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DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT
OFFICE OF PUBLIC WORKS

Water Resources
TECHNICAL REPORT
No. 27

APPLICATIONS OF DIGITAL MODELING FOR EVALUATING THE GROUND-WATER RESOURCES OF THE "2,000-FOOT" SAND OF THE BATON ROUGE AREA, LOUISIANA

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1982

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Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
foot (ft)	0.3048	meter (m)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
foot per year (ft/yr)	0.3048	meter per year (m/yr)
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)
gallon (gal)	0.003785	cubic meter (m^3)
gallon per day per foot [(gal/d)/ft]	0.01242	meter squared per day (m^2/d)
gallon per minute (gal/min)	6.309×10^{-5}	cubic meter per second (m^3/s)
inch (in.)	2.540	centimeter (cm)
mile (mi)	1.609	kilometer (km)
million gallons per day (Mgal/d)	3.785×10^3	cubic meter per day (m^3/d)

APPLICATIONS OF DIGITAL MODELING FOR EVALUATING THE GROUND-WATER RESOURCES OF THE "2,000-FOOT" SAND OF THE BATON ROUGE AREA, LOUISIANA

By L. J. Torak and C. D. Whiteman, Jr.

ABSTRACT

Extensive development of ground-water resources at Baton Rouge has caused the potentiometric surface of the Miocene aquifer known as the "2,000-foot" sand to decline about 430 feet from 1914 to 1979. Although conservation measures employed by industry since late 1974 and early 1975 have caused a rise in the potentiometric surface of about 25 feet, increased ground-water withdrawal for public supply threatens to renew the declining trend. A finite-difference, digital-computer model simulating ground-water flow in three dimensions was developed as a management tool to simulate the potentiometric surface of the "2,000-foot" sand as it responds to variations in pumping at Baton Rouge.

Hydrogeologic factors controlling the availability of ground water in the "2,000-foot" sand are: leakage from confining layers and other related aquifers; the restriction of ground-water flow caused by the Baton Rouge fault; and spatial variations in hydraulic characteristics of the aquifer and confining layers. The effects of these factors were quantified in preliminary investigations using finite-difference, digital-computer models that simulated ground-water flow in one, two, and three dimensions. One model indicated that leakage (both steady and transient) from confining layers and other aquifers contributed about 50 percent of the total volume of water withdrawn from the "2,000-foot" sand by pumping. As a result, a modified version of the three-dimensional model was used to simulate these leakage effects.

Calibration for the period 1914-61 was facilitated through the use of a parameter-estimation program that statistically analyzed changes to aquifer and confining-layer characteristics. The model was verified for the years 1962-79 without changes to parameter values. Three simulations using possible future variations in pumpage were performed and the resulting potentiometric surface configurations for the "2,000-foot" sand obtained. These simulations indicate excessive drawdowns can be averted and relatively stable water levels can be achieved in the industrial area at Baton Rouge if pumpage is reduced about 10 percent from the 1979 rates of withdrawal. At a distance of about 35 miles from the industrial district the model showed continued water-level declines, although pumpage was reduced by as much as 30 percent from the 1979 rates.

INTRODUCTION

Extensive development of ground-water resources for industry and public supply at Baton Rouge has caused the potentiometric surface of the Miocene aquifer known as the "2,000-foot" sand to decline about 430 ft during the years 1914-79. The "2,000-foot" sand at Baton Rouge is the most heavily pumped aquifer in a 12-aquifer system of alternating sands and clays totaling about 3,000 ft in thickness. Over the 20-year period 1954-74, pumpage of ground water from this aquifer in the Baton Rouge area increased three-fold, from 13.5 to 40.4 Mgal/d, causing water levels to decline nearly 300 ft in the industrial district. Conservation measures employed by industry since late 1974 and early 1975 caused a rise in the potentiometric surface of the "2,000-foot" sand of about 25 ft. However, population growth in the Baton Rouge area, has resulted in increased ground-water withdrawal from this aquifer for public supply, which may lead to new water-level declines.

Although aquifers above and below the "2,000-foot" sand have shown lesser declines in their potentiometric surfaces, increased pumpage from the "2,000-foot" sand may be necessary to meet future demands for ground water by industry and public supply. The effects of increased pumpage on water levels in wells in the "2,000-foot" sand are difficult to predict because of the interaction of the hydrogeologic factors involved. Because of the complexity of the interaction of these factors, a digital model is needed to make the necessary predictions to efficiently manage the water resources of the "2,000-foot" sand.

PURPOSE AND SCOPE

In 1975, the U.S. Geological Survey, as part of the cooperative program of water-resource investigations with the Louisiana Department of Transportation and Development, Office of Public Works, and the Capital Area Groundwater Conservation Commission, began this study to determine how future development of ground-water resources of the "2,000-foot" sand in the five-parish project area (fig. 1) will affect the potentiometric surface of this aquifer. To determine what effect future stresses will have on the "2,000-foot" sand, it was necessary to identify the hydrogeologic factors controlling the ground water availability from the aquifer. Simulation techniques involving digital models of ground-water flow were used in this study to identify these factors and to quantify their effects on the availability of water in the "2,000-foot" sand. Once these factors were determined, a digital computer model that simulates ground-water flow and accounts for the effects of the hydrogeologic factors was developed as a management tool to simulate the potentiometric surface of the "2,000-foot" sand in response to variations in pumpage.

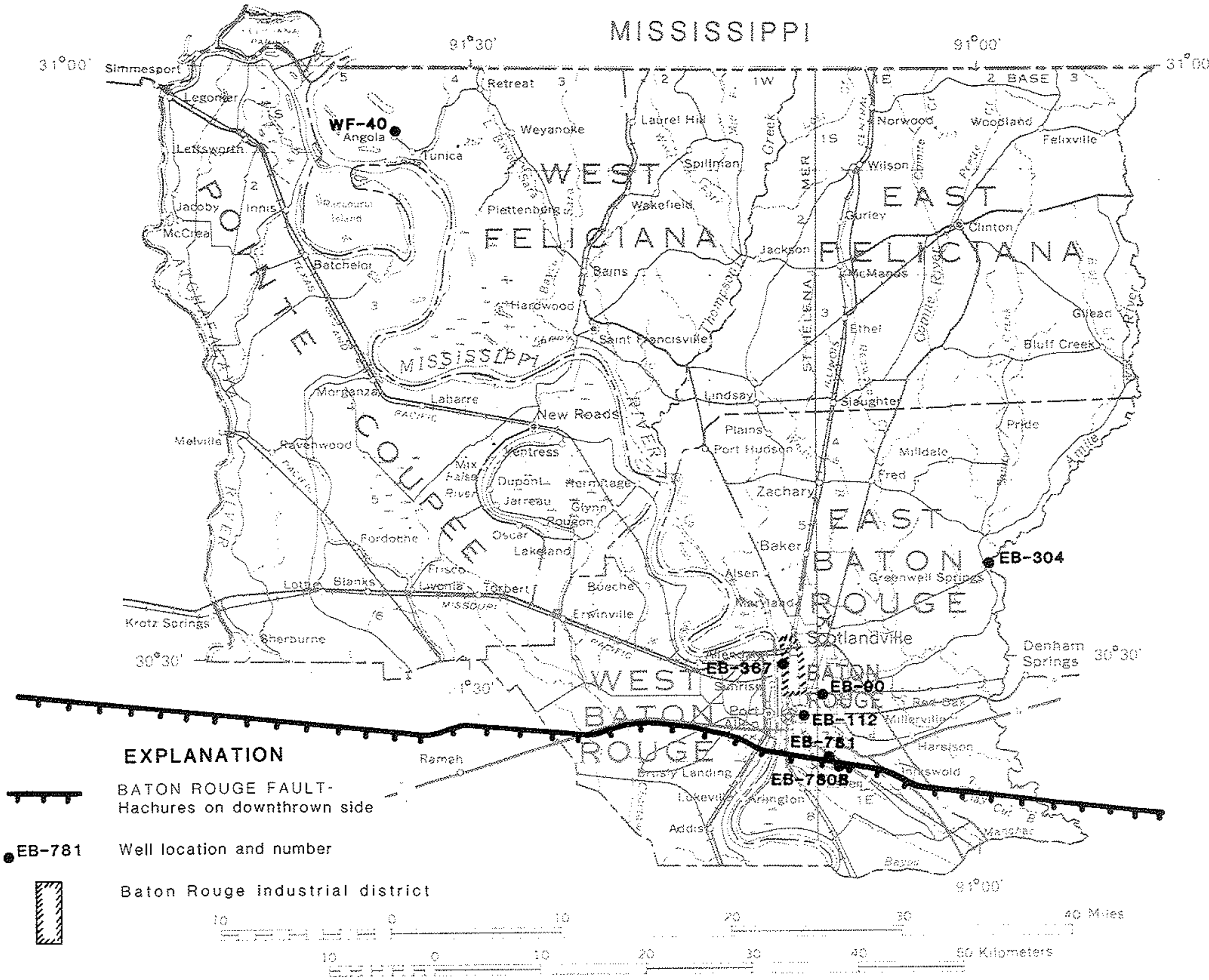


Figure 1.--Five-parish project area showing location of Baton Rouge fault and selected wells.

INVESTIGATION OF HYDROGEOLOGIC FACTORS

Certain hydrogeologic factors controlling ground-water availability in the "2,000-foot" sand were identified, and their effects quantified using digital computer models of ground-water flow. These factors are: leakage from aquifers and confining layers above and below the "2,000-foot" sand; the restriction of ground-water flow northward to pumping centers by the Baton Rouge fault; and spatial variations in hydrologic parameters of the "2,000-foot" sand. An investigation of these hydrogeologic factors using simulation techniques led to the development of a conceptual model for the "2,000-foot" sand, which provided the basis for the digital model used to evaluate the aquifer. The following sections define elements of the conceptual model and describe how they were identified and quantified for input to the digital model.

Leakage From Confining Layers and Other Aquifers

The withdrawal of ground water from a confined aquifer, such as the "2,000-foot" sand, creates hydraulic gradients that cause ground water to flow towards the area of withdrawal (usually, a well). Ground-water flow in response to pumpage is predominantly horizontal, downgradient, and within the areal dimensions of the aquifer. However, aquifers in the project area are bounded above and below by confining layers comprised of clay and other low-permeability materials. Hydraulic gradients are established in these layers and also in the overlying and underlying aquifers, causing vertical leakage of ground water into the aquifer that is pumped.

During the initial stages of pumping, hydraulic gradients propagate a short distance vertically into the confining layers, with leakage derived primarily from the release of water from storage within the affected zones (transient leakage). If a constant pumping rate is maintained, a uniform hydraulic gradient will be established across the confining layers into the other aquifers, and water will flow between aquifers by virtue of this gradient (steady leakage). Thus, transient components of leakage from the confining layers eventually dissipate, resulting in only steady leakage through these layers from the overlying and underlying aquifers.

The "2,000-foot" sand is the most heavily pumped aquifer in the system of alternating sands and confining layers in the Baton Rouge area. Because of the unequal pumpage distribution among aquifers, the "2,000-foot" sand has the most drawdown. This results in vertical leakage into this aquifer through the confining layer above, from the "1,500- 1,700-foot" sand, and through the confining layer below, from the "2,400-foot" sand. Pumpage from these aquifers has increased steadily since the early 1900's and has varied in areal distribution; therefore, uniform hydraulic gradients through the confining layers have not been established throughout the area and transient-leakage effects persist in these layers.

The type of leakage into the "2,000-foot" sand is also affected by the variable thickness of the confining layers, which ranges from about 50 to 300 ft in the industrial area of Baton Rouge. Where the confining layers are thin, conditions of steady leakage may be established within a short time after pumping begins, as uniform hydraulic gradients can be established quickly across these zones. However, where thick confining layers are present, a uniform hydraulic gradient may not be established until long after pumping begins, and transient-leakage effects will prevail.

Two-Dimensional Model

A simple conceptual model of the "2,000-foot" sand, assuming transient-leakage effects to be negligible, was tested for its validity. This test was conducted to determine if the "2,000-foot" sand responds to pumpage as a single hydrogeologic unit, or as part of a multi-layered system of aquifers and confining layers with steady-leakage effects. A finite-difference, digital model for simulation of ground-water flow in two dimensions by Trescott, Pinder, and Larson (1976) was used in this preliminary investigation. The flow of ground water in the "2,000-foot" sand and steady leakage from a confining layer above this unit were simulated by the model as pumping was imposed on this aquifer at Baton Rouge.

Data Requirements

Values of thickness for the "2,000-foot" sand and the overlying confining layer in the project area (fig. 1), were obtained from analyses of electrical logs of wells. Estimates of hydraulic conductivity and storage coefficient of the "2,000-foot" sand were obtained from previous studies in the Baton Rouge area by Meyer and Turcan (1955) and Morgan (1961). These values ranged from 1.70×10^{-3} to 2.35×10^{-3} ft/s for hydraulic conductivity, and from 5.7×10^{-4} to 7.9×10^{-4} for storage coefficent. An estimate of vertical hydraulic conductivity (2.0×10^{-10} ft/s) and specific storage (1.6×10^{-5}) of the confining layer above the "2,000-foot" sand was obtained from a report by Whiteman (1980).

Ground-water pumpage used in the preliminary model was compiled from data files of the District Office of the U.S. Geological Survey, Baton Rouge, and the Capital Area Groundwater Conservation Commission. Pumpage for the years 1916-75 was divided into 10 pumping periods ranging from 1 to 14 years in length, with the average pumping rate (table 1) for each period used as input to the model.

Design of the Finite-Difference Grid

The design of the finite-difference grid for the two-dimensional model investigation was influenced by the distribution of pumpage and hydrogeologic factors present in the Baton Rouge area. For this investigation pumpage was simulated at Baton Rouge by one node measuring 6.0 by 7.0 mi. The grid was oriented so that the principal directions ($\underline{X}$ and $\underline{Y}$ axes) used in the finite-difference equations were parallel and perpendicular to the trend of the Baton Rouge fault and to the regional dip of

Table 1.--Temporal distribution of pumpage for preliminary two-dimensional model of "2,000-foot" sand

Pumping period	Years simulated	Average pumping rate, in Mgal/d
1	1916-25	2.0
2	1926-39	4.0
3	1940-50	12.7
4	1951-56	14.5
5	1957-60	20.7
6	1961-65	24.6
7	1966-67	29.6
8	1968-69	35.1
9	1970-74	38.3
10	1975	36.8

the aquifers. This orientation allowed one row in the grid to represent the restriction to ground-water flow created by the fault and another row to represent the area of recharge to the north, where the "2,000-foot" sand approaches the surface. The grid consisted of 13 rows and 15 columns and is shown in figure 2.

Boundary Conditions

The northern boundary of the model area was simulated using both constant-head nodes and nodes containing storage coefficients characteristic of water-table aquifers. (See fig. 2.) In the lowland areas, and where it was determined that the head of the "2,000-foot" sand is controlled primarily by stream levels, constant-head nodes were used to simulate a source of water to the aquifer. In the upland areas, or in areas where the main recharge mechanism to the aquifer is precipitation, nodes were assigned values of storage coefficient that are characteristic of water-table aquifers.

No-flow boundaries were established sufficiently far to the east, west, and south of the pumping center so that drawdowns computed by the model for the Baton Rouge area were not significantly affected by their placement. A sensitivity test was performed by substituting constant-head boundaries for no-flow. It showed that drawdowns computed for the Baton Rouge area varied less than 5 percent in response to the change in boundary conditions. No-flow boundaries surround the model grid shown in figure 2.

Note that the southern boundary of the model area (fig. 2), is not as far from the pumping center as the boundaries to the east and west, a result of the restriction to ground-water flow caused by the fault zone south of the pumping center. An estimated value for the hydraulic conductivity of the fault zone was used in the preliminary model. A more-representative value for the hydraulic conductivity of the fault zone was determined later and is discussed in the section on leakage across the fault.

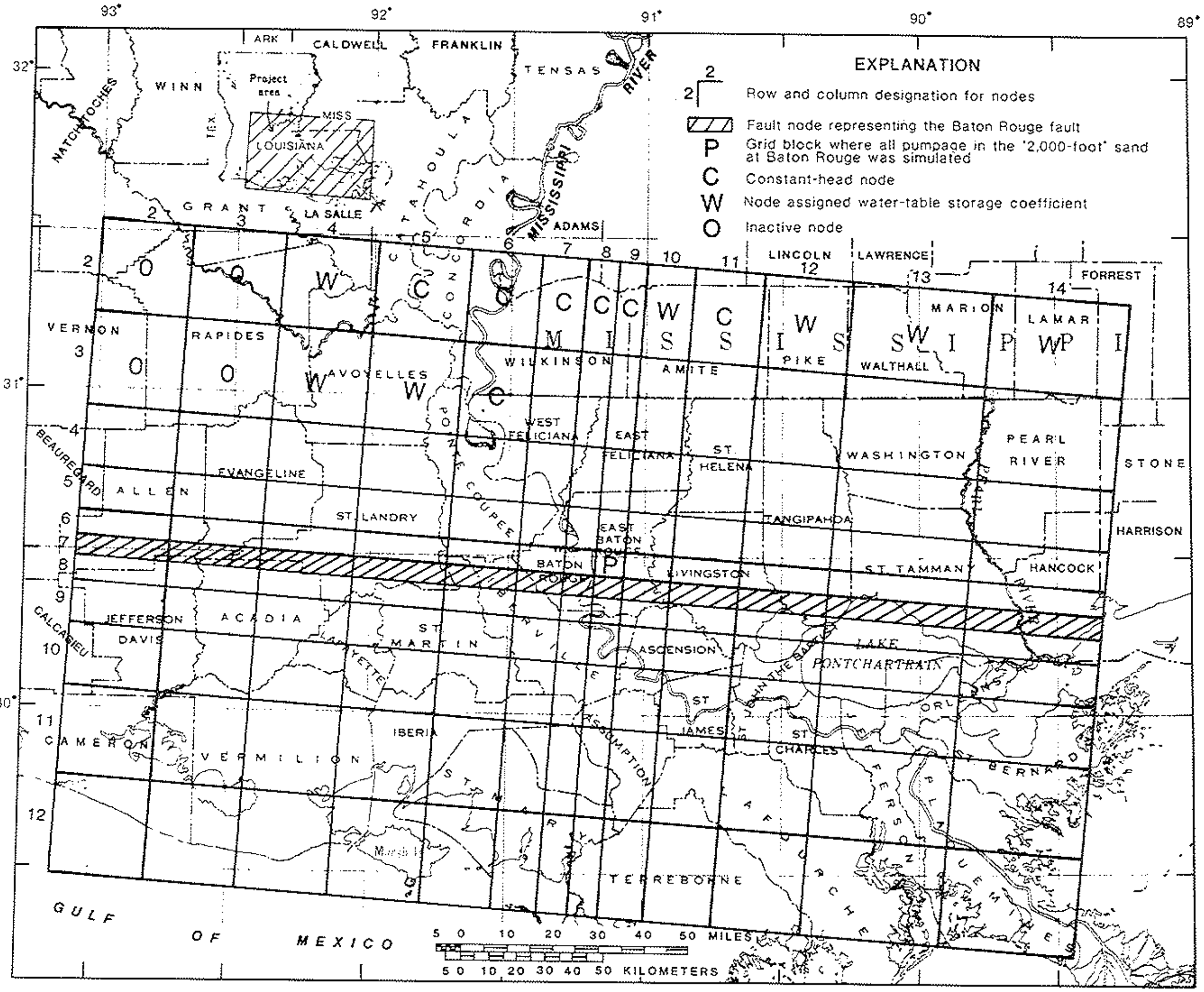


Figure 2.--Finite-difference grid of model area for preliminary investigations.

For the preliminary investigations, it was assumed that the "2,000-foot" sand and other hydrologically connected units extend at least as far as the model boundaries. This assumption was found to be valid when electrical logs of wells were analyzed in the model area.

