PUMP,FACTOR,
     1ERR,FACS,FACT,TMAX,TEST,CHK,PNCH,CONTR,NUM,QCOEF,SS,TT,HYCOND,
     2HEADNG,FACH,FACSS,FACPP,CHCK,SPACR,SPACT,SPACS,SPACV,SPACSS,FLOW
      COMMON /DOUBLE/ PHI,KEEP,DELT,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,
     1RHOP,PARAM,IMK
      COMMON /CHKWRT/ CONET,PUMPT,DELQT,DIFF,DIFFT,DELQ,DELQR
      COMMON /PRNTOT/ SYM,PRNT,BLANK,DDN
      DOUBLE PRECISION DELS
C     ******************************************************************
C
C     THIS SUBROUTINE COMPUTES THE ERROR IN THE SOLUTION ON A MASS
C     BALANCE BASIS
C
      DIFF=0
      DELQR=0.0
      DO 10 I=2,DIML
      DO 10 J=2,DIMW
      IF(T(I,J).EQ.0.) GO TO 10
      AREA=DELX(J)*DELY(I)
      T1=((2.*T(I,J-1)*T(I,J))/(T(I,J)*DELX(J-1)+T(I,J-1)*DELX(J)))*DELY
     1(I)
      T2=((2.*T(I,J+1)*T(I,J))/(T(I,J)*DELX(J+1)+T(I,J+1)*DELX(J)))*DELY
     1(I)
      T3=((2.*T(I-1,J)*T(I,J))/(T(I,J)*DELY(I-1)+T(I-1,J)*DELY(I)))*DELX
     1(J)
      T4=((2.*T(I+1,J)*T(I,J))/(T(I,J)*DELY(I+1)+T(I+1,J)*DELY(I)))*DELX
     1(J)
      QIN=-T1*(PHI(I,J)-PHI(I,J-1))-T3*(PHI(I,J)-PHI(I-1,J))
      QOUT=-T2*(PHI(I,J+1)-PHI(I,J))-T4*(PHI(I+1,J)-PHI(I,J))
      DELS=-S(I,J)*AREA*(PHI(I,J)-KEEP(I,J))*FUDGE
      DELPMP=-PUMP(I,J)
      DELQ(I,J)=QCOEF(I,J)*(-PHI(I,J))*AREA
      DELQR=DELQR+DELQ(I,J)
      CONET=CONET+DELS
      PUMPT=PUMPT+DELPMP*DELT
      DELQT=DELQT+DELQ(I,J)*DELT
      DIF=(QOUT-QIN-(DELPMP+DELQ(I,J)))*DELT-DELS
      DUM=ABS(DIF)
      DIFF=AMAX1(DIFF,DUM)
      DIFFT=DIFFT+DIF
   10 CONTINUE
      RETURN
      END
```

Table 6.-Continued.

```
      SUBROUTINE PRNT1
C     SUBPROGRAM NO.8
C     ******************************************************************
      INTEGER DIML,DIMW
      REAL*8 KEEP,IMK
      REAL NUM
      DIMENSION S(50,55),RATE(50,55),KEEP(50,55),G(55),TEMP(55),BE(55),
     1RHOP(25),CHK(5),T(50,55),PHI(50,55),PUMP(50,55),DELX(55),DELY(50),
     2SYM(39),QCOEF(50,55),HEADNG(33),HYCOND(50,55),SS(50,55),PRNT(55),
     3BLANK(60),DDN(55),DELQ(50,55)
      DOUBLE PRECISION PHI,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,DELT,
     1RHOP,PARAM
      COMMON /INTEGR/ DIML,DIMW,NUMT,LENGTH,ITMAX,INO1,JNO1,KTH
      COMMON /SINGLE/ SUM,DELX,DELY,RATE,S,SPACNG,T,FUDGE,PUMP,FACTOR,
     1ERR,FACS,FACT,TMAX,TEST,CHK,PNCH,CONTR,NUM,QCOEF,SS,TT,HYCOND,
     2HEADNG,FACH,FACSS,FACPP,CHCK,SPACR,SPACT,SPACS,SPACV,SPACSS,FLOW
      COMMON /DOUBLE/ PHI,KEEP,DELT,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,
     1RHOP,PARAM,IMK
      COMMON /CHKWRT/ CONET,PUMPT,DELQT,DIFF,DIFFT,DELQ,DELQR
      COMMON /PRNTOT/ SYM,PRNT,BLANK,DDN
C     ******************************************************************
C
C     THIS SUBROUTINE PRINTS OUT DRAWDOWN IN NUMERICAL FORM
C
      WRITE(6,30)
      DO 20 I=1,DIML
      DO 10 J=1,DIMW
   10 DDN(J)=PHI(I,J)
   20 WRITE(6,40) I,(DDN(L),L=1,DIMW)
      RETURN
C
C     ******************************************************************
C
   30 FORMAT(1H1,58X,16HDRAWDOWN,IN FEET//)
   40 FORMAT(1H0,I5,11E11.3/(6X,11E11.3))
      END
```

Table 6.-Continued.