Initial Conditions

At the beginning of the simulation period (1916), the potentiometric surface of the "2,000-foot" sand was assumed to represent steady-state conditions. Prior to this date, ground-water withdrawals from this aquifer and from aquifers immediately above or below the "2,000-foot" sand totalled less than 0.5 Mgal/d. Pumping rates of this magnitude were found to have negligible effects on the potentiometric surface of the "2,000-foot" sand. Therefore, the two-dimensional model simulated drawdowns since 1916, which were then superposed onto the steady-state head distribution to obtain computed water levels for the period simulated. The initial pumping period used in this preliminary investigation simulated a withdrawal rate of 2 Mgal/d from the "2,000-foot" sand for the years 1916-25.

The data set used in this model appears in appendix I. These data are arranged according to the input format required by the two-dimensional, finite-difference model of Trescott, Pinder, and Larson (1976), as modified by Larson (1978) to include the D4 direct-solution algorithm.

Results of Two-Dimensional Preliminary Investigation

This investigation showed that the "2,000-foot" sand does not respond to pumpage as an independent hydrologeologic unit, and that transient effects of leakage from confining layers are significant to the water budget of this aquifer. After the first pumping period, 1916-25, the model indicated the volume of water derived from leakage from a confining layer above the "2,000-foot" sand approximated 44 percent of the total volume withdrawn by pumping. Leakage rates computed by the model show this effect is transient in nature, with a non-uniform gradient established across the confining layer and water released from storage within the layer.

Values of dimensionless time ($k't/b^2Ss$)[1/] less than 0.5 were computed by the model for the last time step of the initial pumping period, indicating that transient leakage had not dissipated by the end of the 10-year simulation of pumpage. Thus, water derived from transient leakage was entering the "2,000-foot" sand as the pumping period terminated.

[1/]For the computation of dimensionless time, k' is the vertical hydraulic conductivity of the confining layer, b is its thickness, Ss is specific storage, and t is time-step size, all in consistent units. (See documentation of two-dimensional model by Trescott, Pinder, and Larson, 1976 for explanation of leakage versus dimensionless time.)

An analysis of the terms contained in the cumulative-mass balance for the remaining pumping periods showed transient effects were present at the conclusion of each pumping period. For the entire 60-year simulation, leakage amounted to about 36 percent of the total volume of water withdrawn by pumpage. Values for dimensionless time were consistently below 0.5 at the end of each pumping period, indicating transient leakage from the confining layer.

The two-dimensional, digital model used on this investigation does not preserve flow rates of transient leakage from one pumping period to the next. The model assumes these effects have dissipated in the confining layer before each pumping period ends. Therefore, as succeeding pumping periods with transient effects present at the end of each are simulated in the "2,000-foot" sand, a significant volume of water is lost from the model, indicating that the percentage of water derived from leakage is even larger than shown in this simulation.

The model used in this study can only simulate the effects of one confining layer, situated above the "2,000-foot" sand. The large percentage of water indicated to be derived from leakage, both steady and transient, by the two-dimensional model indicates the need to use a digital model that can accurately simulate leakage effects from confining layers above and below the "2,000-foot" sand.

The inability to accurately account for transient leakage from confining layers and the inability to simulate these effects from both above and below the aquifer rendered the two-dimensional model inappropriate for simulating ground-water flow in the "2,000-foot" sand. However, this model was useful in evaluating the effects of leakage from a confining layer and in refining the conceptual model of the "2,000-foot" sand to include this hydrogeologic factor. As a result, an aquifer system comprised of the "2,000-foot" sand and other aquifers (separated by confining layers) was simulated as described in the following sections, using a digital model for ground-water flow in three dimensions.

Three-Dimensional Model

Model Description and Data Requirements

The preliminary investigations were designed to determine the vertical extent needed in a model of the aquifer system at Baton Rouge to accurately represent leakage into the "2,000-foot" sand from confining layers. Systems comprised of five and seven aquifers, each bounded by confining layers, were used in these investigations (fig. 3). The seven-aquifer model simulated the entire system of freshwater aquifers beneath Baton Rouge.

A finite-difference model for simulation of ground-water flow in three dimensions (Trescott, 1975; and Trescott and Larson, 1976) was used in these investigations. The modified three-dimensional, finite-difference equation described in the program documentation was used to simulate each aquifer with one layer in the model (fig. 3). Modifications similar to those by Posson and others (1980) were made to the original computer

Layer number					
5- and 7-layer model	Detailed 3-layer model	Aquifer	Transmissivity (ft^2/s)	Storage Coefficient	Average Thickness (ft)
7*		"400-600-foot" sand	0.125	5.0×10^{-4}	315
6*		"800-foot" sand	0.04	5.0×10^{-4}	100
5		"1,200-foot" sand	0.11	1.2×10^{-4}	130
4	3	"1,500-1,700-foot" sand	0.02-4.50	5.0×10^{-4}	20-250
3	2	"2,000-foot" sand	0.04-3.20	5.0×10^{-4}	30-300
2	1	"2,400-foot" sand	0.03-0.50	1.0×10^{-4}	0-300
1		"2,800-foot" sand	0.20	1.0×10^{-4}	200

*Not simulated in 5-layer model.

(dashed-line symbol) Confining layers separating aquifers--
Vertical hydraulic conductivity = 2.0×10^{-10} ft/s,
Specific storage = 1.6×10^{-5} ft^{-1}

Figure 3.--Diagrammatic section of aquifer system at Baton Rouge and parameter values used in preliminary three-dimensional model.

program to allow the simulation of transient-leakage effects in the confining layers. The finite-difference grid used in the preliminary three-dimensional models was the same as that used in the two-dimensional investigation, 13 rows by 15 columns (fig. 2).

The seven-layer model determined the sensitivity of the entire aquifer system to pumping in the "2,000-foot" sand. This preliminary model simulated a pumping history identical to that used in the two-dimensional investigation (table 1). All pumpage by industry and public supply was placed in one node having the same dimensions and location as that used in the two-dimensional model (fig. 2).

The second preliminary model consisted of five-layers (fig. 3), and included pumpage from three aquifers; the "1,500- 1,700-foot", "2,000-foot", and "2,400-foot" sands. By simulating drawdown in these aquifers, leakage effects from confining beds immediately above and below the "2,000-foot" sand approximated realistic responses to pumping. Pumpage from three aquifers was simulated for the same historical record of 60 years and 10 pumping periods as the previous investigation. Pumping rates for this simulation are listed in table 2. All pumpage for each aquifer was placed in one node, by design of the finite-difference grid (fig. 2).

Table 2.--Temporal distribution of pumpage for preliminary three-dimensional model of "2,000-foot" sand

Pumping period	Years simulated	Pumping rate (Mgal/d)		
		Layer 1 ("2,400-foot" sand)	Layer 2 ("2,000-foot" sand)	Layer 3 ("1,500- 1,700-foot" sand)
1	1916-25	0.5	2.0	3.0
2	1926-39	1.5	4.0	2.0
3	1940-50	5.0	12.7	3.0
4	1951-56	9.0	14.5	6.5
5	1957-60	10.0	20.7	8.1
6	1961-65	9.0	24.6	9.0
7	1966-67	11.0	29.6	11.5
8	1968-69	13.0	35.1	12.0
9	1970-74	13.0	38.3	19.5
10	1975	12.6	36.8	22.4

Estimates of values for aquifer parameters used in the three-dimensional models were obtained from hydrogeologic reports on the Baton Rouge area by Meyer and Turcan (1955), Morgan (1961), and Morgan and Winner (1964). Thickness data for the aquifers and confining layers were obtained through analysis of electrical logs of wells. Areal variations of transmissivity for the "1,500- 1,700-foot", the "2,000-foot", and the "2,400-foot" sands, were represented in these investigations with matrices containing variable data. Values of storage coefficient were increased, as in the two-dimensional model, to represent the recharge area north of Baton Rouge. The ranges of values are shown in figure 3.

The hydraulic parameters of the remaining aquifers and confining layers were represented in these models with uniform values. However, storage coefficients were varied in the recharge area, and transmissivities were reduced along the row representing the Baton Rouge fault, as in the two-dimensional model. These values are also shown in figure 3.

Inputs of thickness, vertical hydraulic conductivity, and specific storage for each confining layer are part of the additional data requirements for the three-dimensional model resulting from modifications that simulate transient leakage. If these parameters are well defined, transient leakage from the confining layers can be accurately simulated by the model.

The variable thickness of the two confining layers separating the "1,500- 1,700-foot", "2,000-foot", and "2,400-foot" sands (fig. 3), was input to the models in matrix form. Due to the paucity of data defining vertical hydraulic conductivity and specific storage, uniform values for these parameters were assigned to all confining layers as an initial estimate. The ranges of values for thickness of these confining layers and the values of vertical hydraulic conductivity and specific storage are shown in figure 3.

The complete data set used for these investigations can be found in appendix II. These data are listed according to the input format specified in the documentation of the three-dimensional model by Trescott (1975), and according to the additional data inputs required for the transient-leakage approximation. Instructions for these additional data inputs are given in appendix IV-B.

Results of Seven-Layer Model

At the end of the 60-year simulation, drawdown at the pumping node in the "2,000-foot" sand was about 230 ft. Although the actual drawdown in the industrial district of Baton Rouge was about 400 ft for the same interval of time, the computed value is a reasonable estimate for the preliminary model. It represents an average drawdown for a grid-block that is 42 mi^2 in area, one quarter of which contains the industrial district (fig. 2). Because the concentrated pumping by industry was distributed over a large area, local depressions in the potentiometric surface of the "2,000-foot" sand could not be simulated with the preliminary model. However, this did not detract from the usefulness of the model in evaluating the sensitivity of the seven-aquifer system to pumping from the "2,000-foot" sand.

Drawdowns above and below the pumping node in the "2,000-foot" sand reached 6.7 ft for the "1,500- 1,700-foot" sand and 7.8 ft for the "2,400-foot" sand. These values each represent about 3 percent of the total drawdown that occurred at the pumping node in the "2,000-foot" sand. Drawdown at the same node for the "1,200-foot" sand was about 0.3 ft, and about 0.6 ft for the "2,800-foot" sand. Above the "1,200-foot" sand, about 0.01 ft of drawdown was computed at this node for the "800-foot" sand.

Vertical leakage from the confining layers was evaluated using terms listed in the printout for cumulative mass balance of the seven-layer model. The volume of water attributed to leakage from confining layers amounted to about 57 percent of the total volume withdrawn by pumping. This is about 13 percent higher than the value obtained from the two-dimensional investigation. The higher value is probably a more accurate representation of leakage because the three-dimensional model was able to simulate transient effects in the confining layers at the end of the pumping periods.

The impact of drawdown in the "2,000-foot" sand on the aquifers immediately above and below created large hydraulic gradients in the confining layers between these units. As a result, leakage effects from confining layers in contact with the "2,000-foot" sand were shown to contribute significant volumes of water to the aquifer as pumpage was simulated. Leakage from confining layers above the "1,500- 1,700-foot" sand and below the "2,400-foot" sand had negligible effects on the "2,000-foot" sand.

Additional simulations in which upper aquifers ("400-600-foot", "800-foot", and "1,200-foot" sands) and the lowermost aquifer ("2,800-foot" sand) were eliminated indicated that these layers had negligible effects on drawdowns in the "2,000-foot" sand. The effects of pumping from the "2,000-foot" sand were vertically limited to the "1,500- 1,700-foot", "2,000-foot", and "2,400-foot" sands and the confining layers separating them.

Although pumping occurs in every aquifer that was simulated in the seven-layer model, the purpose of this investigation was to determine how far and through how many aquifers and confining layers the effects of pumping in the "2,000-foot" sand would extend. By only simulating pumpage from the "2,000-foot" sand, the values obtained for leakage and the head differences between aquifers would represent very conservative values, that is, worst-case conditions. In actuality, head differences between the "2,000-foot" sand and the aquifers directly above and below are less than those indicated by the seven-layer model and smaller amounts of water would be derived from leakage from confining layers.

Results of Five-Layer Model

When pumpage was simulated in three aquifers for this investigation, computed drawdowns at the pumping nodes in the "1,500- 1,700-foot", "2,000-foot", and "2,400-foot" sands represented reasonable average values. For the "2,000-foot" sand, drawdown increased about 6 ft from the value of 230 ft computed by the seven-layer model. This increase was in response to pumping in the "1,500- 1,700-foot" and "2,400-foot" sands, which was not simulated in the seven-layer model. Drawdowns computed for the "1,500- 1,700-foot" and "2,400-foot" sands were about 153 ft and 111 ft, respectively. Actual drawdowns for each of these aquifers in the industrial area of Baton Rouge were about 230 ft for the 60-year period. About 3 ft of drawdown for the "1,200-foot" sand was computed above the pumping nodes and about 4 ft was computed below these nodes for the "2,800-foot" sand.

The increased drawdown of about 3 percent computed for the "2,000-foot" sand by this model compared to that computed by the seven-layer model can be attributed to a reduction in head differences causing a reduction in steady leakage between the aquifers. Head differences between the aquifers were reduced from about 223 ft in the seven-layer model to about 125 ft between the "2,000-foot" and the "2,400-foot" sands, and about 83 ft between the "2,000-foot" and the "1,500- 1,700-foot" sands. Although an increase in drawdown was expected in the "2,000-foot" sand as the adjacent aquifers were pumped, the increase of only 6 ft indicates that most of the leakage from the confining layers is transient in nature, and not dependent upon uniform gradients established between the aquifers. If steady-leakage effects were dominant over transient effects, then larger drawdowns than those computed for the "2,000-foot" sand by the five-layer model would have occurred as the hydraulic gradients that control steady leakage between aquifers were substantially reduced by pumping from adjacent aquifers.

Vertical sensitivity to pumping of the five-layer model was similar to that of the seven-layer model; drawdowns were greatly attenuated across the confining layers in contact with the aquifers stressed by pumping. Only about 2 to 3 percent of the total drawdown computed for the pumping nodes of the "1,500- 1,700-foot" and "2,400-foot" sands was computed by the model for the "1,200-foot" and "2,800-foot" sands. This created large hydraulic gradients across the confining layers and consequent leakage effects that contribute water to the "1,500- 1,700-foot" and "2,400-foot" sands.

Although leakage into the "1,500- 1,700-foot" sand from the confining layer above and into the "2,400-foot" sand from the confining layer below is substantial, these effects need not be represented in the model to simulate the flow system of the "2,000-foot" sand. Computing the approximate head distribution in response to pumping in the "1,500- 1,700-foot" and the "2,400-foot" sands approximates the hydraulic gradients in the confining layers separating these aquifers from the "2,000-foot" sand and allows the proper leakage effects to be simulated. The five-layer model demonstrated that computed drawdowns in the "2,000-foot" sand were not very sensitive to reductions in the head differences between this aquifer and the "1,500- 1,700-foot" and the "2,400-foot" sands. Therefore, small errors involved in the computed head distributions resulting from excluding leakage effects in the model from the overlying confining layer to the "1,500- 1,700-foot" sand and from the underlying layer to the "2,400-foot" sand would have little effect on leakage into the "2,000-foot" sand.

Summary of Three-Dimensional Model Investigations

Preliminary investigations using five- and seven-layer models evaluated the sensitivity of the aquifer system at Baton Rouge to pumping from the "2,000-foot" sand and from aquifers directly above and below this unit. This resulted in refinements to a conceptual model of the "2,000-foot" sand to include pumpage in the "1,500- 1,700-foot" and "2,400-foot" sands and leakage from confining layers separating these aquifers.

Because leakage effects are controlled in part by the hydraulic gradients established across the confining layers, drawdowns in the "1,500- 1,700-foot" and "2,400-foot" sands were simulated by the digital model in addition to drawdown in the "2,000-foot" sand. Leakage effects are also controlled by the vertical hydraulic conductivity and specific storage of the confining layers. Values used to represent these parameters in the preliminary investigations were based on only a few measurements and leakage was shown to be an important source of water to the "2,000-foot" sand, so refinement of the data base defining these parameters was necessary.

The coarse-grid models used in the preliminary investigations identified other variables and hydrogeologic factors present in the study area that required additional evaluation. The hydraulic conductivity of the Baton Rouge fault was needed so that its effect in restricting ground-water flow northward to the pumping centers could be accurately represented in the detailed model. The location and rates of pumping and the spatial variations of aquifer parameters were needed for the study area so that their localized effects could be simulated. The identification of these variables and hydrogeologic factors contributed to a refinement of the conceptual model for the "2,000-foot" sand and a better understanding of the flow system for this aquifer.

Leakage Across the Baton Rouge Fault--One-Dimensional Model

Background

The Baton Rouge fault is an east-west trending normal fault located south of the pumping centers at Baton Rouge (fig. 1). Three hundred feet or more of vertical displacement has occurred below a depth of about 1,000 ft, causing the "1,500- 1,700-foot" sands south of the fault to become hydraulically connected to the "2,000-foot" sand to the north. In the same manner, the "1,200-foot" and the "2,000-foot" sands south of the fault are connected to the "1,500- 1,700-foot" and "2,400-foot" sands, respectively, north of the fault. The geology of the fault zone in the project area and the role of the fault in restricting the northward movement of ground water has been described in reports by Rollo (1969), Smith (1976, 1979), and Whiteman (1979).

This fault is part of the "Baton Rouge fault zone" (Cardwell and others, 1967), that extends from south-central Louisiana through Baton Rouge and across the northern part of Lake Pontchartrain (pl. 1). It was assumed that the Baton Rouge fault represented a continuous barrier across the model area that restricts ground-water flow.

Water levels in observation wells completed in aquifers that are connected across the fault indicate that the Baton Rouge fault restricts, but does not prevent, the northward flow of ground water. Although water levels in well EB-781 north of the fault were about 200 ft lower than the levels in well EB-780B on the south side, water levels in well EB-780B reflect water-level declines in well EB-781 and effects of pumpage to the north. (See fig. 5 in Smith, 1976.)

For accurate simulation of ground-water flow in the "2,000-foot" sand, it was necessary to determine the hydraulic conductivity of the fault zone. Hydrographs from wells EB-781 north of the fault and EB-780B south of the fault were utilized in a digital model of ground-water flow to solve for the hydraulic conductivity of the fault zone.

Modeling Approach

The expression for the equation of ground-water flow used in this investigation was a one-dimensional version of equation 3 used in the finite-difference model for the simulation of ground-water flow by Trescott (1975, p. 3):

$$\frac{\partial}{\partial x}\left(k_{xx}\frac{\partial h}{\partial x}\right)=S_s\frac{\partial h}{\partial t}$$

in which k_{xx} = the principal component of the hydraulic conductivity tensor $[LT^{-1}]$,
h = hydraulic head $[L]$,
and S_s = specific storage $[L^{-1}]$.

This equation was approximated in a computer program using an implicit finite-difference formula described by Remson and others (1971). The computer code and part of the program output are listed in appendix III.

Water levels for the period April 23, 1965 to April 22, 1969 from well EB-781 north of the fault were input to the model. The hydrograph of well EB-780B, south of the fault, was simulated in the model by adjusting the hydraulic conductivity of the fault zone.

Development of Finite-Difference Grid

A line connecting wells EB-780B and EB-781 was divided into seven equal segments, 600 ft in length, defining the spacing between nodes. Well EB-781 was placed at node 1, north of the fault. The fault was represented at node 2, and well EB-780B was located at node 8 south of the fault (fig. 4). A line of 32 nodes was extended beyond well EB-780B so that boundary effects would not introduce significant errors in computations of water levels south of the fault. The program listing and output in appendix III defines the additional node spacing beyond well EB-780B.