```
      SUBROUTINE PRNT2
C     SUBPROGRAM NO. 9
C     ..................................................................
      INTEGER DIML,DIMW
      REAL*8 KEEP,IMK
      REAL NUM,K
      DIMENSION S(50,55),RATE(50,55),KEEP(50,55),G(55),TEMP(55),BE(55),
     1RHOP(25),CHK(5),T(50,55),PHI(50,55),PUMP(50,55),DELX(55),DELY(50),
     2SYM(39),QCOEF(50,55),HEADNG(33),HYCOND(50,55),SS(50,55),PRNT(55),
     3BLANK(60),DDN(55),DELQ(50,55)
      DOUBLE PRECISION PHI,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,DELT,
     1RHOP,PARAM
      COMMON /INTEGR/ DIML,DIMW,NUMT,LENGTH,ITMAX,INO1,JNO1,KTH
      COMMON /SINGLE/ SUM,DELX,DELY,RATE,S,SPACNG,T,FUDGE,PUMP,FACTOR,
     1ERR,FACS,FACT,TMAX,TEST,CHK,PNCH,CONTR,NUM,QCOEF,SS,TT,HYCOND,
     2HEADNG,FACH,FACSS,FACPP,CHCK,SPACR,SPACT,SPACS,SPACV,SPACSS,FLOW
      COMMON /DOUBLE/ PHI,KEEP,DELT,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,
     1RHOP,PARAM,IMK
      COMMON /CHKWRT/ CONET,PUMPT,DELQT,DIFF,DIFFT,DELQ,DELQR
      COMMON /PRNTOT/ SYM,PRNT,BLANK,DDN
C     ..................................................................
C
C     THIS SUBROUTINE PRINTS OUT DRAWDOWN AS ALPHAMERIC CONTOURS
C
      WRITE(6,50)
      IND=(65-DIMW)/2
      DO 40 IB=1,DIML
      DO 30 JB=1,DIMW
      K=-PHI(IB,JB)/SPACNG
      IF(K.LT.0) GO TO 10
      K=AMOD(K,36.)
      IF(K.LT.1.) PRNT(JB)=SYM(36)
   10 IF(K.LT.0) PRNT(JB)=SYM(39)
      IF(PHI(IB,JB).EQ.0.0) PRNT(JB)=SYM(37)
      N=K
      IF(N.LT.1) GO TO 20
      PRNT(JB)=SYM(N)
   20 IF(PUMP(IB,JB).GT.0.) PRNT(JB)=SYM(32)
      IF(RATE(IB,JB).LT.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
   50 FORMAT(1H0,50X,32HALPHAMERIC CONTOURS FOR DRAWDOWN,////)
   60 FORMAT(1H ,65A2)
   70 FORMAT(10H0LEGEND***/18H0CONTOUR INTERVAL ,F10.3/32H0LOCATION OF R
     1ECHARGE BOUNDARY R/16H0WELL LOCATION W/21H0CONE OF IMPRESSION G)
      END
```

Table 6.-Continued.