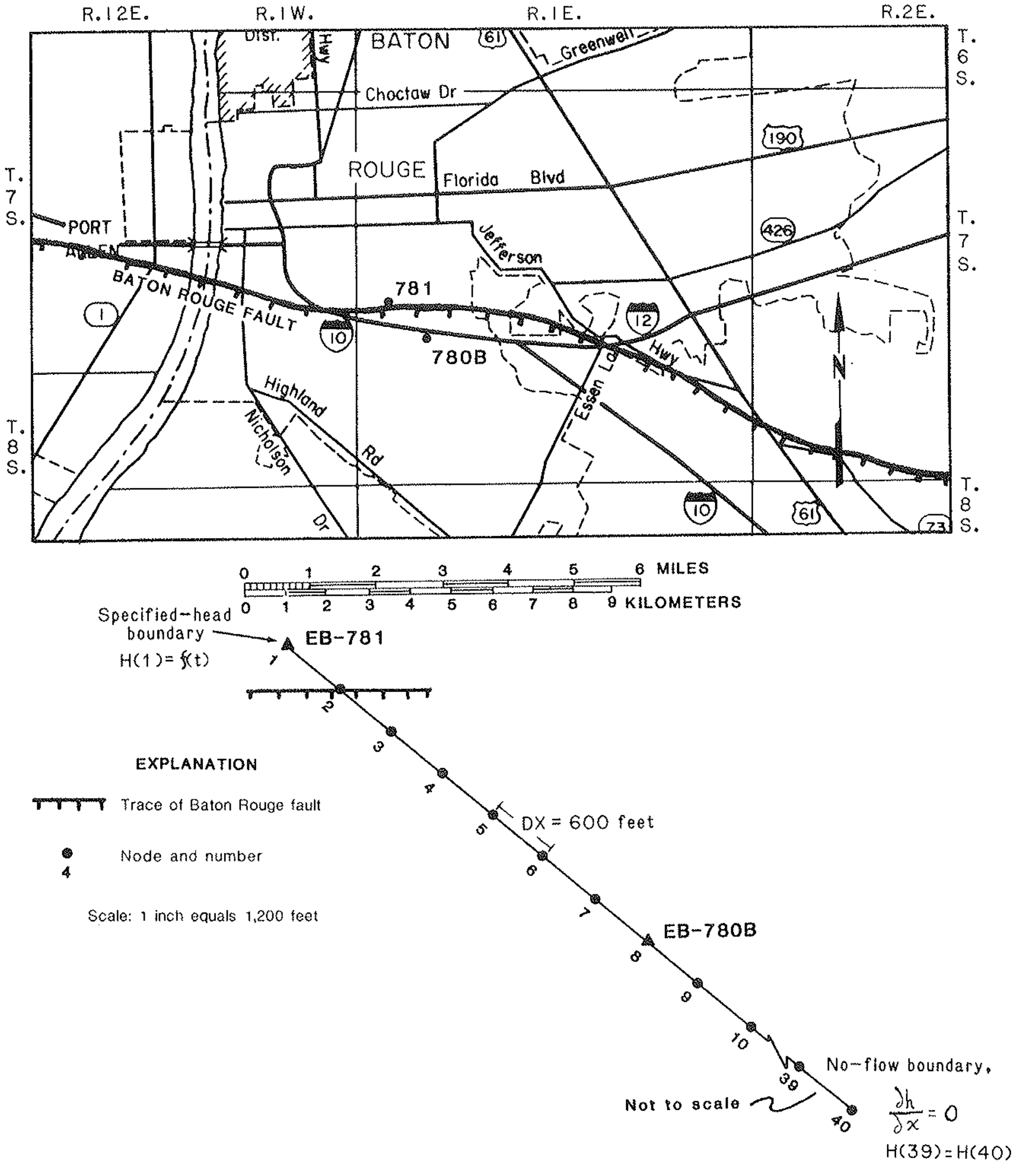


Figure 4.--Finite-difference grid for one-dimensional model across the Baton Rouge fault.

Boundary and Initial Conditions

The first node in the one-dimensional model was defined as a time-dependent, specified-head boundary, the values of which were water levels in well EB-781 (table 3). A no-flow boundary was placed at the other end of the model grid, and was established by computing identical values of water levels for the last two nodes. (See fig. 4 and program listing in appendix III.)

The initial head distribution was computed north of the fault using a hydraulic gradient of 20 ft/mi (Rollo, 1969), and the water level in well EB-781 on April 23, 1965. South of the fault, the initial head distribution was obtained using the water level in well EB-780B for this date, and a gradient of 0.3 ft/mi.

Hydraulic conductivities of 1.93×10^{-3} ft/s for the "2,000-foot" sand and 1.64×10^{-3} ft/s for "1,500- 1,700-foot" sand were obtained from a report by Meyer and Turcan (1955). A value of specific storage of 1.94×10^{-5} ft^{-1} was input to the model.

Results of the One-Dimensional Investigation

Water levels at the node corresponding to well EB-780B, south of the fault, were computed by the one-dimensional model based on the input of water levels on the north side at well EB-781 (table 3). Values for the hydraulic conductivity of the fault node were changed on a trial-and-error basis until computed water levels for well EB-780B matched the actual hydrograph of the well for the simulation period. Figure 5 shows computed water levels and the actual hydrograph of well EB-780B for the period April 23, 1965 to April 22, 1969.

A value of 3.47×10^{-7} ft/s was selected to represent the hydraulic conductivity of the fault node in the one-dimensional model. (See fig. 5.) This is about 3.5 orders of magnitude less than the hydraulic conductivity of the adjacent nodes in the aquifer.

The value for hydraulic conductivity at the fault node is representative of a 600-foot-wide zone, by design of the one-dimensional model. It does not represent the actual hydraulic conductivity of the fault itself. However, the actual value of this parameter for the fault need not be known in order for its effects to be simulated.

A manipulation of Darcy's Law (Davis and DeWiest, p. 157, 1966), yields

$$Q/\Delta h = Ak/L$$

where: Q = volumetric flow rate across the fault $[L^3/T]$,
Δh = head loss over a distance L, across the fault zone $[L]$,
A = cross-sectional area normal to Q $[L^2]$,
k = hydraulic conductivity of the fault $[L/T]$,
and L = distance over which head loss Δh occurs $[L]$.

[WATER LEVELS IN FEET BELOW LAND-SURFACE DATUM (LSD).
LSD = 28.00 FEET ABOVE THE NATIONAL GEODETIC VERTICAL DATUM OF 1929]

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
APR. 23, 1965	122.38	FEB. 20, 1966	122.25	DEC. 20, 1966	147.30	OCT. 15, 1967	159.33
APR. 26	122.78	FEB. 25	121.51	DEC. 25	146.80	OCT. 20	158.80
APR. 30	122.50	FEB. 28	119.82	DEC. 31	146.10	OCT. 25	158.65
MAY 5	124.95	MAR. 5	120.08	JAN. 5, 1967	146.20	OCT. 31	159.12
MAY 10	126.00	MAR. 10	119.78	JAN. 10	145.90	NOV. 5	159.69
MAY 15	126.00	MAR. 15	119.12	JAN. 15	146.73	NOV. 10	157.08
MAY 20	125.71	MAR. 20	120.35	JAN. 20	148.45	NOV. 15	157.70
MAY 25	124.00	MAR. 25	120.95	JAN. 25	149.05	NOV. 20	158.84
JUNE 1	125.25	MAR. 31	121.20	JAN. 31	149.50	NOV. 25	159.29
JUNE 5	127.17	APR. 5	123.03	FEB. 5	150.00	NOV. 30	157.92
JUNE 10	126.73	APR. 15	126.20	FEB. 10	149.80	DEC. 5	158.21
JUNE 15	127.35	APR. 20	125.55	FEB. 15	149.30	DEC. 10	159.54
JUNE 20	129.40	APR. 25	124.50	FEB. 20	143.32	DEC. 15	158.73
JUNE 25	129.70	APR. 30	126.25	FEB. 25	143.58	DEC. 20	159.09
JUNE 30	128.51	MAY 5	125.11	FEB. 28	144.42	DEC. 25	161.49
JULY 15	127.18	MAY 10	123.97	MAR. 5	145.25	DEC. 31	161.35
JULY 20	127.81	MAY 15	125.60	MAR. 10	147.92	JAN. 5, 1968	160.37
JULY 25	131.63	MAY 20	126.10	MAR. 15	147.58	JAN. 10	159.73
JULY 31	132.07	MAY 25	127.35	MAR. 20	148.74	JAN. 15	159.62
AUG. 5	131.35	MAY 31	127.80	MAR. 25	150.10	JAN. 20	159.70
AUG. 10	131.37	JUNE 5	128.25	MAR. 31	150.63	JAN. 25	159.67
AUG. 15	129.22	JUNE 10	130.87	APR. 5	150.98	JAN. 31	159.50
AUG. 20	126.13	JUNE 15	131.63	APR. 10	151.36	FEB. 5	160.80
AUG. 25	125.00	JUNE 20	131.13	APR. 15	152.05	FEB. 10	159.90
AUG. 31	123.86	JUNE 25	133.72	APR. 20	153.65	FEB. 15	160.00
SEP. 5	125.41	JUNE 30	136.09	APR. 25	152.98	FEB. 20	161.10
SEP. 10	125.89	JULY 5	133.33	APR. 30	153.20	FEB. 25	160.80
SEP. 15	127.00	JULY 10	135.01	MAY 5	152.94	FEB. 29	160.80
SEP. 20	128.40	JULY 15	136.20	MAY 10	153.19	MAR. 5	160.80
SEP. 25	129.20	JULY 20	136.30	MAY 15	153.42	MAR. 10	161.20
SEP. 30	127.67	JULY 25	135.90	MAY 20	154.14	MAR. 15	158.40
OCT. 5	125.95	JULY 31	137.70	MAY 25	152.84	MAR. 20	158.20
OCT. 10	125.20	AUG. 5	139.50	JUNE 9	155.28	MAR. 25	159.70
OCT. 15	127.25	AUG. 10	139.60	JUNE 15	155.71	MAR. 31	157.20
OCT. 20	127.91	AUG. 15	138.32	JUNE 20	155.59	APR. 5	157.99
OCT. 25	128.50	AUG. 20	139.50	JUNE 25	155.65	APR. 10	159.20
OCT. 31	127.80	AUG. 25	138.16	JUNE 30	156.51	APR. 15	160.60
NOV. 5	129.27	AUG. 31	138.60	JULY 5	153.78	APR. 20	155.20
NOV. 10	129.08	SEP. 5	140.40	JULY 10	154.17	APR. 25	153.10
NOV. 15	128.73	SEP. 12	140.59	JULY 15	154.38	MAY 3	167.60
NOV. 20	129.73	SEP. 15	142.80	JULY 20	154.21	MAY 15	167.12
NOV. 25	129.09	SEP. 20	142.70	JULY 25	154.44	JUNE 10	170.35
NOV. 30	127.67	SEP. 25	142.75	JULY 31	156.46	JULY 17	175.23
DEC. 5	126.13	SEP. 30	143.20	AUG. 5	159.50	JULY 20	174.46
DEC. 10	125.27	OCT. 5	143.35	AUG. 10	160.21	JULY 25	174.28
DEC. 15	125.11	OCT. 10	143.35	AUG. 15	159.64	JULY 31	176.15
DEC. 20	123.16	OCT. 15	143.00	AUG. 20	158.01	AUG. 5	174.26
DEC. 25	122.50	OCT. 20	143.20	AUG. 25	157.71	AUG. 10	175.78
DEC. 31	121.65	NOV. 1	146.49	AUG. 31	156.62	AUG. 15	171.37
JAN. 5, 1966	121.65	NOV. 5, 1966	147.00	SEP. 2	157.35	AUG. 19	169.00
JAN. 10	121.81	NOV. 10	147.50	SEP. 13	160.56	AUG. 29	169.26
JAN. 15	121.39	NOV. 15	147.80	SEP. 15	159.86	SEP. 10	168.61
JAN. 20	122.26	NOV. 20	147.10	SEP. 20	159.48	OCT. 2	175.55
JAN. 25	122.76	NOV. 25	147.20	SEP. 25	159.88	OCT. 17	178.76
JAN. 31	125.58	NOV. 28	146.40	SEP. 30	160.18	NOV. 19	179.54
FEB. 5	125.96	DEC. 5	147.30	OCT. 5	159.96	FEB. 4, 1969	177.27
FEB. 10	124.85	DEC. 10	147.50	OCT. 10	160.60	APR. 24	180.62
FEB. 15	123.34	DEC. 15	147.40				

Table 3.--Water levels for well EB-781, north of Baton Rouge fault, used as input to one-dimensional model.

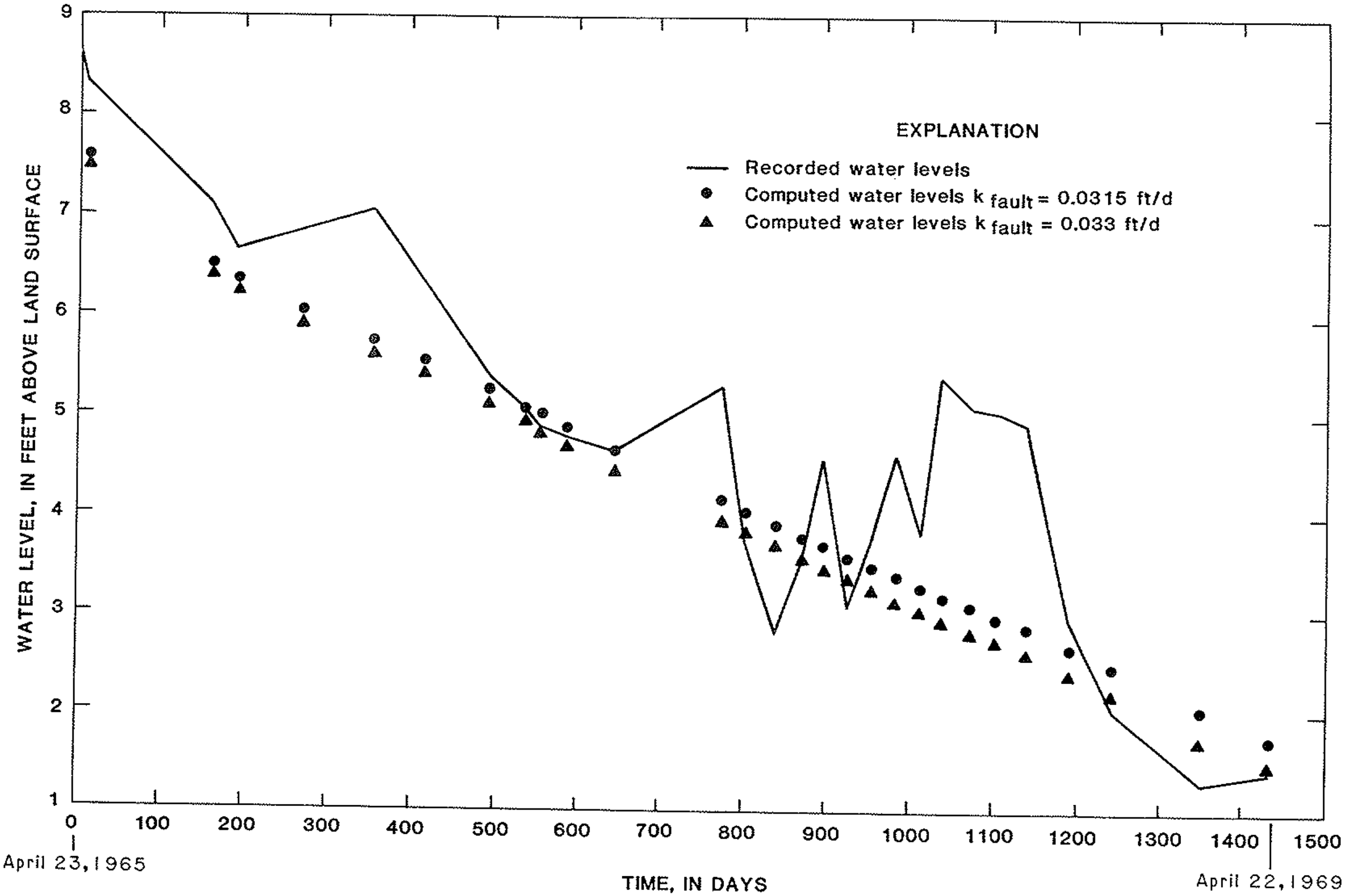


Figure 5.--Computed and actual water levels in well EB-780B showing results of one-dimensional simulation across the Baton Rouge fault.

The ratio $Q/\Delta h$, called hydraulic conductance, was determined across the fault zone in the model. When changing the scale of the grid from that used in the one-dimensional model to that used in the three-dimensional model, the ratio $Q/\Delta h$ remains constant (M. S. Bedinger, U.S. Geological Survey, written commun., August 1979). The hydraulic conductivity of the fault zone, k, was determined by the one-dimensional model and does not change when the fault is represented in the three-dimensional model. However, the cross-sectional area normal to the flow direction, A, and the distance over which the head loss occurs, L, are changed to reflect the change in model scale. In transforming the results obtained in the one-dimensional model into a form compatable with the input to the three-dimensional model, the cross-sectional area becomes the product of the aquifer thickness and the width of the flow path, which is defined by the grid spacing in the column direction (Δx_j). The length, L, is the grid spacing for the row representing the fault (Δy_i). The value of hydraulic conductivity obtained for the fault zone is multiplied by the aquifer thickness and input as transmissivity to the three-dimensional model.

DEVELOPMENT OF DETAILED THREE-DIMENSIONAL MODEL

Aquisition and Interpretation of Data for Aquifer Parameters

Hydrogeologic data defining aquifer parameters for the preliminary investigations were obtained from previous studies in the Baton Rouge area by Meyer and Turcan (1955), Morgan (1961), Morgan and Winner (1964), and Rollo (1969). For the detailed model, fence diagrams and geologic sections in these reports were supplemented by electrical logs of wells to provide additional data for aquifer thicknesses. Values of hydraulic conductivity and storage coefficient were taken from published data and aquifer-test data in files of the U.S. Geological Survey. The values of hydraulic conductivity were combined with thickness data to obtain the areal distribution of transmissivity for each aquifer.

The nomenclature for the aquifers at Baton Rouge (for example, "2,000-foot" sand) had not been used universally throughout the model area. Therefore, these aquifers were correlated with hydrogeologically connected units outside the Baton Rouge area, using geologic sections from Morgan (1963) and recent electrical logs of wells.

In East and West Feliciana Parishes, Morgan (1963) identified three zones of Tertiary age which form part of the aquifer system at Baton Rouge. The "1,700-foot" and "2,000-foot" sands were contained in Zone 2, and the "1,500-foot" sand was placed in Zone 1 with the "1,000-foot" and "1,200-foot" sands. Zone 3 contained the "2,400-foot" and "2,800-foot" sands.

In Pointe Coupee Parish, Winner and others (1968) identify Zone 2 as the "1,500-foot", "1,700-foot", and "2,000-foot" sands, and Zone 3 as the "2,400-foot" and "2,800-foot" sands. Geologic sections on plate 2 of their report were also supplemented by drillers' logs and electrical logs of wells to obtain thickness data for the detailed model.

For the model area west of Pointe Coupee Parish, thickness data for aquifers and confining layers were obtained predominantly from electrical logs of wells. Geologic sections by Jones (1954) and Whitfield (1975) identify Tertiary deposits correlative with aquifers at Baton Rouge as the Evangeline and Jasper aquifers. The latter report also contained estimates for the hydraulic conductivity and storage coefficient of these aquifers.

Geologic sections across East Feliciana Parish prepared by Morgan (1963), were continued southeastward by Winner (1963) across St. Helena, Livingston, Tangipahoa, and St. Tammany Parishes. Additional geologic sections crossing the latter two parishes (Nyman and Fayard, 1978) and in Washington Parish (Case, 1979) were used along with electrical logs of wells in these areas to obtain thicknesses of aquifers and confining layers. These reports also contained results of aquifer tests which yielded values of transmissivity, hydraulic conductivity, and storage cofficient for aquifers correlated with the aquifers at Baton Rouge.

As these aquifers were correlated northward and eastward into Mississippi, reports of areal studies in the southern part of the State provided necessary data for aquifer and confining-layer parameters. (See References.) Studies by Brown and Guyton (1943) and Brown (1944) contributed to the refinement of the data base for the recharge area in Mississippi.

Design of Finite-Difference Grid

The finite-difference grid used in the preliminary investigations (fig. 2) required additional discretization, or detailing, in the Baton Rouge area to account for local variations in pumping and aquifer characteristics. The original grid-block of 42 mi^2, containing all pumpage for each aquifer (fig. 2), was divided into smaller blocks ranging in area from 1.0 to 5.1 mi^2. Figure 6 shows the project area around Baton Rouge with the detailed finite-difference grid superposed.

The dimensions of the grid-blocks were expanded with distance from Baton Rouge until the entire model area was represented by a grid comprised of 26 rows and 30 columns. Plate 1 shows the finite-difference discretization of the active model area. The first and last row and column are excluded from this illustration because they represent inactive (noflow) boundaries. The largest active block measures 12 by 54 mi, and is located in the recharge area in Mississippi (pl. 1). The total active model area measures 120 by 267 mi, or 32,000 mi^2.

Evaluation of Leakage Parameters for Confining Layers--Steady-State Model

Background

The modified version of the three-dimensional computer code used in this study required input of thickness, vertical hydraulic conductivity, and specific storage of the confining layers to simulate the effects of

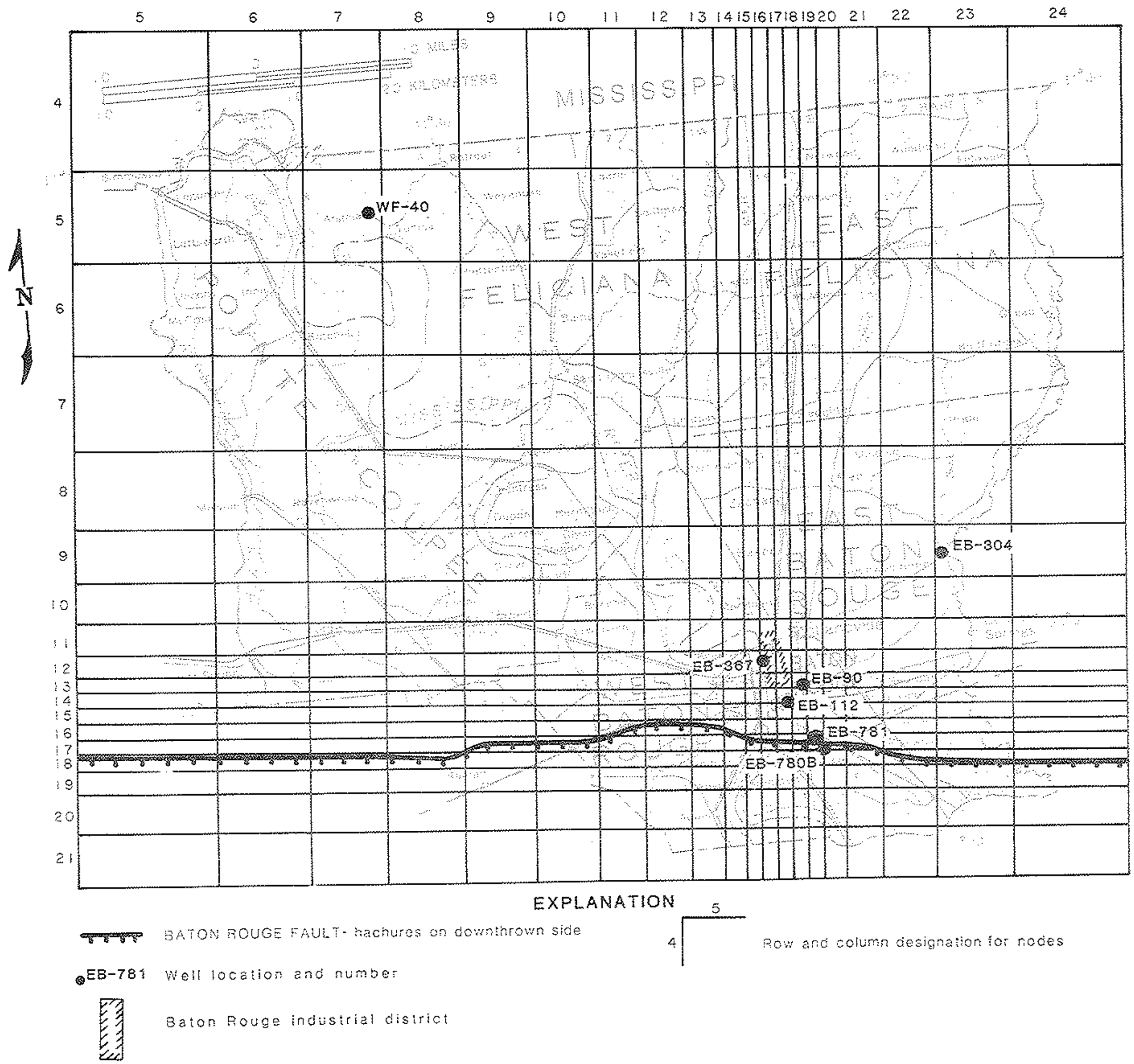


Figure 6.--Project area showing finite-difference grid for three-dimensional model.

leakage. Although the preliminary two- and three-dimensional models indicated that leakage from confining layers contributes significant quantities of water to the "2,000-foot" sand, the parameters controlling leakage, particularly vertical hydraulic conductivity and specific storage, were not well defined in those models. Additional values of confining-bed thickness were obtained through the analysis of electrical logs of wells. However, the only values for vertical hydraulic conductivity and specific storage of the confining layers were a few contained in a report by Whiteman (1980). To obtain a better estimate of vertical hydraulic conductivity, an investigation was conducted using a three-dimensional model of the Baton Rouge area to solve for this parameter.

Modeling Approach

Steady-state conditions of ground-water flow, as existed before the initiation of pumpage at Baton Rouge, were simulated using a three-dimensional, finite-difference digital model. The finite-difference grid shown on plate 1 was used to represent the model area for this simulation. For the steady-state model it was assumed that the distribution of aquifer transmissivities was known and that adjustments to these values was unnecessary. This simulation was to reconstruct the regional flow patterns that existed in the "1,500- 1,700-foot", the "2,000-foot", and the "2,400-foot" sands before pumping began. Differences in the computed results of this simulation and the actual prepumping-flow regime were resolved by adjusting values of vertical hydraulic conductivity of the confining layers. The areal distribution of vertical hydraulic conductivity resulting from the steady-state simulation provided a better estimate of this parameter than the original data that was available.

Boundary and Initial Conditions

In the recharge and discharge areas of the model, water levels were input as constant-head boundaries, providing the driving force for ground-water flow. (See pl. 2.) Reports on the ground-water resources of Mississippi by Stephenson and others (1928) and at Camp Van Dorn, Mississippi by Brown and others (1943) supplied water levels for the recharge area.

To the west of Baton Rouge, Whitfield (1975) describes a north-south trending area of discharge where upward movement of ground water occurs from the Jasper and Evangeline aquifers into the Chicot aquifer and the Achafalaya River. Water levels in this report and in reports by Meyer and Turcan (1955) and Maher (1940) supplied values for the constant-head boundary along the western side of the model. (See pl. 2.)

The establishment of a discharge area south of the Baton Rouge fault (pl. 2) was discussed by Rollo (1969) in a report on saltwater encroachment in the aquifers at Baton Rouge. Figure 1 of his report indicates an average hydraulic gradient of about 2.0 ft/mi from the recharge area of the "2,000-foot" sand southward to Baton Rouge before pumping began. Using this gradient and water levels measured about 1914 in wells completed in the "1,500- 1,700-foot", "2,000-foot", and "2,400-foot" sands;

water levels at the constant-head boundary in the discharge area were determined. The eastern side of the model was represented by a no-flow boundary because regional flow for conditions of steady state was parallel to this boundary.

A value of 2.0 X 10^{-10} ft/s was used to represent the vertical hydraulic conductivity of the confining layers. Although the confining layers simulated in this study contain silt and fine-grained sand as well as clay, this value determined for a clay (Whiteman, 1980, p. 18) was used as an initial estimate.

Results of Steady-State Simulation

Values of vertical hydraulic conductivity were adjusted locally for each confining layer on a trial-and-error basis until the model simulated actual conditions of steady-state flow. The conditions representing this type of flow in the model area as described by Rollo (1969) and diagrammed by Morgan (1963) include: (1) movement of ground water downward in the recharge area of Mississippi; (2) a zone of horizontal flow across East and West Feliciana, St. Helena, northern Tangipahoa, and Washington Parishes; and, (3) upward flow of ground water in the discharge area to the west and south of Baton Rouge. Results of the steady-state model simulating these effects are shown on plate 2.

The two matrices that define the distribution of vertical hydraulic conductivity for the confining layers resulting from the steady-state simulations are illustrated in figure 7. In the matrix representation of vertical hydraulic conductivities (fig. 7), an element value of 0.02 corresponds to the value of 2.0 X 10^{-10} ft/s which was originally input for this parameter. An inspection of the values of each element in these matrices reveals that, in certain areas of the model, vertical hydraulic conductivities for the confining layers were increased almost three orders of magnitude from the initial value. In areas of the model where the confining layers are thick, generally greater than 150 ft, values of vertical hydraulic conductivity are close to the initial value input to the model. Perhaps in these areas the confining layers contain a higher percentage of clay than in areas where the confining layers are thin. Distinct zones of vertical hydraulic conductivity in the confining layers are delineated in figure 7. Because the new values are generally larger than the initial one, leakage from confining layers separating the "1,500- 1,700-foot", "2,000-foot", and "2,400-foot" sands will be greater over most of the model area than indicated by the preliminary models, and sensitivity of each aquifer to pumping in the others will be increased.

Pumpage

For the detailed model, pumpage was included from outside of the Baton Rouge area. This pumpage distribution differs from that used in the preliminary investigations, where only pumpage at Baton Rouge was simulated. Pumpage of ground water at Baton Rouge from the "1,500-1,700-foot", "2,000-foot", and "2,400-foot" sands was tabulated by years for the period 1914-79. Beyond the five-parish project area, estimates

CONFINING LAYER SEPARATING "2000-FOOT" SAND FROM "2400-FOOT" SAND

ROW \ COLUMN	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
2	.02	.02	.02	.02	.02	.02	.02	.02	.02	.2	.7	2	2	2	2	2	2	2	2	2	7	10	10	10	10	10	2	2
3		.02	.02	.02	.02	.02	.02	.02	2	2	2	2	2	2	2	2	2	2	2	2	7	7	10	15	10	17	2	2
4		.02	.02	.02	.02	.02	.02	2	2	2	2	2	2	2	2	2	2	2	2	2	7	7	7	.7	.7	2	.2	.2
5		.02	.02	.02	.02	.02	.02	2	2	2	2	2	2	2	2	2	2	2	2	2	2	7	10	10	10	7	.2	.2
6		.02	.02	.02	.01	.01	.01	.2	.7	.7	.7	2	2	2	2	2	2	2	2	2	2	.7	10	7	7	.2	2	.2
7		.7	.7	.7	.7	.7	.7	.7	.7	.7	.7	.7	2	2	2	2	2	2	2	2	7	2	2	2	2	.2	2	.7
8			.2	.2	.2	.2	.2	.2	.07	.07	.07	.07	2	2	2	2	2	2	2	2	2	2	2	2	7	7	2	.7
9			.2	.2	.2	.2	.2	.2	.2	.07	.07	.07	.07	2	2	2	2	2	2	2	2	2	2	.2	7	7	2	.2
10			.2	.2	.2	.2	.02	.2	.2	.07	.07	.07	.07	2	2	2	2	2	2	2	2	2	.2	.2	7	7	2	.2
11			.2	.2	.07	.07	.07	.07	.07	.07	.07	.07	.07	2	2	2	2	2	2	2	2	2	2	7	7	7	2	.2
12			.7	.7	.07	.07	.07	.07	.07	.07	.07	.07	.07	2	2	2	2	2	2	2	2	2	2	7	7	7	2	.2
13			.7	.7	.07	.07	.07	.07	.07	.07	.07	.07	.07	2	2	2	2	2	2	2	2	2	2	7	7	7	2	.2
14			.1	.1	.07	.07	.07	.07	.07	.07	.07	.07	.07	2	2	2	2	2	2	2	2	2	2	.7	2	.7	2	.2
15			.1	.1	.07	.07	.07	.07	.07	.07	.07	.07	.07	2	2	2	2	2	2	2	2	2	2	.7	2	.7	2	.2
16			.1	.1	.1	.1	.1	.1	.1	.05	.05	.05	.05	2	2	2	2	2	2	2	2	.2	.2	2	2	2	2	.2
17			.1	.1	.1	.1	.1	.05	.05	.1	.1	.2	2	.05	.05	.05	.05	.05	.05	.05	2	.2	.2	2	2	2	2	.2
18			.05	.05	.05	.05	.05	.2	.2	.2	.2	.2	2	2	2	2	2	2	2	2	.01	.01	.01	.01	.01	.01	.05	.05
19				.1	.1	.1	.1	.1	.1	.1	.1	.2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
20				.1	.1	.1	.1	.1	.1	.1	.1	.2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
21				.1	.1	.1	.1	.1	.1	.1	.1	.2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
22				.1	.1	.1	.1	.1	.1	.1	.2	.2	2	2	2	2	2	2	2	2	2	.7	.7	.7	.7	2	2	2

CONFINING LAYER SEPARATING "1500-1700 FOOT" SAND FROM "2000-FOOT" SAND

ROW	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
2	10	10	10	10	10	10	10	10	10	.7	.7	.7	.7	.7	.7	.7	.7	.7	.7	.7	.7	.7	.7	.7	.7	.7	.7	.7
3		10	10	10	10	10	10	10	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
4		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	7	2	2
5		.2	.2	.2	.2	.2	.2	.2	.2	.2	2	2	2	2	2	2	2	2	2	2	.7	.7	.2	7	.2	.7	.2	.2
6		.2	.2	.2	.2	.2	.2	.2	.2	.2	2	2	2	2	2	2	2	2	2	2	.7	.7	.2	2	.2	.7	.2	.2
7		.1	.1	.1	.1	.1	.1	.1	.1	.2	2	2	2	2	2	2	2	2	2	2	.7	.7	.2	.2	.2	.7	.2	.2
8			.1	.1	.1	.1	.07	.07	.1	.2	2	2	2	2	2	2	2	2	2	2	.7	.7	.2	.2	.2	.7	.02	.02
9			.1	.1	.1	.1	.07	.07	.07	.1	2	2	2	2	2	2	2	2	2	2	2	2	2	.2	.2	.7	.02	.02
10			.1	.1	.1	.1	.1	.05	.05	.07	7	7	7	7	7	2	2	2	2	2	2	2	2	.2	.2	.7	.02	.02
11			.1	.1	.1	.1	.1	.1	.07	.1	7	10	10	10	10	2	2	2	2	2	2	2	2	.2	.2	.7	2	2
12			.1	.1	.1	.1	.1	.1	.1	.1	10	10	10	10	10	2	2	2	2	2	2	2	2	.2	.2	.2	2	2
13			.1	.1	.1	.1	.1	.1	.1	.1	10	10	10	10	10	2	2	2	2	2	2	2	2	.2	.2	.2	2	2
14			.1	.1	.1	.1	.1	.1	.1	.1	10	10	10	10	10	2	2	2	2	2	2	2	2	2	.2	2	2	2
15			.1	.1	.1	.1	.1	.1	.1	.1	10	10	10	10	10	2	2	2	2	2	2	2	2	2	.2	2	2	2
16			.1	.1	.1	.1	.1	.1	.1	.05	.05	.05	.05	2	2	2	2	2	2	2	2	2	2	2	.2	2	2	2
17			.1	.1	.1	.1	.1	.05	.05	2	2	2	2	.05	.05	.05	.05	.05	.05	.05	2	2	2	2	.2	2	2	2
18			.05	.05	.05	.05	.05	2	2	2	2	.7	.7	.7	2	2	2	2	2	2	.01	.02	.02	.02	.02	.01	.01	.01
19				2	2	2	2	2	2	2	.7	.7	.7	.7	.7	2	2	2	2	2	2	2	2	2	2	2	2	2
20				2	2	2	2	2	2	2	2	.7	.7	.7	2	2	2	2	2	2	2	2	2	2	2	2	2	2
21				2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
22				2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

Figure 7.--Nodal values of vertical hydraulic conductivity for confining layers resulting from steady-state simulation. (Only active nodes shown; see plate 2 for location of rows and columns. Multiply nodal values by 1 X 10^{-8} ft/s to obtain actual values of hydraulic conductivity.)

of pumpage from aquifers correlative with those at Baton Rouge were obtained for selected localities in Livingston, Tangipahoa, and Washington Parishes. Pumping rates were obtained from files of the U.S. Geological Survey, and from computer-tabulated records supplied by the Capital Area Groundwater Conservation Commission.

For simulation in the detailed model, historical pumpage was divided into 28 periods (table 4) based on temporal variations in pumpage observed at Baton Rouge for the "2,000-foot" sand. Grid blocks used to simulate pumpage for this model are shown on plate 1.

DESCRIPTION OF DETAILED THREE-DIMENSIONAL MODEL

An aquifer system composed of the "1,500- 1,700-foot", "2,000-foot", and "2,400-foot" sands, and the confining beds separating these units (fig. 4), was represented in a detailed digital-model simulating ground-water flow in three dimensions. The finite-difference model described earlier in this report, modified to include leakage effects from confining layers, was used to simulate this aquifer system at Baton Rouge.

Because of the few wells in and the low pumpage from the aquifer system before 1914, steady-state conditions of ground-water flow were assumed to exist prior to that year, the beginning of the first pumping period that was simulated. The model was used to solve for total drawdown since 1914, which was computed for the conclusion of each pumping period. Values of drawdown at selected nodes were converted to water levels with respect to the National Geodetic Vertical Datum of 1929 (NGVD) and land-surface datum (LSD), and compared to observed water levels in wells.

Boundary conditions for the detailed model were similar to the ones used in the preliminary two-dimensional and three-dimensional investigations. No-flow boundaries bordered the model on the east, west, and south. They were located sufficiently far from the pumping centers so their effects on drawdowns computed in the area of interest were negligible. A combination of constant-head nodes and nodes assigned water-table storage coefficients were used to represent the recharge area north of Baton Rouge. This configuration of model boundaries is illustrated on plate 1.

Although the aquifer of interest in this study was the "2,000-foot" sand, drawdowns in all three aquifers were simulated. As previously discussed, realistic vertical hydraulic gradients were established across the confining layers, allowing leakage effects from the confining layers to be simulated by the model.

The complete set of data for the detailed, three-dimensional model can be found in appendix IV-A. It is listed in a format compatable with the data inputs required for execution of the program documented by Trescott (1975). Additional data-input instructions pertaining to modifications for the solution of leakage from confining layers appear in appendix IV-B.

Table 4.--Temporal distribution of pumpage for detailed three-dimensional model of the "2,000-foot" sand

Pumping[1/] period	Years simulated	Pumping rates in cubic feet per second (million gallons per day)					
		Layer 1 ("2,400-foot" sand)		Layer 2 ("2,000-foot" sand)		Layer 3 ("1,500- 1,700-foot" sand)	
1	1914-15	0		0.67	(0.43)	0	
2	1916-19	0		2.48	(1.60)	0	
3	1920-26	0		4.22	(2.73)	0	
4	1927-29	0		6.71	(4.34)	1.70	(1.10)
5	1930-39	0		7.35	(4.75)	1.80	(1.16)
6	1940	0		11.75	(7.59)	4.57	(2.95)
7	1941	0		33.89	(21.9)	5.02	(3.24)
8	1942-43	5.89	(3.81)	42.75	(27.6)	6.14	(3.97)
9	1944-46	11.73	(7.58)	41.84	(27.0)	5.84	(3.77)
10	1947	12.04	(7.58)	43.09	(27.8)	9.22	(5.96)
11	1948-52	12.82	(8.28)	38.62	(25.0)	13.21	(8.54)
12	1953-55	15.01	(9.70)	38.10	(24.6)	13.51	(8.73)
13	1956-57	15.39	(9.95)	46.34	(29.9)	13.77	(8.90)
14	1958-59	12.57	(8.12)	51.35	(33.2)	14.91	(9.64)
15	1960-61	15.72	(10.2)	52.54	(34.0)	17.07	(11.0)
16	1962-63	15.72	(10.2)	52.54	(34.0)	17.07	(11.0)
17	1964-65	16.47	(10.6)	54.69	(35.4)	17.54	(11.3)
18	1966-67	19.39	(12.5)	56.90	(36.8)	19.42	(12.5)
19	1968-70	23.32	(15.1)	74.23	(48.0)	19.60	(12.7)
20	1971	24.41	(15.8)	79.33	(51.3)	21.39	(13.8)
21	1972	23.97	(15.5)	83.67	(54.1)	23.25	(15.0)
22	1973	24.44	(15.8)	87.72	(56.7)	23.71	(15.3)
23	1974	24.07	(15.6)	88.94	(57.5)	23.91	(15.4)
24	1975	24.00	(15.5)	84.31	(54.5)	26.07	(16.8)
25	1976	23.01	(14.9)	83.20	(53.8)	29.26	(18.9)
26	1977	23.24	(15.0)	80.83	(52.2)	28.70	(18.6)
27	1978	26.45	(17.1)	82.22	(53.1)	28.12	(18.2)
28	1979	25.41	(16.4)	84.56	(54.6)	29.17	(18.8)

1/ Pumping periods 1-15 used for calibration of model; periods 16-28 used for verification.