```
      SUBROUTINE PRNT3
C     SUBPROGRAM NO.10
C     ******************************************************************
      INTEGER DIML,DIMW
      REAL*8 KEEP,IMK
      REAL NUM
      DIMENSION S(50,55),RATE(50,55),KEEP(50,55),G(55),TEMP(55),BE(55),
     1RHOP(25),CHK(5),T(50,55),PHI(50,55),PUMP(50,55),DELX(55),DELY(50),
     2SYM(39),QCOEF(50,55),HEADNG(33),HYCOND(50,55),SS(50,55),PRNT(55),
     3BLANK(60),DDN(55),DELQ(50,55)
      DOUBLE PRECISION PHI,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,DELT,
     1RHOP,PARAM
      COMMON /INTEGR/ DIML,DIMW,NUMT,LENGTH,ITMAX,INO1,JNO1,KTH
      COMMON /SINGLE/ SUM,DELX,DELY,RATE,S,SPACNG,T,FUDGE,PUMP,FACTOR,
     1ERR,FACS,FACT,TMAX,TEST,CHK,PNCH,CONTR,NUM,QCOEF,SS,TT,HYCOND,
     2HEADNG,FACH,FACSS,FACPP,CHCK,SPACR,SPACT,SPACS,SPACV,SPACSS,FLOW
      COMMON /DOUBLE/ PHI,KEEP,DELT,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,
     1RHOP,PARAM,IMK
      COMMON /CHKWRT/ CONET,PUMPT,DELQT,DIFF,DIFFT,DELQ,DELQR
      COMMON /PRNTOT/ SYM,PRNT,BLANK,DDN
C     ******************************************************************
C
C     THIS SUBROUTINE PRINTS OUT INDUCED LEAKAGE TO THE CONFINED AQUIFER
C
      WRITE(6,30)
      DO 20 I=1,DIML
      DO 10 J=1,DIMW
   10 DDN(J)=DELQ(I,J)
   20 WRITE(6,40) I,(DDN(L),L=1,DIMW)
      WRITE(6,50) DELQR
      RETURN
C
C     ******************************************************************
C
   30 FORMAT(1H1,55X,22HINDUCED LEAKAGE,IN GPD///)
   40 FORMAT(1H0,I5,11E11.3/(6X11E11.3))
   50 FORMAT(1H0,///,50X,25H RATE OF INDUCED LEAKAGE=,1PE11.3)
      END
```

Table 6.-Continued.

```
      BLOCK DATA
C
C     *******************************************************************
      INTEGER DIML,DIMW
      REAL*8 KEEP,IMK
      REAL NUM
      DIMENSION S(50,55),RATE(50,55),KEEP(50,55),G(55),TEMP(55),BE(55),
     1RHOP(25),CHK(5),T(50,55),PHI(50,55),PUMP(50,55),DELX(55),DELY(50),
     2SYM(39),QCOEF(50,55),HEADNG(33),HYCOND(50,55),SS(50,55),PRNT(55),
     3BLANK(60),DDN(55),DELQ(50,55)
      DOUBLE PRECISION PHI,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,DELT,
     1RHOP,PARAM
      COMMON /INTEGR/ DIML,DIMW,NUMT,LENGTH,ITMAX,INO1,JNO1,KTH
      COMMON /SINGLE/ SUM,DELX,DELY,RATE,S,SPACNG,T,FUDGE,PUMP,FACTOR,
     1ERR,FACS,FACT,TMAX,TEST,CHK,PNCH,CONTR,NUM,QCOEF,SS,TT,HYCOND,
     2HEADNG,FACH,FACSS,FACPP,CHCK,SPACR,SPACT,SPACS,SPACV,SPACSS,FLOW
      COMMON /DOUBLE/ PHI,KEEP,DELT,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,
     1RHOP,PARAM,IMK
      COMMON /CHKWRT/ CONET,PUMPT,DELQT,DIFF,DIFFT,DELQ,DELQR
      COMMON /PRNTOT/ SYM,PRNT,BLANK,DDN
C     *******************************************************************
C
C
      DATA CHK(1)/5HPUNCH/,CHK(2)/6HCONTOU/,CHK(3)/6HNUMERI/,CHK(4)/5HCH
     1ECK/,CHK(5)/6HLEAKAG/,QCOEF/2750*0.0/,PHI/2750*0.0/
      DATA SYM/1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9,1HA,1HB,1HC,1HD,1HE,1
     1HF,1HG,1HH,1HI,1HJ,1HK,1HL,1HM,1HN,1HO,1HP,1HQ,1HR,1HS,1HT,1HU,1HV
     2,1HW,1HX,1HY,1HZ,1H0,1H ,1H*,1HG/,BLANK/60*1H /
      DATA RATE/2750*0.0/,HYCOND/2750*0.0/,SS/2750*0.0/
C
      END
```

Table 6.-Continued.