CALIBRATION OF THE DETAILED THREE-DIMENSIONAL MODEL

The calibration period for the detailed model was established as the first fifteen pumping periods listed in table 4, simulating the years 1914-61. The ending year 1961 was selected for calibration because many water-level measurements in wells in the aquifer system had been made then. Drawdowns were determined from observed water levels in wells at the start and end of the calibration period, and were compared to values computed by the model.

Point data on water levels were used for model calibration, although interpretive maps of potentiometric contours were available for some periods of record. A contoured surface derived from a limited number of points contains errors of subjectivity imposed by the contourer. Using point values of drawdown eliminated this potential source of error from the calibration procedure.

Sensitivity Analysis

A sensitivity analysis was performed to determine which parameters had the greatest effect on computed drawdowns. The most sensitive parameters required the most accurate representation in the model and were involved in the initial calibration procedures.

Using independent simulations, the aquifer parameters of transmissivity and storage coefficient were changed by an order of magnitude, and the resulting changes in computed drawdown were compared. These simulations indicated greater sensitivity (computed drawdowns were affected more) to changes in transmissivity than to changes in storage coefficient. Therefore, transmissivities of the aquifers were adjusted first during the calibration.

A similar sensitivity analysis was performed on the confining layers, using available values of specific storage and vertical hydraulic conductivity. This analysis showed that the model was more sensitive to changes in vertical hydraulic conductivity than to changes in specific storage. Thus, vertical hydraulic conductivities were adjusted in the initial calibration procedures, along with transmissivities of the aquifers.

A sensitivity analysis was not performed on values of pumpage or initial and boundary conditions used in the model. Pumping rates were accurately known for recent years and good estimates could be made for earlier years; therefore, pumping rates were not changed during calibration. The initial conditions of steady state appeared to be valid, due to the lack of stress (pumpage) imposed on the aquifer system prior to 1914. Boundary conditions were evaluated when the model area and finite-difference grid were selected and required no additional adjustments for calibration.

Trial-and-Error Adjustments

Initial calibration involved trial-and-error adjustments to the transmissivity of the aquifers and the vertical hydraulic conductivity of the confining layers. Adjustments were made within plausible limits to either the entire matrix defining each parameter, or to discrete locations in the model area, until computed drawdowns approached the observed values.

Initial simulations indicated a need to reduce the transmissivity of the fault nodes in all three aquifers. Because this parameter was defined initially for only one section across the fault, it was allowed to vary over a range of values until the correct aquifer response was obtained.

Trial-and-error adjustments to the parameters allowed simulated drawdowns to approach the observed values. However, because the aquifer system responds as a whole to changes in the values of each element, changing one parameter in the model to produce a desired response in one aquifer often caused an unfavorable response in another. Although combinations of changes to the parameters were considered for calibration, a combination of values that would accurately calibrate the model with a reasonable number of trials could not be obtained using the trial-and-error method. Therefore, parameter changes were made using the parameter-estimation technique described in the next section.

Use of Parameter-Estimation Program

A computer program for parameter estimation (J. V. Tracy, written commun., April 1980) was used to quantify the sensitivity of the aquifers as changes were made to each parameter. The program statistically analyzed the effects of varying a parameter on computed drawdowns, providing an objective and efficient means of calibrating the three-dimensional model. This program uses the output of computed heads generated by the three-dimensional finite-difference model as input for the parameter-estimation procedure. The computer code and instructions for data input to the program are listed in appendix V.

Transmissivities of the aquifers and vertical hydraulic conductivities of the confining layers were the first parameters tested using the parameter-estimation program. A "base run" of the model to simulate the calibration period was executed using a given set of parameter values. On successive "perturbation runs", a parameter value was increased, the calibration period was simulated, and then the parameter value was returned to its base-run value. Thus, each perturbation run represented the effects on the aquifer system of changing one parameter.

Observed values of drawdown and the computed values of drawdown from base and perturbation runs at the corresponding nodes were input to the parameter-estimation program. The "sensitivity", or change in drawdown caused by the change in parameter value, was computed by the program using results of base and perturbation runs. A sum of squares was then computed from the differences between observed drawdowns and those obtained from the base run. Estimates of the percentage change in parameter values that would reduce the sum of squares were provided as part of the program output.

Values for transmissivity and vertical hydraulic conductivity were allowed to vary within plausible limits as dictated by the output of the parameter-estimation program. Parameters were changed by adjusting a multiplier value on a card that preceeds each matrix. (See appendix IV and program documentation by Trescott, 1975.) All elements of the matrix defining a parameter were multiplied by this value. This type of adjustment preserves lateral nonhomogeneities between nodes while changing the values of all elements in the matrix.

After four sets of base and perturbation runs, subsequent analyses by the parameter-estimation program, and adjustment of the model (changing parameters as indicated by the parameter-estimation program), the sum of squares for computed and observed drawdowns was reduced to about half of its original value. The mean difference between observed and computed drawdowns decreased 4.6 ft (from 15.6 to 11.0 ft) after four simulations. After the fourth set of base and perturbation runs, the parameter-estimation program indicated that a change in each parameter of less than 10 percent would cause optimum reduction in the sum of squares. Table 5 lists computed and observed drawdowns for the fourth simulation.

When the parameter-estimation program indicated changes to parameter values of less than 10 percent, these changes were made and additional base and perturbation runs were executed. Resulting values for the sum of squares and mean difference are plotted in figure 8. These graphs show no significant decrease in the sum of squares or mean difference as five additional simulations and changes to parameter values were made. Thus, after the ninth calibration run, the detailed three-dimensional model was considered calibrated with respect to aquifer transmissivity and vertical hydraulic conductivity of the confining layers.

To complete the calibration procedure, storage coefficients of the aquifers and specific storages of the confining layers were evaluated by the parameter-estimation program. The specific storage of both confining layers was treated as a single parameter. Figure 8 shows a slight reduction in the sum of squares and a decrease of only 0.4 ft in the mean difference during four simulations involving changes to the storage parameters. Because neither the sum of squares nor the mean difference was reduced significantly in simulations involving changes to storage parameters, calibration of the detailed model was concluded. Computed and observed drawdowns for the final simulation of the calibration period are listed in table 5.

Figure 9 shows computed lines of equal drawdown and observed drawdowns at wells for the "2,000-foot" sand in the five-parish project area. A well-defined cone of depression in the potentiometric surface was established around Baton Rouge by the end of the calibration period (1961), and computed drawdowns closely matched the observed values. The

NODE IDENTIFICATION			DRAWDOWN, IN FEET		
LAYER (K)	ROW (I)	COLUMN (J)	OBSERVED	* COMPUTED	** COMPUTED
1	6	13	66.00	48.31	48.37
1	7	7	19.00	23.53	23.08
1	8	9	44.00	47.21	47.58
1	8	26	35.00	22.41	22.79
1	9	7	44.00	31.34	31.86
1	9	19	80.00	92.01	91.86
1	10	7	52.00	32.61	33.26
1	11	7	39.00	33.39	34.11
1	12	23	94.00	85.83	85.85
2	5	5	11.00	4.520	4.520
2	6	16	36.00	49.02	48.30
2	7	18	82.00	65.50	63.93
2	8	26	32.00	22.25	22.66
2	8	27	11.00	17.45	17.70
2	9	9	69.00	57.74	53.95
2	9	23	84.00	88.71	86.07
2	9	27	20.00	15.85	16.12
2	10	8	28.00	47.98	44.17
2	10	9	60.00	59.77	55.75
2	10	26	31.00	25.15	25.08
2	11	8	41.00	48.10	44.20
2	12	15	202.0	220.6	222.8
2	12	16	232.0	238.1	241.1
2	12	23	92.00	102.8	99.57
2	13	6	44.00	29.32	26.29
2	13	16	257.0	255.0	259.4
2	13	23	89.00	102.6	99.20
2	13	26	38.00	23.16	22.94
2	14	18	228.0	224.8	227.8
2	15	16	233.0	241.6	244.7
2	15	18	240.0	223.3	226.5
2	17	14	35.00	33.79	33.76
2	19	14	40.00	30.16	31.52
3	8	27	24.00	16.73	17.07
3	9	10	78.00	67.10	65.76
3	9	27	21.00	15.50	15.98
3	10	7	52.00	36.04	37.66
3	10	11	67.00	78.09	75.46
3	10	17	98.00	111.8	104.9
3	10	25	40.00	40.59	41.12
3	10	27	32.00	14.84	15.37
3	11	7	32.00	35.84	37.50
3	11	24	76.00	66.49	64.95
3	11	25	40.00	40.92	41.46
3	11	27	15.00	14.45	15.01
3	12	24	81.00	67.22	65.61
3	12	27	27.00	14.17	14.74
3	14	18	138.0	154.4	141.4
3	18	16	20.00	20.94	20.89

*RESULTS AFTER FOURTH SIMULATION. **RESULTS AFTER FINAL SIMULATION.

Table 5.--Observed and computed drawdowns, by node, used to calibrate the detailed three-dimensional model of "2,000-foot" sand.

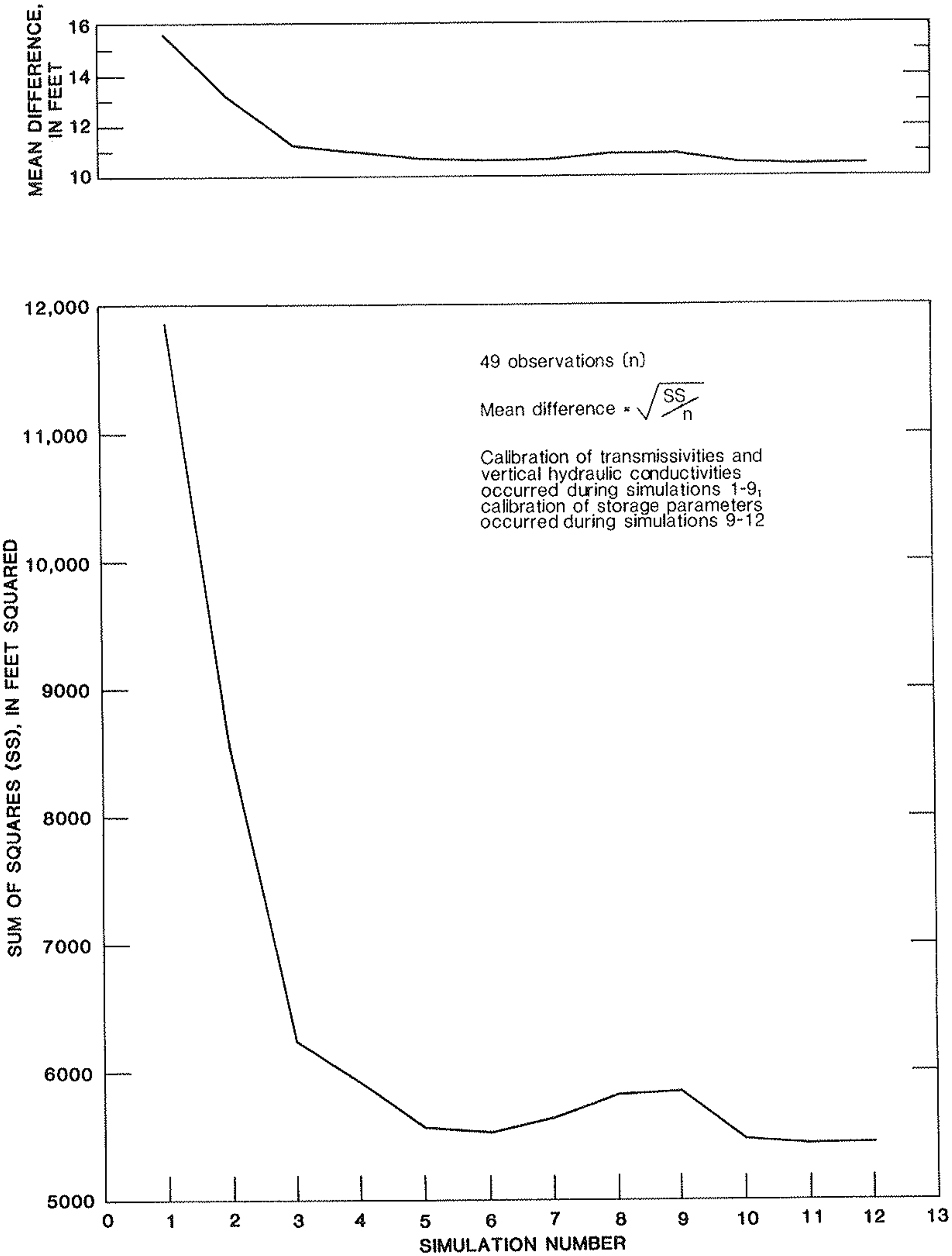


Figure 8.--Mean difference and sum of squares versus simulation number for calibration runs.

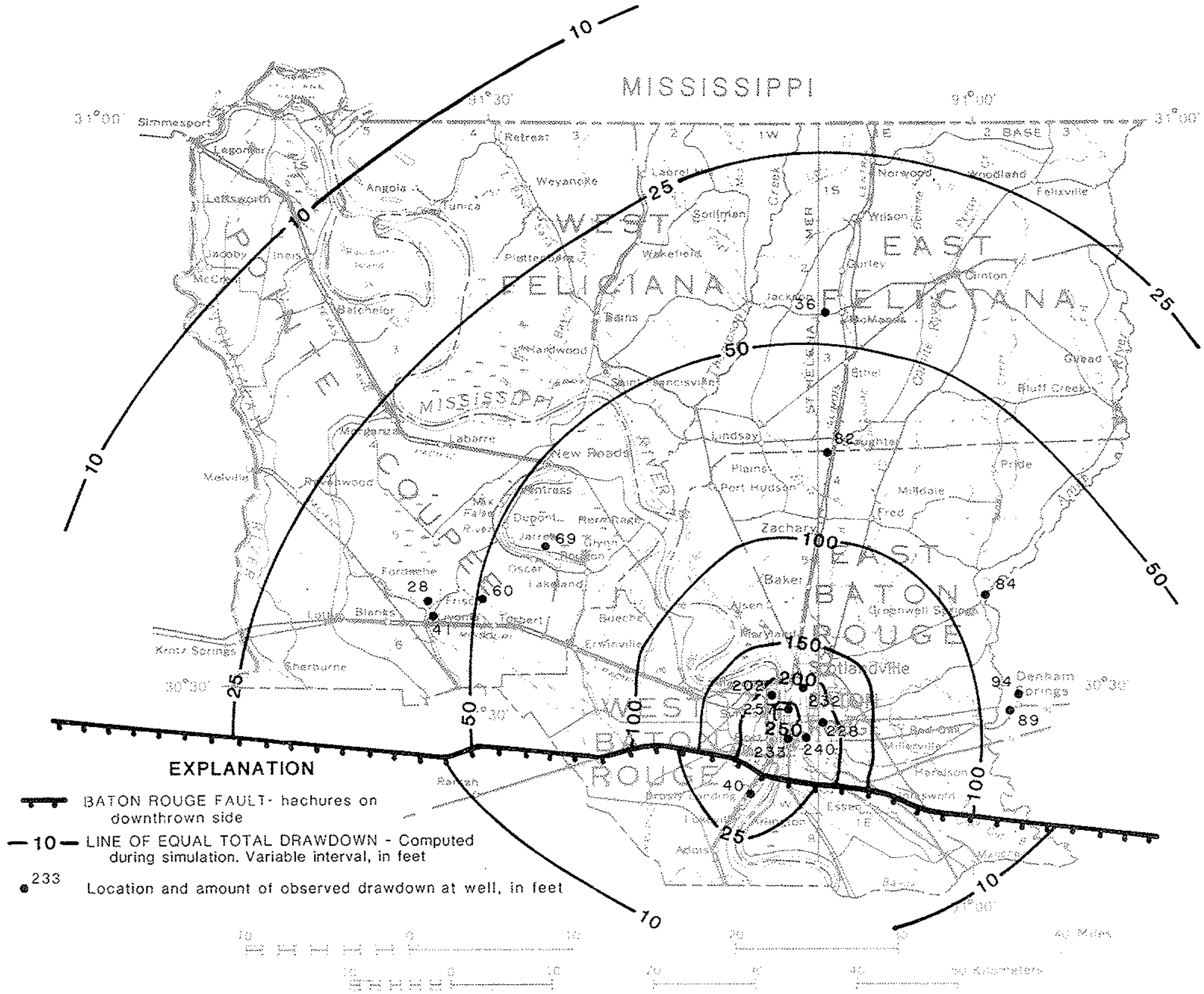


Figure 9.--Five-parish project area showing computed and actual drawdowns for the "2,000-foot" sand for calibration period.

mean difference of 10.5 ft, obtained from the last base run for calibration (fig. 8) represents an error in computed drawdowns in the industrial district of about 5 percent.

The role of the Baton Rouge fault in restricting ground-water flow is apparent from the map showing drawdowns in the project area (fig. 9). In 1961, the maximum head differential across the fault for the "2,000-foot" sand was about 200 ft. The computed drawdowns plotted in figure 9 indicate that this differential was simulated by the detailed model for the calibration period.

A comparison was made between parameter values originally input to the detailed model and those derived from calibration procedures to insure reasonableness of the model. Transmissivities used to obtain the best match of computed and actual water levels were about 30 percent less for each aquifer than the initial values.

Values for transmissivity were few and were concentrated in pumping centers where the aquifers are thick and most permeable. In contrast, numerous data for aquifer thickness were available; values ranged from 0, where aquifers pinched out, to 500 ft, where aquifers coalesced. The variable thickness of the aquifers creates a non-uniform distribution of transmissivity over the model area, which was not represented by the available data. To account for the large non-homogeneities, values of hydraulic conductivity were computed from known transmissivities and then multiplied by the aquifer thicknesses characteristic of each grid block. The thickness data was assumed to have only small errors, as these values were derived from interpretations of electrical logs of wells. Significant deviations from actual transmissivities probably occurred, however, as hydraulic conductivities determined from only a few sites where the aquifers are thick and permeable were multiplied by widely varying aquifer thicknesses across the modeled area to obtain transmissivities for each node.

Vertical hydraulic conductivities of the confining layers derived from the calibration procedures ranged in value from 1.1×10^{-7} to 6.2×10^{-11} ft/s. These values bracket the initial value of 2.0×10^{-10} ft/s assigned to this parameter, which was determined for a sample of clay (Whiteman, 1980). Because the confining layers include fine-grained materials other than clay, values for this parameter were expected and allowed to vary over several orders of magnitude.

Storage coefficients for all three aquifers were increased slightly in the model as a result of the calibration procedures. Table 6 lists the initial storage coefficients and the resultant values obtained from calibration of the detailed model. These values are within the range of artesian storage coefficients and were assigned to each element of their respective matrices except in the recharge area, where coefficients typical of water table conditions were used. (See storage matrices in appendix IV.)

Table 6.--List of values for storage terms originally input to detailed three-dimensional model and values resulting from calibration

[S, storage coefficient; Ss, specific storage in ft^{-1}]

Parameter	Hydrogeologic unit	Original value	Resultant value
S	"1,500- 1,700-foot" sand--	1.20×10^{-4}	2.25×10^{-4}
S	"2,000-foot" sand---------	5.0×10^{-4}	2.30×10^{-3}
S	"2,400-foot" sand---------	1.0×10^{-4}	1.50×10^{-4}
Ss	Confining layers----------	1.60×10^{-5}	1.50×10^{-5}

The specific storage of the confining layers was reduced slightly, from 1.6×10^{-5} ft^{-1} to 1.5×10^{-5} ft^{-1}, during calibration. (See table 6.) The original value was derived from a sample of clay (Whiteman, 1980).

VERIFICATION OF THE DETAILED THREE-DIMENSIONAL MODEL

Verification of the detailed model was performed by simulating the pumping history, and consequent drawdowns, for the years 1962-79. Pumpage for this interval was divided into 13 periods, listed in table 4. Simulations used to verify the model were executed as "continuation runs" from the end of the calibration period. Transient conditions existed in the aquifer system at the end of the calibration period that would affect the aquifer response during the verification period. Therefore, it was necessary to begin verification with transient conditions computed by the previous simulation (calibration) present in the model of the aquifer system.

The computed drawdown, leakage, and mass-balance parameters obtained at the end of calibration were input to the model at the start of verification. Terms defining transient leakage from confining layers were also required for verification. The additional data inputs of leakage parameters required for a continuation run necessitated modifications to the computer code to store and retrieve these terms.

Values for aquifer and confining-layer parameters determined during calibration were not adjusted during verification. Thus, the verification period tested the validity of the parameter values obtained from calibration. Except for the input of transient conditions from the calibration period required to initiate verification, the calibration and verification simulations were independent.

Computed drawdowns for the 18-year interval, 1962-79, were compared to observed values for verification of the model. The location of a node at the center of a grid block generally did not correspond to the actual locations of the wells used to compare actual data with computed values. Table 7 lists results of this simulation and the observed drawdowns. A mean difference of 12.0 ft between observed and computed drawdowns was

Table 7.--Observed and computed drawdowns, by node, used to verify the detailed three-dimensional model of the "2,000-foot" sand

Node identification			Drawdown in feet	
Layer (K)	Row (I)	Column (J)	Observed	Computed
1	5	3	13.9	3.2
1	5	7	19.9	21.6
1	6	13	56.4	56.8
1	6	16	59.2	59.4
1	6	27	6.9	1.5
1	7	26	45.7	24.5
1	8	11	57.4	68.1
1	10	8	61.1	49.9
1	10	26	58.4	44.9
1	9	19	83.8	79.8
1	13	23	88.4	86.1
1	18	20	40.0	35.2
1	20	18	46.5	33.8
2	6	7	15.2	22.2
2	6	27	7.4	9.9
2	9	23	75.6	88.1
2	10	8	69.4	59.7
2	10	10	72.3	84.8
2	10	17	107.9	118.0
2	10	26	26.0	45.5
2	11	8	60.4	59.4
2	11	23	82.6	95.6
2	11	26	37.2	44.4
2	12	15	158.9	134.8
2	12	16	146.1	137.1
2	12	23	82.6	96.3
2	12	26	34.0	43.9
2	13	16	171.5	149.1
2	14	18	148.6	152.0
2	15	18	150.0	151.1
2	17	14	93.9	66.0
2	18	20	32.4	37.4
2	14	18	45.7	58.5
3	9	10	70.4	74.8
3	9	27	32.0	16.7
3	10	25	43.8	49.9
3	12	24	74.3	72.9
3	14	27	39.4	19.0
3	18	20	36.0	27.6

calculated from the values listed in table 7. Because of this relatively small error in computed drawdowns, the model was considered verified without any adjustments to parameter values.

The potentiometric surface of the "2,000-foot" sand for 1979, simulated by the model, is illustrated on plate 3. Observed water levels at selected locations are also plotted on this plate for comparison to the computed results. There is a close match between observed and computed water levels at points where observations were available in the model area.

Because drawdowns (rather than water levels) were computed by the three-dimensional model, the results of two simulations were needed to obtain the contoured surface shown on plate 3. Values for total drawdown since 1914, computed during verification, were combined with the results of the steady-state simulation of ground-water levels prior to 1914 to obtain the computed potentiometric surface for 1979. This computed surface was then compared to observations at the locations shown on plate 3.

Inspection of plate 3 shows that the cone of depression in the potentiometric surface of the "2,000-foot" sand was fairly symmetric around Baton Rouge, with two exceptions. South of the pumping centers, the cone was nearly bisected by the Baton Rouge fault. This created a maximum head differential of about 220 ft across the fault, indicating a major restriction to the northward flow of ground water. About 10 mi northwest of Baton Rouge, pumping by industry starting about 1969 has caused the 50-ft contour of the potentiometric surface to extend northwestward.

At a few locations in the industrial area of Baton Rouge, the computed water levels are higher than the observed values. (See pl. 3.) Most of the differences can be attributed to the comparison of computed water levels that represent large grid areas to point values obtained at a well. Localized depressions in the potentiometric surface created by pumping wells are averaged over the area of the grid block where pumpage is simulated. Thus, for a given observation well near pumping wells, computed drawdowns may be less than observed values.

Away from the pumping centers of the Baton Rouge area, the cone of depression in the potentiometric surface has a relatively flat gradient. These outlying areas are less sensitive to the localized distribution of pumping at Baton Rouge than the areas adjacent to the pumping centers. In the outlying areas, the location of wells within the grid blocks is less critical, thus a closer match between observed and computed water levels may be obtained.

Drawdowns in the "2,000-foot" sand computed during the 66-year simulation were compared to hydrographs of wells in the model area. The computed drawdowns were converted to water levels with respect to land surface and superposed onto plots of the historical record. Plate 1 shows locations of the wells used in these comparisons.

The hydrograph shown in figure 10 is that of well EB-90, a public-supply well at the Lula Avenue pumping station. (See pl. 1.) A close match between computed and observed water levels was obtained at this location for the entire period of record. Figure 10 shows observed water levels had risen about 25 ft during 1974-75 due to a reduction in pumpage during those years. However, the figure also shows that computed and observed water levels have declined for the last two years of record (1978-79), and are approaching the 1973 level.

A plot of observed and computed water levels for well EB-367 in the industrial district is shown in figure 11. This well is about 2.5 mi northwest of the Lula Avenue pumping station. (See pl. 1.) Although a 22-year hiatus in the water-level record occurred for this well after an initial measurement in 1942, the decline of actual water levels and their match with computed values is apparent from this plot. The computed water levels plotted in figure 11 are consistently higher than the actual values because the computed values are averages representative of the entire grid-block area (in this case, 1 mi^2).

Figure 12 is a plot of observed and computed water levels for well EB-112, located about 1.3 mi southwest of the Lula Avenue pumping station. (See pl. 1.) As in figure 11, computed water levels are slightly higher than the observed values, but, in general, a close match with the historical record was obtained. The actual and computed levels were declining for the last two years of record (1978-79), following a water-level rise in the mid-seventies. This decline appears to be approaching the lowest value previously obtained at this location in 1972 (year-end measurements used for comparison).

About 15 mi northeast of the pumping centers at Baton Rouge near Greenwell Springs, the computed and observed water levels for well EB-304 (plotted in fig. 13) show a decline of about 160 ft, about 40 percent of the drawdown at Baton Rouge. Figure 13 shows a break in the historical record during the mid-seventies, but a resumption of water-level measurements for the years 1976-79 indicates a steady decline in the potentiometric surface, which was also simulated by the computed results.

Computed and actual hydrographs for wells WF-40 and Li-54 are presented in figure 14A and B, respectively. Well WF-40 is about 39 mi northwest of Baton Rouge, at Angola, and well Li-54 about 36 mi east of the city, near Albany. (See pl. 1.) At these locations, the response of the "2,000-foot" sand to pumping at Baton Rouge is attenuated by distance from the pumping centers. About 35 ft of total drawdown occurred at well WF-40 during the historical period shown in figure 14A, and about 55 ft occurred at well Li-54. Although computed water levels are higher than the actual values for well WF-40, the actual rate of decline in water levels with time (fig. 14A) was simulated by the model at this location. In figure 14B, the computed values are shown to be a close match with the observed water levels for well Li-54.

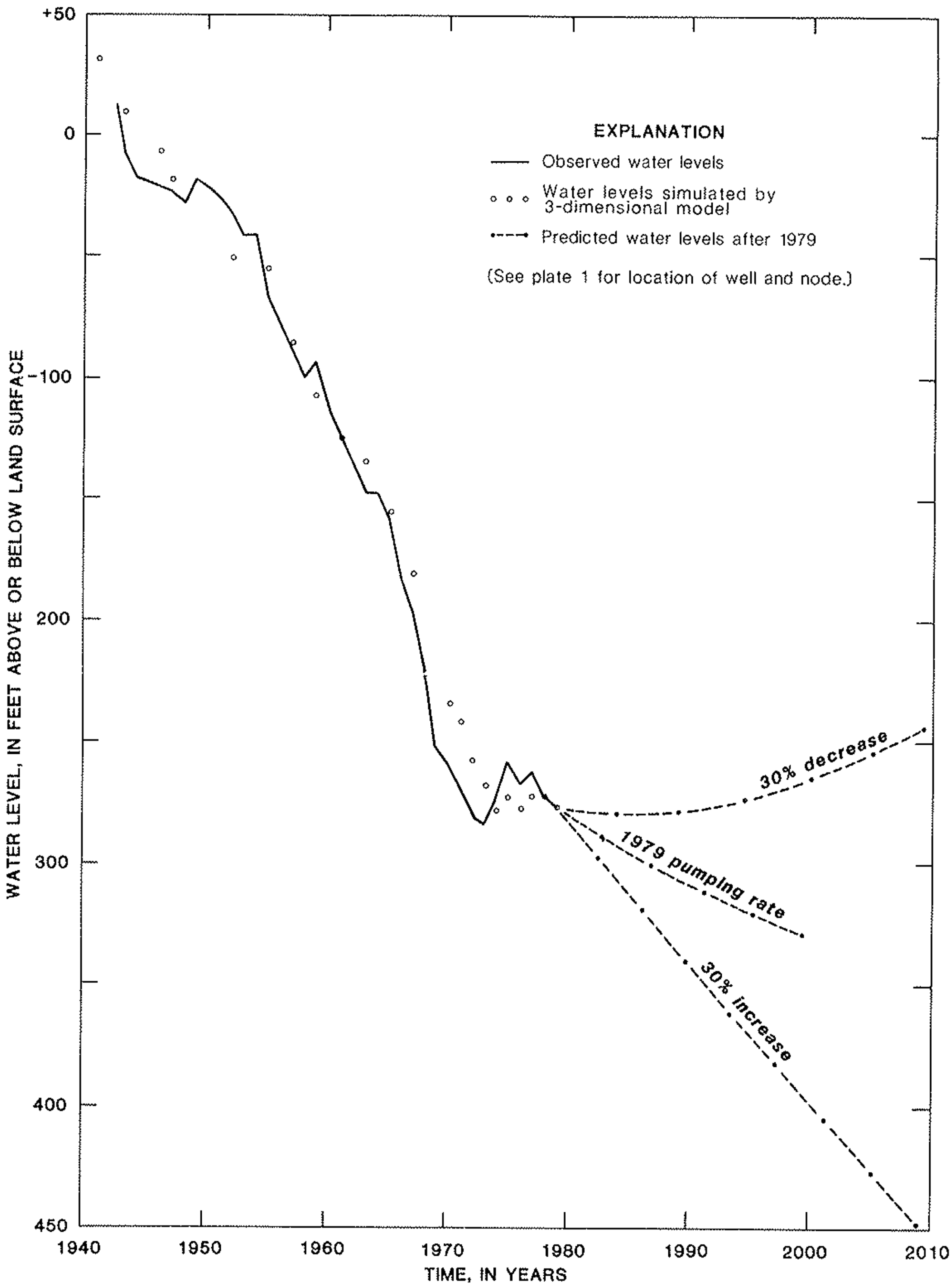


Figure 10.--Simulated water levels for node 2,14,18 and actual hydrograph of well EB-90 at Baton Rouge, La.

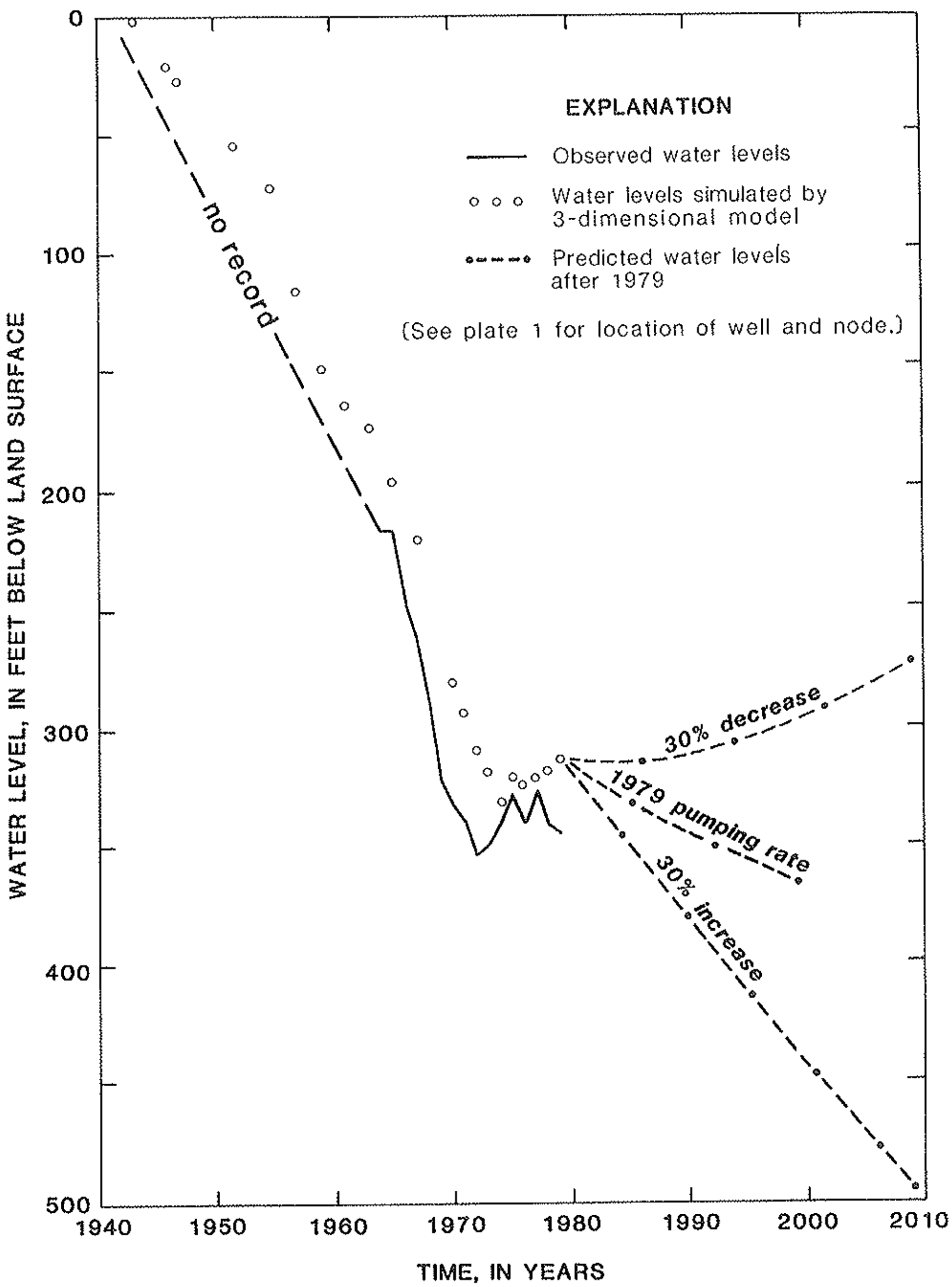


Figure 11.--Simulated water levels for node 2,13,16 and actual hydrograph of well EB-367 at Baton Rouge, La.

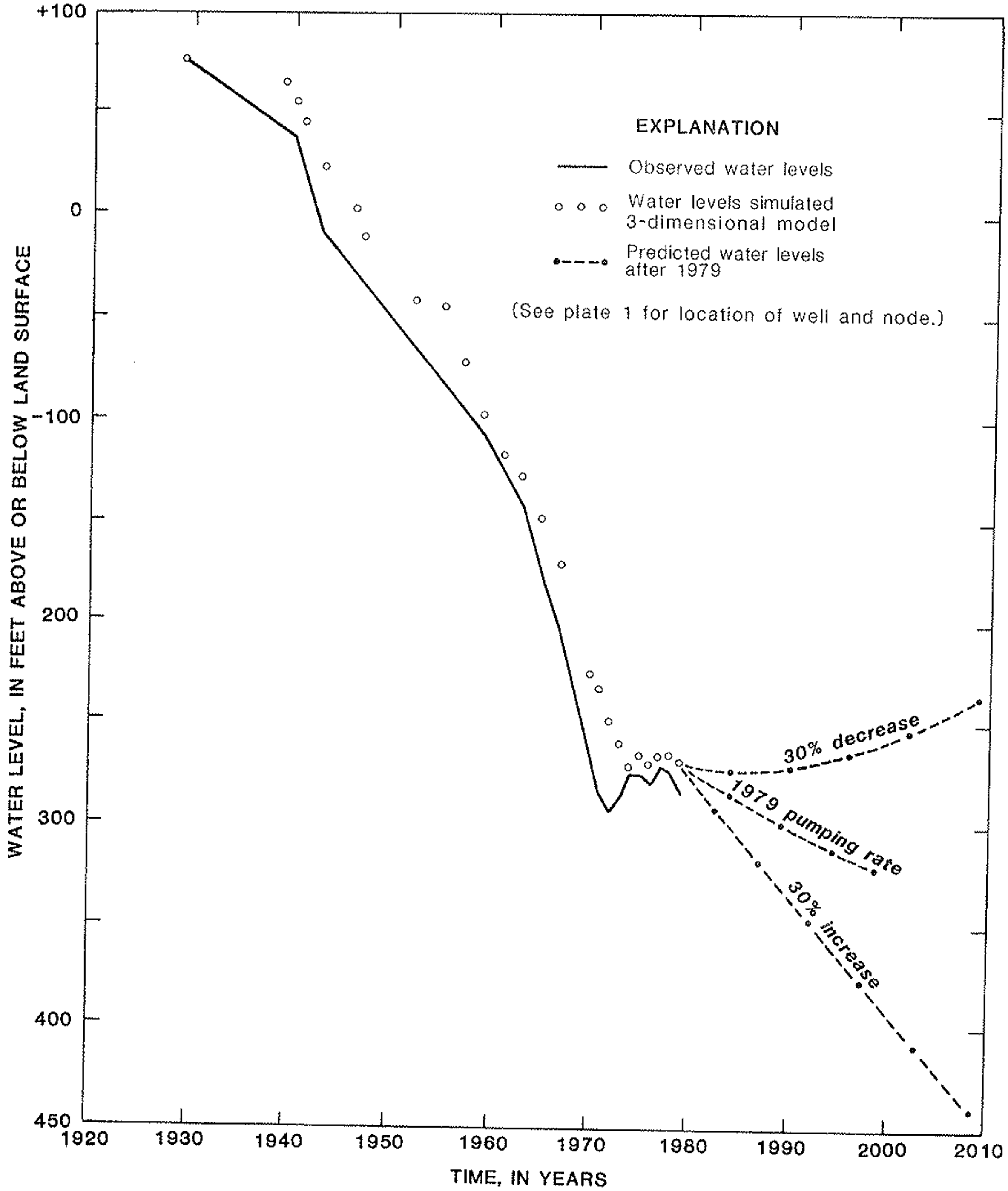


Figure 12.--Simulated water levels for node 2,15,18 and actual hydrograph of well EB-112 at Baton Rouge, La.