```
      SUBROUTINE PRNTA
C     SUBPROGRAM NO.11
C     *****************************************************************
      INTEGER DIML,DIMW
      REAL*8 KEEP,IMK
      REAL NUM,K
      DIMENSION S(50,55),RATE(50,55),KEEP(50,55),G(55),TEMP(55),BE(55),
     1RHOP(25),CHK(5),T(50,55),PHI(50,55),PUMP(50,55),DELX(55),DELY(50),
     2SYM(39),QCOEF(50,55),HEADNG(33),HYCOND(50,55),SS(50,55),PRNT(55),
     3BLANK(60),DDN(55),DELQ(50,55)
      DOUBLE PRECISION PHI,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,DELT,
     1RHOP,PARAM
      COMMON /INTEGR/ DIML,DIMW,NUMT,LENGTH,ITMAX,INO1,JNO1,KTH
      COMMON /SINGLE/ SUM,DELX,DELY,RATE,S,SPACNG,T,FUDGE,PUMP,FACTOR,
     1ERR,FACS,FACT,TMAX,TEST,CHK,PNCH,CONTR,NUM,QCOEF,SS,TT,HYCOND,
     2HEADNG,FACH,FACSS,FACPP,CHCK,SPACR,SPACT,SPACS,SPACV,SPACSS,FLOW
      COMMON /DOUBLE/ PHI,KEEP,DELT,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,
     1RHOP,PARAM,IMK
      COMMON /CHKWRT/ CONET,PUMPT,DELQT,DIFF,DIFFT,DELQ,DELQR
      COMMON /PRNTOT/ SYM,PRNT,BLANK,DDN
C     *****************************************************************
C
C     THIS SUBROUTINE PRINTS OUT TRANSMISSIVITY VALUES AND LOCATION
C         OF BARRIER BOUNDARIES
C
      WRITE(6,100)
      IND=(65-DIMW)/2
      DO 110 IB=1,DIML
      DO 120 JB=1,DIMW
      K=T(IB,JB)/(SPACT*.99999999)
      IF(T(IB,JB).EQ.0) GO TO 130
      K=AMOD(K,36.)
      IF(K.LT.1.) PRNT(JB)=SYM(36)
  130 IF(T(IB,JB).EQ.0) PRNT(JB)=SYM(11)
      N=K
      IF(N.LT.1) GO TO 120
      PRNT(JB)=SYM(N)
  120 CONTINUE
  110 WRITE(6,140) (BLANK(I),I=1,IND),(PRNT(JB),JB=1,DIMW)
      WRITE(6,150) SPACT
      WRITE(6,160)
      DO 170 I=1,DIML
      DO 180 J=1,DIMW
  180 DDN(J)=T(I,J)
  170 WRITE(6,190) I,(DDN(L),L=1,DIMW)
      RETURN
C
C     *****************************************************************
C
  100 FORMAT(1H1,47X,38HALPHAMERIC CONTOURS FOR TRANSMISSIVITY,///)
  140 FORMAT(1H ,65A2)
  150 FORMAT(18H CONTOUR INTERVAL ,F13.3/31H0LOCATION OF BARRIER BOUNDAR
     1Y B)
  160 FORMAT(1H1,51X,30HTRANSMISSIVITY,IN GPD PER FOOT//)
  190 FORMAT(1H0,I5,11E11.3/(6X,11E11.3))
      END
```

Table 6.-Continued.

```
      SUBROUTINE PRNTB
C     SUBPROGRAM NO.12
C     ******************************************************************
      INTEGER DIML,DIMW
      REAL*8 KEEP,IMK
      REAL NUM,K
      DIMENSION S(50,55),RATE(50,55),KEEP(50,55),G(55),TEMP(55),BE(55),
     1RHOP(25),CHK(5),T(50,55),PHI(50,55),PUMP(50,55),DELX(55),DELY(50),
     2SYM(39),QCOEF(50,55),HEADNG(33),HYCOND(50,55),SS(50,55),PRNT(55),
     3BLANK(60),DDN(55),DELQ(50,55)
      DOUBLE PRECISION PHI,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,DELT,
     1RHOP,PARAM
      COMMON /INTEGR/ DIML,DIMW,NUMT,LENGTH,ITMAX,INO1,JNO1,KTH
      COMMON /SINGLE/ SUM,DELX,DELY,RATE,S,SPACNG,T,FUDGE,PUMP,FACTOR,
     1ERR,FACS,FACT,TMAX,TEST,CHK,PNCH,CONTR,NUM,QCOEF,SS,TT,HYCOND,
     2HEADNG,FACH,FACSS,FACPP,CHCK,SPACR,SPACT,SPACS,SPACV,SPACSS,FLOW
      COMMON /DOUBLE/ PHI,KEEP,DELT,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,
     1RHOP,PARAM,IMK
      COMMON /CHKWRT/ CONET,PUMPT,DELQT,DIFF,DIFFT,DELQ,DELQR
      COMMON /PRNTOT/ SYM,PRNT,BLANK,DDN
C     ******************************************************************
C
C     THIS SUBROUTINE PRINTS OUT STORAGE COEFFICIENT VALUES
C
      WRITE(6,100)
      IND=(65-DIMW)/2
      DO 110 IB=1,DIML
      DO 120 JB=1,DIMW
      K=S(IB,JB)/(SPACS*.99999999)
      K=AMOD(K,36.)
      IF(K.LT.1.) PRNT(JB)=SYM(36)
      N=K
      IF(N.LT.1) GO TO 120
      PRNT(JB)=SYM(N)
  120 CONTINUE
  110 WRITE(6,140) (BLANK(I),I=1,IND),(PRNT(JB),JB=1,DIMW)
      WRITE(6,150) SPACS
      WRITE(6,160)
      DO 170 I=1,DIML
      DO 180 J=1,DIMW
  180 DDN(J)=S(I,J)
  170 WRITE(6,190) I,(DDN(L),L=1,DIMW)
      RETURN
C
C     ******************************************************************
C
  100 FORMAT(1H1,44X,43HALPHAMERIC CONTOURS FOR STORAGE COEFFICIENT,///)
  140 FORMAT(1H ,65A2)
  150 FORMAT(18H CONTOUR INTERVAL ,F14.8)
  160 FORMAT(1H1,56X,19HSTORAGE COEFFICIENT//)
  190 FORMAT(1H0,I5,11E11.3/(6X,11E11.3))
      END
```

Table 6.-Continued.