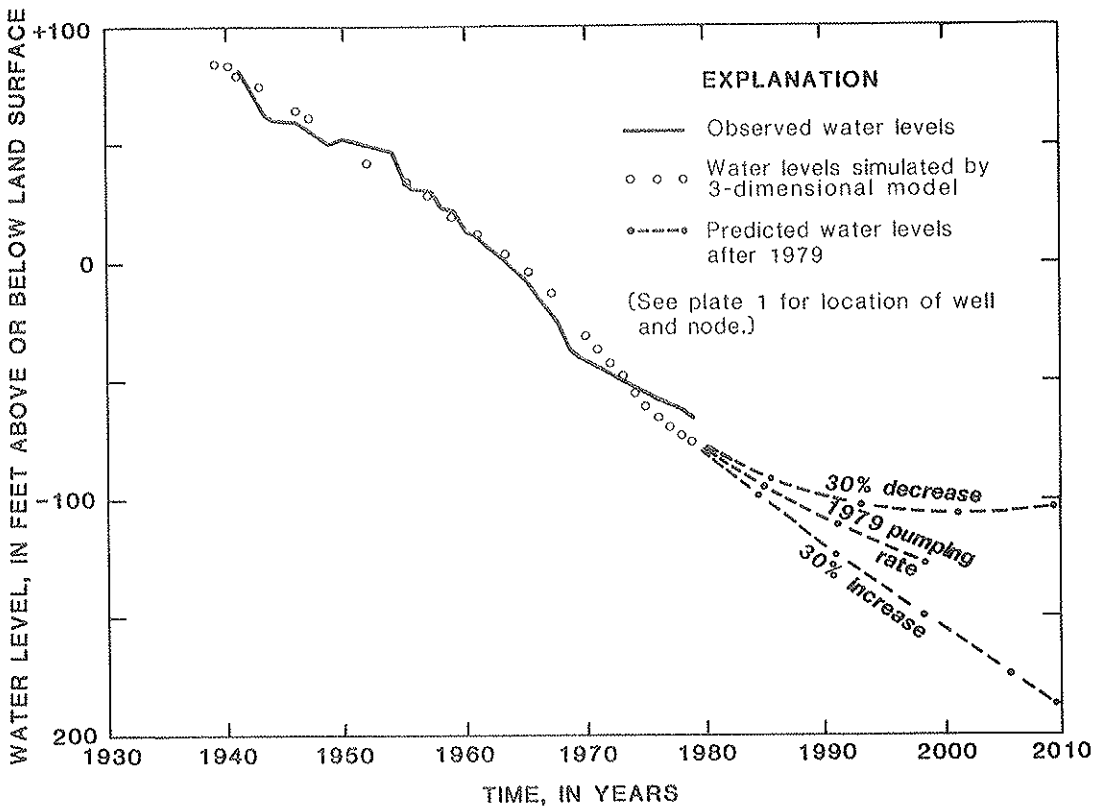
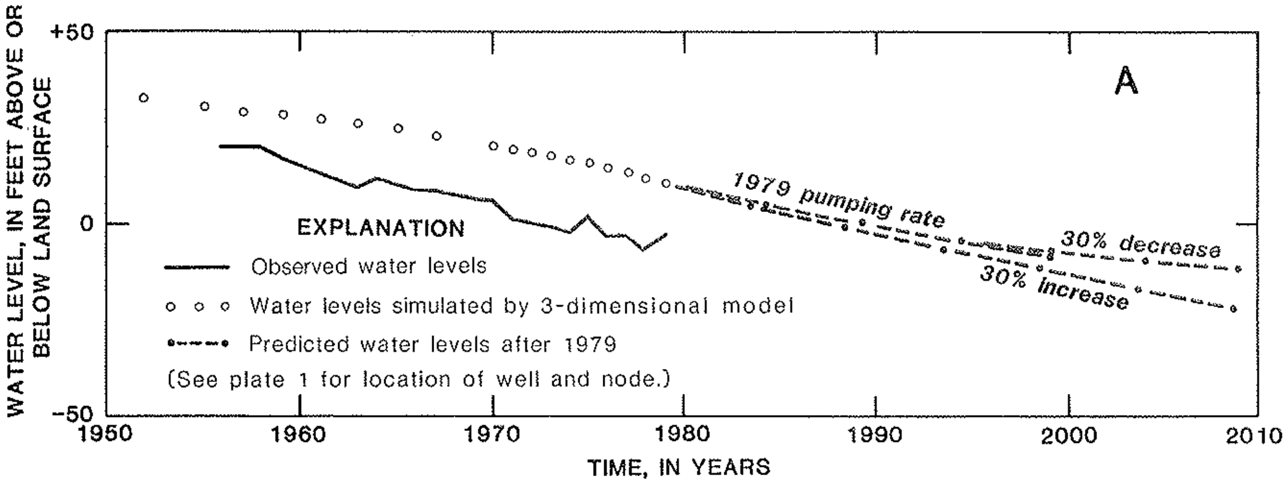


Figure 13.--Simulated water levels for node 2,9,23 and actual hydrograph of well EB-304 at Greenwell Springs, La.

EVALUATION OF COMPONENTS OF THE FLOW SYSTEM

A water budget was computed for the flow system of the "2,000-foot" sand based on values derived from the model output of cumulative-mass balance. The percentage contribution of each component of the flow system during the 66-year simulation period was computed from these values. Flow rates for each component, computed for the end of the simulation period (1979), are listed in table 8. Because leakage from confining layers has a significant effect on the availability of ground water in the "2,000-foot" sand, its effects on the water budget are discussed in detail below.

In general, the water budget indicates that leakage from confining layers constitutes about 48 percent of the total volume of water pumped from the aquifers during the simulated 66-year period. Another 48 percent of the total volume pumped was attributed to the release of water from storage within the aquifers, and the remaining volume (about 4 percent) was derived from the constant-head sources in the recharge area. (See table 8A.) These percentages apply to the entire flow system composed of three aquifers and the confining layers separating them and not specifically to the "2,000-foot" sand.



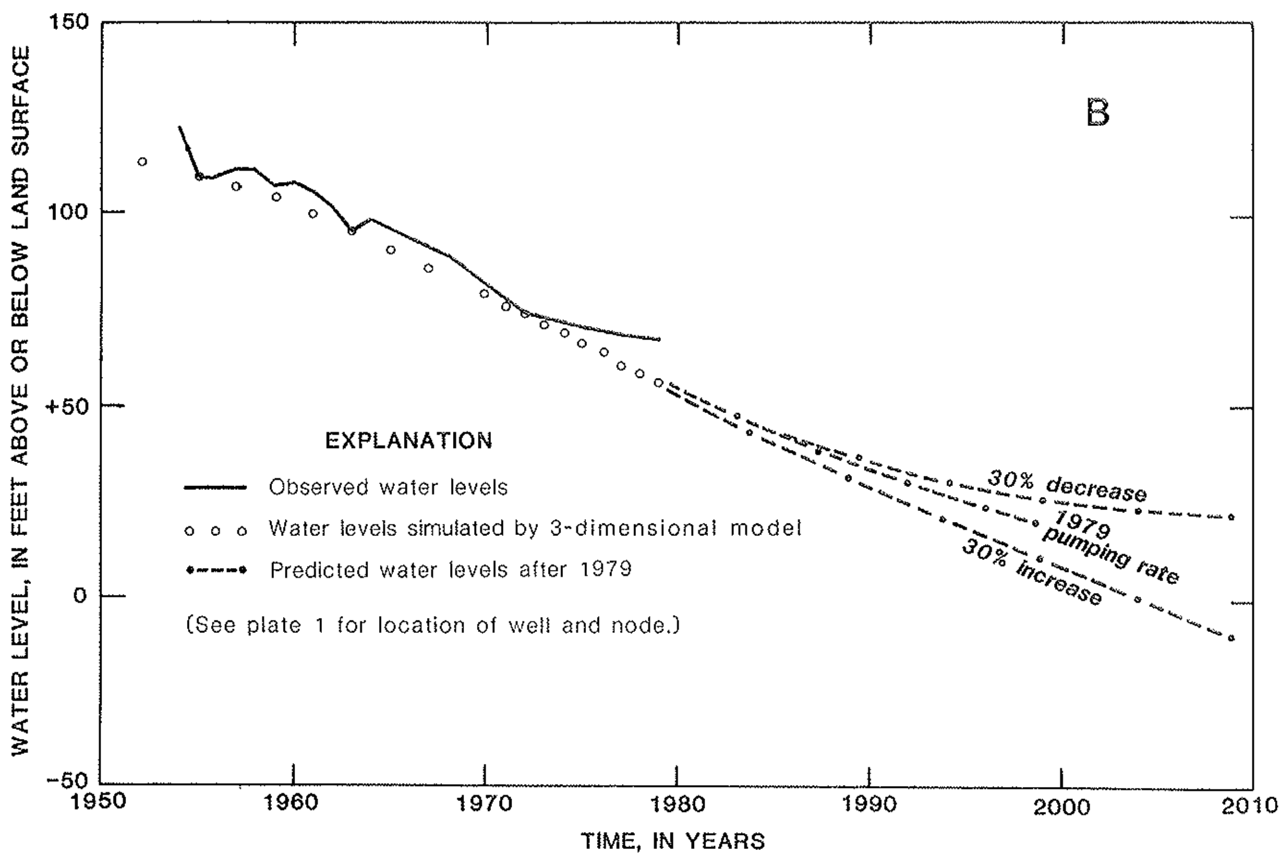


Figure 14.--Simulated water levels and actual hydrographs: (A) node 2,5,7, well WF-40 at Angola, La.; and (B) node 2,11,26, well Li-54, near Albany, La.

Table 8.--Water budget and breakdown of leakage components for flow system[1] of the "2,000-foot" sand model

A. Water budget for the flow system

Sources	Total volume for simulation period, 1914-79, in Mgal	Percent of total source	Rates for last time step, in Mgal/d
Aquifer storage---	418,000	48.4	43.8
Constant-head sources----------	29,000	3.4	5.3
Leakage-----------	417,000	48.3	40.7
Total sources-----	864,000	100.1	89.8
Discharge by pumpage----------	865,000		89.9

B. Leakage rates for the "2,000-foot" sand, in Mgal/d

Leakage components	Confining layer 1 [2/] Rate	Confining layer 1 [2/] Percent	Confining layer 2 [3/] Rate	Confining layer 2 [3/] Percent
Inflow				
Steady leakage----------	10.2	51.8	15.4	61.1
Transient leakage------	9.5	48.2	9.8	38.9
Total inflow rate------	19.7	100.0	25.2	100.0
Outflow				
Total outflow rate-----	11.5		3.4	
Net inflow rate--------	8.2		21.8	

1/ Includes the "1,500-foot", "2,000-foot", and "2,400-foot" sands.
2/ Confining layer between the "2,000-foot" and "2,400-foot" sands.
3/ Confining layer between the "1,500-foot" and "2,000-foot" sands.

Leakage rates across the top and bottom boundaries of the confining layers were computed at each node in the model. (See table 8B.) Total inflow to the "2,000-foot" sand from the confining layer separating the "2,000-foot" sand from the "2,400-foot" sand (confining layer 1) was 19.7 Mgal/d, computed from the nodal leakage rates at the end of the simulation period (1979). Most of this leakage occurs at nodes located within the five-parish project area as a result of pumping at Baton Rouge. Total outflow from the "2,000-foot" sand into confining layer 1 was computed as 11.5 Mgal/d. Most of this flow occurs north of Baton Rouge, and extends to the recharge area. The areas of computed inflow to and outflow from the "2,000-foot" sand from this confining layer are shown on plate 4.

Nodal leakage rates for the confining layer separating the "2,000-foot" sand from the "1,500- 1,700-foot" sand (confining layer 2) indicate a total inflow of 25.2 Mgal/d to the "2,000-foot" sand, and a total outflow of 3.4 Mgal/d. Inflow to the "2,000-foot" sand from confining layer 2 occurs predominantly in the five-parish project area around Baton Rouge, with some downward flow (inflow) indicated in the recharge area. The areas where inflow to and outflow from the "2,000-foot" sand were computed for this confining layer are also shown on plate 4.

Combining leakage rates to the "2,000-foot" sand from both confining layers yields a total inflow of 44.9 Mgal/d and a total outflow of 14.9 Mgal/d. The resulting net leakage rate of about 30 Mgal/d is 55 percent of the pumping rate (54.56 Mgal/d) simulated in the "2,000-foot" sand during the last time step. However, proper assessment of leakage into this aquifer requires that this rate be resolved into its transient and steady components of flow.

More important than the total rate of inflow is the "steady" component of leakage, or flow of water through confining layers from aquifers above and below the "2,000-foot" sand. The other component of leakage, the transient component, is water derived from the adjacent confining layers. This source will eventually dissipate as uniform hydraulic gradients are established across the confining layers. A summation of nodal leakage rates for the model area yields values of 10.2 and 15.4 Mgal/d as the steady components of leakage for confining layers 1 and 2, respectively (table 8B).

Of the total leakage rates (inflow) to the "2,000-foot" sand from each confining layer, the steady-leakage component comprises about 52 percent of the leakage from confining layer 1, and about 61 percent of the leakage from confining layer 2 (table 8B). The remaining leakage is attributed to transient-leakage effects from the release of water from storage within the confining layers.

SIMULATED AQUIFER RESPONSE TO ALTERNATIVE PUMPING PLANS

The degree of accuray demonstrated by the model in simulating observed drawdowns during calibration and verification is an indication of the accuracy of the model to simulate the effects of alternative pumping plans on the aquifer. The model can be no more accurate in simulating effects of alternative pumping plans than the accuracy experienced during calibration and verification. The mean difference of 12 ft between computed and observed drawdowns during verification corresponds to an 8-ft error in drawdowns computed in the industrial area. This value may be used as an estimate of the magnitude of error in simulating drawdowns resulting from alternative pumping plans in the industrial area, provided these simulations are not affected by the boundary conditions used in the model.

To determine the effects of future ground-water withdrawals on the potentiometric surface of the "2,000-foot" sand, particularly in the five-parish project area, three simulations were made utilizing possible future distributions of pumpage from the existing pumping centers.

The first simulation computed water levels for the "2,000-foot" sand for 1999 with 1979 pumping rates held constant for 20 years. The simulated potentiometric surface of the "2,000-foot" sand in 1999, shown on plate 5, is about 50 ft lower than the 1979 surface (pl. 3) at all locations north of the fault in East and West Baton Rouge Parishes and in southeastern Pointe Coupee Parish. For most of East and West Feliciana Parishes and northern Pointe Coupee Parish, about 25 ft of additional drawdown occurred during the simulated 20-year period.

South of the Baton Rouge fault, the model simulated 25 ft of additional drawdown, 1980-99. The simulation indicated a maximum head-differential across the fault of about 270 ft directly south of the pumping centers at Baton Rouge.

Computed hydrographs (figs. 10-14) illustrate response of the "2,000-foot" sand at selected locations in the model area to future pumpage at 1979 rates. These hydrographs indicate that steady-state conditions in the "2,000-foot" sand were not achieved by 1999, although the 1979 pumping rates were held constant during the 20-year simulation. Water levels continued to decline in the industrial area of Baton Rouge (figs. 10-12) at the rate of about 3 ft/yr during the first 10 years of this simulation (1980-89), and about 2 ft/yr during the last 10 years (1990-99).

The next simulation of water levels involved an increase in pumping rates for all three aquifers of the flow system of the "2,000-foot" sand over the 30-year period, 1980-2009. Beginning with a 5-percent increase from the 1979 pumping rates, six 5-year pumping periods were simulated, with pumping rates in each succeeding period increased by 5 percent of the 1979 rates. Thus, the last pumping period, simulating the years 2005-09, represented a 30-percent increase over the 1979 pumping rates for the three aquifers modeled.

The potentiometric surface of the "2,000-foot" sand at the end of the simulation period (2009) is illustrated on plate 6. A comparison of this surface and the computed surface of 1979 (pl. 3), indicates about 180 ft of additional drawdown in the industrial area of Baton Rouge as a result of this distribution of pumpage. South of the Baton Rouge fault, about 65 ft of drawdown is simulated for the 30-year period. The simulation indicated a maximum head-differential across the fault of about 360 ft at the nodes directly south of the industrial area. Over most of East and West Feliciana and Pointe Coupee Parishes, a decline of about 1-2 ft/yr is indicated.

In figures 10-14, water levels from the above simulation indicate a steady decline in the potentiometric surface of the "2,000-foot" sand. For the industrial area of Baton Rouge, this decline is about 6 ft/yr.

Under the severe drawdown conditions of this simulation, the artificial boundary conditions imposed on the model of the aquifer system appear to have negligible effects on computed results. Plate 7 illustrates the total drawdown in the "2,000-foot" sand for the entire simulation period, 1914-2009. The 0- and 10-ft lines of equal drawdown are included in this figure to show their location relative to the model boundaries. About 1 percent of the maximum drawdown computed in the industrial area of Baton Rouge for the "2,000-foot" sand (587 ft) appears at the western boundary of the model, and about 1.5 percent of this maximum value occurs at the eastern boundary. About 2 to 3 percent of the total drawdown computed at Baton Rouge occurs at the southern boundary. Because of the small drawdown present at the model boundaries for this simulation, the effects of the model boundaries on computed drawdowns were considered negligible.

The final simulation involved the same 30-year period, 1980-2009, but pumping rates in each of the six 5-year pumping periods were decreased by 5 percent of the 1979 rates. As a result, pumping rates for the last pumping period of this simulation, for the years 2005-09, represented a 30 percent reduction in the 1979 pumping rates for all three aquifers.

The potentiometric surface of the "2,000-foot" sand as simulated for the year 2009 with decreased pumpage is illustrated on plate 8. A comparison between this surface and the potentiometric surface computed for 1979 (pl. 3) indicates a recovery of water levels from the 1979 potentiometric surface of about 40 ft in the industrial area of Baton Rouge. Within about 5 mi of the pumping centers, recovery of water levels from the 1979 potentiometric surface had ceased, and additional drawdowns were simulated for the rest of the model area.

Water levels of the "2,000-foot" sand for this simulation are shown in figures 10-14. A recovery of water levels in the industrial area due to reduced pumping rates is evident in figures 10-12. These figures show that water levels would stabilize near the industrial area within the first 10 years of the simulation period.

About 15 mi northeast of the pumping centers at Baton Rouge, the simulation indicates that water levels for the "2,000-foot" sand will stabilize with 20 years, when the 1979 pumpage has been reduced by 20 percent. (See fig. 13.) The computed hydrograph in figure 13 shows a decelerating water-level decline during the first 20 years of the simulation (1980-99), and a slight recovery of about 3 ft during the remaining 10 years of the period. However, computed water levels at this location do not recover to the 1979 level by the end of the simulation. Instead, additional drawdown of about 27 ft was computed for this period.

Computed hydrographs in figure 14 indicate that water levels of the "2,000-foot" sand would continue to decline at a distance of about 35 mi from the pumping centers at Baton Rouge even though pumping rates were reduced for this simulation. At Angola (well WF-40, fig. 14A), rates of water-level decline were relatively low for all simulations; by the end of the two 30-year simulations, computed values differed only by about 10 ft. By comparison, about 35 mi east of Baton Rouge (near Albany), the model shows that the "2,000-foot" sand is more responsive to variations in pumpage at Baton Rouge. Figure 14B shows that, after 30 years of reduced pumping, water levels would be about 30 ft higher than after 30 years of increased pumping. The simulation involving a decrease in pumping showed that the water-level decline had decreased to a very low rate after 30 years.

CONCLUSIONS

Pertinent hydrogeologic factors controlling the availability of water from the "2,000-foot" sand were identified and quantified using digital-computer models. The following factors were evaluated and included in a conceptual model for the "2,000-foot" sand: leakage from aquifers and confining layers directly above and below the "2,000-foot" sand; the role of the Baton Rouge fault in restricting the movement of ground water northward to the pumping centers; and spatial variations in the thickness, hydraulic conductivity, and storage coefficient of aquifers and confining layers.

A two-dimensional, finite-difference, computer model of ground-water flow indicated that the "2,000-foot" sand does not respond to pumping as an independent hydrogeologic unit, but rather as part of a complex system of aquifers and confining layers. Leakage, both steady and transient, from confining layers and other aquifers proved to be significant to the water budget of the "2,000-foot" sand. For this reason, the two-dimensional model was inappropriate for simulating ground-water flow in this aquifer.