```
      SUBROUTINE PRNTC
C     SUBPROGRAM NO.13
C     ******************************************************************
      INTEGER DIML,DIMW
      REAL*8 KEEP,IMK
      REAL NUM,K
      DIMENSION S(50,55),RATE(50,55),KEEP(50,55),G(55),TEMP(55),BE(55),
     1RHOP(25),CHK(5),T(50,55),PHI(50,55),PUMP(50,55),DELX(55),DELY(50),
     2SYM(39),QCOEF(50,55),HEADNG(33),HYCOND(50,55),SS(50,55),PRNT(55),
     3BLANK(60),DDN(55),DELQ(50,55)
      DOUBLE PRECISION PHI,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,DELT,
     1RHOP,PARAM
      COMMON /INTEGR/ DIML,DIMW,NUMT,LENGTH,ITMAX,INO1,JNO1,KTH
      COMMON /SINGLE/ SUM,DELX,DELY,RATE,S,SPACNG,T,FUDGE,PUMP,FACTOR,
     1ERR,FACS,FACT,TMAX,TEST,CHK,PNCH,CONTR,NUM,QCOEF,SS,TT,HYCOND,
     2HEADNG,FACH,FACSS,FACPP,CHCK,SPACR,SPACT,SPACS,SPACV,SPACSS,FLOW
      COMMON /DOUBLE/ PHI,KEEP,DELT,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,
     1RHOP,PARAM,IMK
      COMMON /CHKWRT/ CONET,PUMPT,DELQT,DIFF,DIFFT,DELQ,DELQR
      COMMON /PRNTOT/ SYM,PRNT,BLANK,DDN
C     ******************************************************************
C
C     THIS SUBROUTINE PRINTS OUT PUMPAGE
C
      WRITE(6,100)
      IND=(65-DIMW)/2
      DO 110 IB=1,DIML
      DO 120 JB=1,DIMW
      K=PUMP(IB,JB)
      IF(K.GT.0.) PRNT(JB)=SYM(32)
      IF(K.EQ.0.) PRNT(JB)=SYM(36)
      IF(K.LT.0.) PRNT(JB)=SYM(27)
  120 CONTINUE
  110 WRITE(6,140) (BLANK(I),I=1,IND),(PRNT(JB),JB=1,DIMW)
      WRITE(6,150)
      WRITE(6,160)
      DO 170 I=1,DIML
      DO 180 J=1,DIMW
  180 DDN(J)=PUMP(I,J)
  170 WRITE(6,190) I,(DDN(L),L=1,DIMW)
      RETURN
C
C     ******************************************************************
C
  100 FORMAT(1H1,59X,14HWELL LOCATIONS,///)
  140 FORMAT(1H ,65A2)
  150 FORMAT(29H LOCATION OF DISCHARGE WELL W/28HOLOCATION OF RECHARGE W
     1ELL R)
  160 FORMAT(1H1,59X,14HPUMPAGE,IN GPD//)
  190 FORMAT(1H0,I5,11E11.3/(6X,11E11.3))
      END
```

Table 6.-Continued.

```
      SUBROUTINE PRNTD
C     SUBPROGRAM NO.14
C     *****************************************************************
      INTEGER DIML,DIMW
      REAL*8 KEEP,IMK
      REAL NUM,K
      DIMENSION S(50,55),RATE(50,55),KEEP(50,55),G(55),TEMP(55),BE(55),
     1RHOP(25),CHK(5),T(50,55),PHI(50,55),PUMP(50,55),DELX(55),DELY(50),
     2SYM(39),QCOEF(50,55),HEADNG(33),HYCOND(50,55),SS(50,55),PRNT(55),
     3BLANK(60),DDN(55),DELQ(50,55)
      DOUBLE PRECISION PHI,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,DELT,
     1RHOP,PARAM
      COMMON /INTEGR/ DIML,DIMW,NUMT,LENGTH,ITMAX,INO1,JNO1,KTH
      COMMON /SINGLE/ SUM,DELX,DELY,RATE,S,SPACNG,T,FUDGE,PUMP,FACTOR,
     1ERR,FACS,FACT,TMAX,TEST,CHK,PNCH,CONTR,NUM,QCOEF,SS,TT,HYCOND,
     2HEADNG,FACH,FACSS,FACPP,CHCK,SPACR,SPACT,SPACS,SPACV,SPACSS,FLOW
      COMMON /DOUBLE/ PHI,KEEP,DELT,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,
     1RHOP,PARAM,IMK
      COMMON /CHKWRT/ CONET,PUMPT,DELQT,DIFF,DIFFT,DELQ,DELQR
      COMMON /PRNTOT/ SYM,PRNT,BLANK,DDN
C     *****************************************************************
C
C     THIS SUBROUTINE PRINTS OUT THE SATURATED THICKNESS OF LEAKY
C     CONFINING BEDS AND LOCATION OF RECHARGE BOUNDARIES
C
      WRITE(6,100)
      IND=(65-DIMW)/2
      DO 110 IB=1,DIML
      DO 120 JB=1,DIMW
      IF(SPACR.LE.0.0) SPACR=1.0
      K=RATE(IB,JB)/(SPACR*.99999999)
      IF(K.LT.0) GO TO 130
      K=AMOD(K,36.)
      IF(K.LT.1.) PRNT(JB)=SYM(36)
  130 IF(K.LT.0) PRNT(JB)=SYM(27)
      N=K
      IF(N.LT.1) GO TO 120
      PRNT(JB)=SYM(N)
  120 CONTINUE
  110 WRITE(6,140) (BLANK(I),I=1,IND),(PRNT(JB),JB=1,DIMW)
      WRITE(6,150) SPACR
      WRITE(6,160)
      DO 170 I=1,DIML
      DO 180 J=1,DIMW
  180 DDN(J)=RATE(I,J)
  170 WRITE(6,190) I,(DDN(L),L=1,DIMW)
      RETURN
C
C     *****************************************************************
C
  100 FORMAT(1H1,32X,67HALPHAMERIC CONTOURS FOR SATURATED THICKNESS OF L
     1EAKY CONFINING BEDS,///)
  140 FORMAT(1H ,65A2)
  150 FORMAT(18H CONTOUR INTERVAL ,F14.3/32HOLOCATION OF RECHARGE BOUNDA
     1RY R)
  160 FORMAT(1H1,40X,51HSATURATED THICKNESS OF LEAKY CONFINING BEDS,IN F
     1EET//)
  190 FORMAT(1H0,I5,11E11.3/(6X,11E11.3))
      END
```

Table 6.-Continued.

```
      SUBROUTINE PRNTE
C     SUBPROGRAM NO.15
C     ............................................................
      INTEGER DIML,DIMW
      REAL*8 KEEP,IMK
      REAL NUM,K
      DIMENSION S(50,55),RATE(50,55),KEEP(50,55),G(55),TEMP(55),BE(55),
     1RHOP(25),CHK(5),T(50,55),PHI(50,55),PUMP(50,55),DELX(55),DELY(50),
     2SYM(39),QCOEF(50,55),HEADNG(33),HYCOND(50,55),SS(50,55),PRNT(55),
     3BLANK(60),DDN(55),DELQ(50,55)
      DOUBLE PRECISION PHI,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,DELT,
     1RHOP,PARAM
      COMMON /INTEGR/ DIML,DIMW,NUMT,LENGTH,ITMAX,INO1,JNO1,KTH
      COMMON /SINGLE/ SUM,DELX,DELY,RATE,S,SPACNG,T,FUDGE,PUMP,FACTOR,
     1ERR,FACS,FACT,TMAX,TEST,CHK,PNCH,CONTR,NUM,QCOEF,SS,TT,HYCOND,
     2HEADNG,FACH,FACSS,FACPP,CHCK,SPACR,SPACT,SPACS,SPACV,SPACSS,FLOW
      COMMON /DOUBLF/ PHI,KEEP,DELT,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,
     1RHOP,PARAM,IMK
      COMMON /CHKWRT/ CONET,PUMPT,DELQT,DIFF,DIFFT,DELQ,DELQR
      COMMON /PRNTOT/ SYM,PRNT,BLANK,DDN
C     ............................................................
C
C     THIS SUBROUTINE PRINTS OUT THE VERTICAL HYDRAULIC CONDUCTIVITY OF
C     LEAKY CONFINING BEDS
C
      WRITE(6,100)
      IND=(65-DIMW)/2
      DO 110 IB=1,DIML
      DO 120 JB=1,DIMW
      K=HYCOND(IB,JB)/(SPACV*.99999999)
      K=AMOD(K,36.)
      IF(K.LT.1.) PRNT(JB)=SYM(36)
      N=K
      IF(N.LT.1) GO TO 120
      PRNT(JB)=SYM(N)
  120 CONTINUE
  110 WRITE(6,140) (BLANK(I),I=1,IND),(PRNT(JB),JB=1,DIMW)
      WRITE(6,150) SPACV
      WRITE(6,160)
      DO 170 I=1,DIML
      DO 180 J=1,DIMW
  180 DDN(J)=HYCOND(I,J)
  170 WRITE(6,190) I,(DDN(L),L=1,DIMW)
      RETURN
C
C     ............................................................
C
  100 FORMAT(1H1,27X,79HALPHAMERIC CONTOURS FOR VERTICAL HYDRAULIC CONDU
     1CTIVITY OF LEAKY CONFINING BEDS,///)
  140 FORMAT(1H ,65A2)
  150 FORMAT(18H CONTOUR INTERVAL ,F14.8)
  160 FORMAT(1H1,27X,78HVERTICAL HYDRAULIC CONDUCTIVITY OF LEAKY CONFINI
     1NG BEDS,IN GPD PER SQUARE FOOT/)
  190 FORMAT(1H0,I5,11E11.3/(6X,11E11.3))
      END
```

Table 6.-Continued.

```
      SUBROUTINE PRNTF
C     SUBPROGRAM NO.16
C     ................................................................
      INTEGER DIML,DIMW
      REAL*8 KEEP,IMK
      REAL NUM,K
      DIMENSION S(50,55),RATE(50,55),KEEP(50,55),G(55),TEMP(55),BE(55),
     1RHOP(25),CHK(5),T(50,55),PHI(50,55),PUMP(50,55),DELX(55),DELY(50),
     2SYM(39),QCOEF(50,55),HEADNG(33),HYCOND(50,55),SS(50,55),PRNT(55),
     3BLANK(60),DDN(55),DELQ(50,55)
      DOUBLE PRECISION PHI,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,DELT,
     1RHOP,PARAM
      COMMON /INTEGR/ DIML,DIMW,NUMT,LENGTH,ITMAX,INO1,JNO1,KTH
      COMMON /SINGLE/ SUM,DELX,DELY,RATE,S,SPACNG,T,FUDGE,PUMP,FACTOR,
     1ERR,FACS,FACT,TMAX,TEST,CHK,PNCH,CONTR,NUM,QCOEF,SS,TT,HYCOND,
     2HEADNG,FACH,FACSS,FACPP,CHCK,SPACR,SPACT,SPACS,SPACV,SPACSS,FLOW
      COMMON /DOUBLE/ PHI,KEEP,DELT,D,G,TEMP,BE,W,T1,T2,T3,T4,RHO,A,B,C,
     1RHOP,PARAM,IMK
      COMMON /CHKWRT/ CONET,PUMPT,DELQT,DIFF,DIFFT,DELQ,DELQR
      COMMON /PRNTOT/ SYM,PRNT,BLANK,DDN
C     ................................................................
C
C     THIS SUBROUTINE PRINTS OUT THE SPECIFIC STORAGE
C     OF LEAKY CONFINING BEDS
C
      WRITE(6,100)
      IND=(65-DIMW)/2
      DO 110 IB=1,DIML
      DO 120 JB=1,DIMW
      K=SS(IB,JB)/(SPACSS*.99999999)
      K=AMOD(K,36.)
      IF(K.LT.1.) PRNT(JB)=SYM(36)
      N=K
      IF(N.LT.1) GO TO 120
      PRNT(JB)=SYM(N)
  120 CONTINUE
  110 WRITE(6,140) (BLANK(I),I=1,IND),(PRNT(JB),JB=1,DIMW)
      WRITE(6,150) SPACSS
      WRITE(6,160)
      DO 170 I=1,DIML
      DO 180 J=1,DIMW
  180 DDN(J)=SS(I,J)
  170 WRITE(6,190) I,(DDN(L),L=1,DIMW)
      RETURN
C
C     ................................................................
C
  100 FORMAT(1H1,34X,64HALPHAMERIC CONTOURS FOR SPECIFIC STORAGE OF LEAK
     1Y CONFINING BEDS,///)
  140 FORMAT(1H ,65A2)
  150 FORMAT(18H CONTOUR INTERVAL ,F14.10)
  160 FORMAT(1H1,40X,50HSPECIFIC STORAGE OF LEAKY CONFINING BEDS,IN 1/FE
     1ET/)
  190 FORMAT(1H0,I5,11E11.3/(6X,11E11.3))
      END
```