In other preliminary investigations of the sensitivity of the aquifer system at Baton Rouge, three-dimensional, finite-difference computer models indicated that the "2,000-foot" sand could be accurately modeled by considering only the aquifers and confining layers directly above and below this unit. Leakage from confining layers was shown to have contributed about 48 percent of the total volume of water pumped from the "2,000-foot" sand, and transient-leakage effects existed throughout the entire 66-year simulation. Modifications to the three-dimensional program allowed accurate simulation of leakage effects from confining layers in contact with the "2,000-foot" sand.

An analysis of mass-balance parameters contained in the water budget of this model indicates that the three-dimensional program of Trescott (1975) and Trescott and Larson (1976), with modifications similar to those contained in Posson, and others (1980), for simulating transient leakage from confining layers, is a valid mathematical representation of the conceptual model that describes ground-water flow in the "2,000-foot" sand. More importantly, the same conceptual model can be used to describe ground-water conditions in other aquifers at Baton Rouge and in southern Louisiana. Therefore, the modified three-dimensional program developed in this study for the "2,000-foot" sand can be used in similar hydrogeologic settings.

As a management tool, the digital model simulating ground-water flow in the "2,000-foot" sand can be useful in simulating the response of this aquifer to possible or proposed future changes in the rate and distribution of pumping. Water levels of the "2,000-foot" sand at Baton Rouge will reach new lows if a reduction in pumpage from the 1979 rates does not occur. Simulations using the model show that increased drawdown can be averted and conditions of stability can be achieved in the industrial area of Baton Rouge if pumpage is reduced about 10 percent from the withdrawal rates of 1979. Additional decreases in pumpage will cause a recovery of water levels from the 1979 levels for this area. Recovery of water levels of the "2,000-foot" sand is limited to the immediate Baton Rouge area, however. At a distance of about 35 mi and outward from the pumping centers, the model indicated diminished, but continuing water-level declines for the "2,000-foot" sand after 30 years, even with reductions in the 1979 pumping rates of up to 30 percent. Because of the large extent of the pumping cone resulting from pumping in the Baton Rouge area, long periods of time are required for the cone to adjust to changes in pumping rates.

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APPENDIXES

Appendix I. Data for preliminary, two-dimensional, finite-difference model of "2,000-foot" sand

```
****** 2-D AQUIFER SIMULATION: "2000 FOOT" SAND OF BATON ROUGE AREA, PRELIMINARY
MODEL, COARSE GRID, 13 X 15, D-4 SOLUTION ******
     LEAK                   LSOR CHEC                       NUME
       13         15                       2
                          (blank card)
       10         50        .1             0          0                          0
        1          1          1

                      (Three blank cards)

       0.0             0
  1.0E-04              1
  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  0   0   02000  -1  -1  -1  -1  -12000  -120002000 2000   0
  0   0   020002000  -1   5   5   5   5   5   5   5   5   0
  0   5   5   5   5   5   5   5   5   5   5   5   5   5   0
  0   5   5   5   5   5   5   5   5   5   5   5   5   5   0
  0   5   5   5   5   5   5   5   5   5   5   5   5   5   0
  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  0   5   5   5   5   5   5   5   5   5   5   5   5   5   0
  0   5   5   5   5   5   5   5   5   5   5   5   5   5   0
  0   5   5   5   5   5   5   5   5   5   5   5   5   5   0
  0   5   5   5   5   5   5   5   5   5   5   5   5   5   0
  0   5   5   5   5   5   5   5   5   5   5   5   5   5   0
  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  1.0F-03              1
  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  0   0   0  95 190  70  60  80  95 150 280 230 320 250   0
  0 120 120 120 190 110  80 150 270 160 270 525 200 200   0
  0  40  40  40  50  90 150 250 180 140 230  70  70 140   0
  0  40  40  40  60  75 150 195 320 300 150 190 260 240   0
  0 100 100 100  75 150 150 200 320 240 120 120 230 220   0
  0  .5  .5  .5  .5  .5  .5  .5  .5  .5  .5  .5  .5  .5   0
  0  40  40  40  50  90 110 140 180 150 200 170 230 220   0
  0  40  40  40  50 100 120 110 150 200 250 200 200 200   0
  0  50  50  50  70 100 100 100 130 170 200 180 180 180   0
  0  70  70  70  90 100 100 100 110 150 180 170 150 150   0
  0 100 100 100 100 100 100 100 100 150 150 150 150 150   0
  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  2.0F-10              0
      0.0              0
        1              1
  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  0 100 150 200  50  50  50 100 100 100  50  50  50  50   0
  0 100 150 200  60 100  80 100  70 100  80  80  80  50   0
  0  50  50  50  90 100 230 150 130 250  30 150 180 130   0
  0 100 100 100 150 100 150 250 250 250  90 200 120 150   0
  0 100 100 100 310 120 110 600 150 110 170 230 140 140   0
  0  60  60  60 140 150 150 170 230 200 250 180 200 200   0
  0  50  50  50 200 450 300 230 160 140 150 200 150 150   0
  0  50  50  50 200 400 300 240 150 200 100 270 150 150   0
  0  50  50  50 180 300 200 200 200 200 100 240 150 150   0
  0  50  50  50 160 200 170 160 180 180 100 200 130 150   0
  0  50  50  50 150 150 150 150 150 150 100 150 100 100   0
  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
     5280              1         0
       20             20        20         20         20         15         10          7
        7             10        15         20         30         30         30
     5280              1         0
       20             20        20       13.5          9          6          4          6
        9           13.5        20         20         20
                                  (blank card)
        1              0         1       3650         10        1.5        722
        6              9      -3.1
        2              1         1       5110         10        1.5        722
        6              9      -6.2
        3              2         1       4015         10        1.5        722
        6              9    -19.58
        4              3         1       2190         10        1.5        722
        6              9    -22.38
        5              4         1       1460         10        1.5        722
        6              9    -31.96
        6              5         1       1825         10        1.5        722
        6              9    -37.95
        7              6         1        730         10        1.5        722
        6              9    -45.76
        8              7         1        730         10        1.5        722
        6              9    -54.26
        9              8         1       1825         10        1.5        722
        6              9    -59.30
       10              9         1        365         10        1.5        722
        6              9    -56.95
/*
//
```

Appendix II. Data for preliminary, three-dimensional, finite-difference model of seven-aquifer system at Baton Rouge

```
***** 3-D SIMULATION OF 7-AQUIFER SYSTEM AT BATON ROUGE USING MODIFIED FINITE-DI
FFERENCE PROGRAM (TRACY,1980)*****
       13          15          7          30          45          3
DRAW      MASS                                        ITKR        ITLR
       10          50         .01          6

                          (Four blank cards)

      0.0
      0.0
      0.0
      0.0
      0.0
      0.0
      0.0
   1.E-04             1              0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    02000   -1   -1   -1   -1   -12000   -120002000002000    0
0    020002000    -1   1    1    1    1    1    1    1    1    1    0
0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
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0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   1.E-04             1              0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    02000   -1   -1   -1   -1   -12000   -120002000002000    0
0    020002000    -1   1    1    1    1    1    1    1    1    1    0
0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
 1.0E-04              1              0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    02000   -1   -1   -1   -1   -12000   -120002000002000    0
0    0    020002000    -1   5    5    5    5    5    5    5    5    0
0    5    5    5    5    5    5    5    5    5    5    5    5    5    0
0    5    5    5    5    5    5    5    5    5    5    5    5    5    0
0    5    5    5    5    5    5    5    5    5    5    5    5    5    0
0    5    5    5    5    5    5    5    5    5    5    5    5    5    0
0    5    5    5    5    5    5    5    5    5    5    5    5    5    0
0    5    5    5    5    5    5    5    5    5    5    5    5    5    0
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0    5    5    5    5    5    5    5    5    5    5    5    5    5    0
0    5    5    5    5    5    5    5    5    5    5    5    5    5    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
 1.0E-04              1              0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    02000   -1   -1   -1   -1   -12000   -120002000002000    0
0    020002000002000    -120002000200020002000    -1   -12000    0
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0    5    5    5    5    5    5    5    5    5    5    5    5    5    0
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0    5    5    5    5    5    5    5    5    5    5    5    5    5    0
0    5    5    5    5    5    5    5    5    5    5    5    5    5    0
0    5    5    5    5    5    5    5    5    5    5    5    5    5    0
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 1.2E-04              1              0
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0    0    01667   -1   -1   -1   -1   -11667   -11667166671667    0
0    016671667l667    -11667166716671667l667    -1   -11667    0
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0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
```

```
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5.0E-04             1         0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0200020002000   -12000200020002000200 0   -1   -12000         0
0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
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0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
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0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
5.0E-04             1         0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0200020002000   -120002000200020002000    -1   -12000         0
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0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
0    1    1    1    1    1    1    1    1    1    1    1    1    1    0
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2.0E-04             1                        1         1            .1
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01000100010001000100010001000100010001000100010001000              0
01000100010001000100010001000100010001000100010001000              0
01000100010001000100010001000100010001000100010001000              0
01000100010001000100010001000100010001000100010001000              0
0 250  250  250  250  250  250  250  250  250  250  250  250  250  0
01000100010001000100010001000100010001000100010001000              0
01000100010001000100010001000100010001000100010001000              0
01000100010001000100010001000100010001000100010001000              0
01000100010001000100010001000100010001000100010001000              0
01000100010001000100010001000100010001000100010001000              0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
 1.E-03             1         0              1         1            .1
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0  100  100  100  100  100  100  100  100  100  100  100  100  100  0
0  200  300  350  200  150  150  280  200  160  150  170   80   80  0
0   30   30   30  130  110   50  300  500  400  230  480  530  530  0
0  100  100  100   65  150  130  220  160  220  280  150  420  420  0
0  100  100  100   60  175  220   90  120  250  180  120  150  150  0
0    5    5    5    5    5    5    5    5    5    5    5    5    5  0
0  100  100  100  120  160  300  190  180  220  250  100  150  150  0
0  100  100  100  120  160  250  170  170  200  240  100  130  130  0
0  100  100  100  110  150  200  150  150  180  200  100  100  100  0
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0  100  100  100  100  100  100  100  100  100  100  100  100  100  0
0    0    0    0    0    0    0    0    0    0    0    0    0    0  0
1.0E-03             1         0              1         1            .1
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0  120  120  120  190  110   80  150  270  160  270  525  200  200  0
0   40   40   40   50   90  150  250  180  140  230   70   70  140  0
0   40   40   40   60   75  150  195  320  300  150  190  260  240  0
0  100  100  100   75  150  150  200  320  240  120  120  230  220  0
0    5    5    5    5    5    5    5    5    5    5    5    5    5  0
0   40   40   40   50   90  110  140  180  150  200  170  230  220  0
0   40   40   40   50  100  120  110  150  200  250  200  200  200  0
0   50   50   50   70  100  100  100  130  170  200  180  180  180  0
0   70   70   70   90  100  100  100  110  150  180  170  150  150  0
0  100  100  100  100  100  100  100  100  150  150  150  150  150  0
0    0    0    0    0    0    0    0    0    0    0    0    0    0  0
1.0E-03             1         0              1         1            .1
0    0    0    0    0    0    0    0    0    0    0    0    0    0  0
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0  300  300  330  165  100  100  100  110  130  130  625  130  150  0
0   20   20   20   90  120  150  165  180  210  330  400  250  165  0
0   30   30   30   50   75  360  330  165  215   85  220  410  300  0
0   45   45   45   60  230  280  115  360  150  215  165  240  280  0
0    5    5    5    5    5    5    5    5    5    5    5    5    5  0
0   35   35   35  100  160  280  410  410  425  410  300  175  175  0
0   35   35   35   70  130  280  370  370  370  410  440  360  280  0
0   35   35   35   70  130  280  360  360  360  390  410  350  270  0
0   35   35   35   70  120  250  340  340  340  360  370  340  260  0
0   35   35   35   50  100  220  330  330  330  330  330  330  250  0
0    0    0    0    0    0    0    0    0    0    0    0    0    0  0
```

Appendix II.--Continued

```
1.1E-04            1         0         1         1         .1
0    0    0    0    0    0    0    0    0    0    0    0    0    0     0
010001000100010001000100010001000100010001000100010001000     0
010001000100010001000100010001000100010001000100010001000     0
010001000100010001000100010001000100010001000100010001000     0
010001000100010001000100010001000100010001000100010001000     0
010001000100010001000100010001000100010001000100010001000     0
0  450  450  450  450  450  450  450  450  450  450  450  450  450     0
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010001000100010001000100010001000100010001000100010001000     0
010001000100010001000100010001000100010001000100010001000     0
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010001000100010001000100010001000100010001000100010001000     0
0    0    0    0    0    0    0    0    0    0    0    0    0    0     0
4.0E-02            1         0         1         1         .1
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0    0    0    0    0    0    0    0    0    0    0    0    0    0     0
0    1    1    1    1    1    1    1    1    1    1    1    1    1     0
0    1    1    1    1    1    1    1    1    1    1    1    1    1     0
0    1    1    1    1    1    1    1    1    1    1    1    1    1     0
0    1    1    1    1    1    1    1    1    1    1    1    1    1     0
0    1    1    1    1    1    1    1    1    1    1    1    1    1     0
0    1    1    1    1    1    1    1    1    1    1    1    1    1     0
0    1    1    1    1    1    1    1    1    1    1    1    1    1     0
0    1    1    1    1    1    1    1    1    1    1    1    1    1     0
0    1    1    1    1    1    1    1    1    1    1    1    1    1     0
0    1    1    1    1    1    1    1    1    1    1    1    1    1     0
0    0    0    0    0    0    0    0    0    0    0    0    0    0     0
1.25E-01           1         0         1         1         .1
0    0    0    0    0    0    0    0    0    0    0    0    0    0     0
0    0    0    0    0    0    0    0    0    0    0    0    0    0     0
0    1    1    1    1    1    1    1    1    1    1    1    1    1     0
0    1    1    1    1    1    1    1    1    1    1    1    1    1     0
0    1    1    1    1    1    1    1    1    1    1    1    1    1     0
0    1    1    1    1    1    1    1    1    1    1    1    1    1     0
0    1    1    1    1    1    1    1    1    1    1    1    1    1     0
0    1    1    1    1    1    1    1    1    1    1    1    1    1     0
0    1    1    1    1    1    1    1    1    1    1    1    1    1     0
0    1    1    1    1    1    1    1    1    1    1    1    1    1     0
0    1    1    1    1    1    1    1    1    1    1    1    1    1     0
0    1    1    1    1    1    1    1    1    1    1    1    1    1     0
0    0    0    0    0    0    0    0    0    0    0    0    0    0     0
```

(Six blank cards)

```
2.0E-10
2.0E-10
2.0E-10
2.0E-10
2.0E-10
2.0E-10
   .5              1         0
0    0    0    0    0    0    0    0    0    0    0    0    0    0     0
0  300  300  300  300  300  300  300  300  300  300  300  300  300     0
0  300  300  300  300  300  300  300  300  300  300  300  300  300     0
0  300  300  300  300  300  300  300  300  300  300  300  300  300     0
0  300  300  300  300  300  300  300  300  300  300  300  300  300     0
0  300  300  300  300  300  300  300  300  300  300  300  300  300     0
0  300  300  300  300  300  300  300  300  300  300  300  300  300     0
0  300  300  300  300  300  300  300  300  300  300  300  300  300     0
0  300  300  300  300  300  300  300  300  300  300  300  300  300     0
0  300  300  300  300  300  300  300  300  300  300  300  300  300     0
0  300  300  300  300  300  300  300  300  300  300  300  300  300     0
0  300  300  300  300  300  300  300  300  300  300  300  300  300     0
0    0    0    0    0    0    0    0    0    0    0    0    0    0     0
          1              1         0
0    0    0    0    0    0    0    0    0    0    0    0    0    0     0
0  100  100  100   70   80   80   90  100  150  200  250   75   75     0
0  100  100   90   70   70  120   50  130  150  300  200  150  120     0
0   80   80   80  200  100  100  250  400  200  270  140  100   70     0
0  100  100  110  240  260  200  140  150  120  150  110  120  100     0
0  110  130  140  120  110  150  240  180  140  100   80  100  100     0
0  110  130  140  120  110  150  240  180  140  100   80  100  100     0
0   40   40   40  180  250  150  300  190  190  100  300  200  100     0
0  150  150  150  150  250  150  130  150  120   70  150  150  100     0
0  130  130  130  130  220  130  100  120  100   90  120  120  100     0
0  100  100  100  100  170  110  100  100  100  100  100  100  100     0
0  100  100  100  100  150  100  100  100  100  100  100  100  100     0
0    0    0    0    0    0    0    0    0    0    0    0    0    0     0
          1              1         0
0    0    0    0    0    0    0    0    0    0    0    0    0    0     0
0  100  150  200   50   50   50  100  100  100   50   50   50   50     0
```

```
0 100 150 200  60 100  80 100  70 100  80  80  80  50    0
0  50  50  50  90 100 230 150 130 250  30 150 180 130    0
0 100 100 100 150 100 150 250 250 250  90 200 120 150    0
0 100 100 100 310 120 110 600 150 110 170 230 140 140    0
0 100 100 100 310 120 110 600 150 110 170 230 140 140    0
0  50  50  50 200 450 300 230 160 140 150 200 150 150    0
0  50  50  50 200 400 300 240 250 200 100 270 150 150    0
0  50  50  50 180 300 200 200 200 200 100 240 150 150    0
0  50  50  50 160 200 170 160 180 180 100 200 130 150    0
0  50  50  50 150 150 150 150 150 150 100 150 100 100    0
0   0   0   0   0   0   0   0   0   0   0   0   0   0    0
       .5           1           0
0   0   0   0   0   0   0   0   0   0   0   0   0   0    0
0 340 340 340 340 340 340 340 340 340 340 340 340 340    0
0 340 340 340 340 340 340 340 340 340 340 340 340 340    0
0 340 340 340 340 340 340 340 340 340 340 340 340 340    0
0 340 340 340 340 340 340 340 340 340 340 340 340 340    0
0 340 340 340 340 340 340 340 340 340 340 340 340 340    0
0 340 340 340 340 340 340 340 340 340 340 340 340 340    0
0 340 340 340 340 340 340 340 340 340 340 340 340 340    0
0 340 340 340 340 340 340 340 340 340 340 340 340 340    0
0 340 340 340 340 340 340 340 340 340 340 340 340 340    0
0 340 340 340 340 340 340 340 340 340 340 340 340 340    0
0 340 340 340 340 340 340 340 340 340 340 340 340 340    0
0   0   0   0   0   0   0   0   0   0   0   0   0   0    0
      200           0           0
      100           1           0
0   0   0   0   0   0   0   0   0   0   0   0   0   0    0
0   0   0   0   0   0   0   0   0   0   0   0   0   0    0
0   1   1   1   1   1   1   1   1   1   1   1   1   1    0
0   1   1   1   1   1   1   1   1   1   1   1   1   1    0
0   1   1   1   1   1   1   1   1   1   1   1   1   1    0
0   1   1   1   1   1   1   1   1   1   1   1   1   1    0
0   1   1   1   1   1   1   1   1   1   1   1   1   1    0
0   1   1   1   1   1   1   1   1   1   1   1   1   1    0
0   1   1   1   1   1   1   1   1   1   1   1   1   1    0
0   1   1   1   1   1   1   1   1   1   1   1   1   1    0
0   1   1   1   1   1   1   1   1   1   1   1   1   1    0
0   1   1   1   1   1   1   1   1   1   1   1   1   1    0
0   0   0   0   0   0   0   0   0   0   0   0   0   0    0
1.6E-05
    5280          1          0                                      0         0
      20         20         20         20         20        15       10         7
       7         10         15         20         30        30       30
    5280          1          0                                      0         0
      20         20         20       13.5          9         6        4         6
       9       13.5         20         20         20
       1          1
     200        200        280        250        120
  .99863
       1          0          3       3650         15       1.5     93.6
       2          6          9       -.77
       4          6          9      -4.64
       3          6          9       -3.1
       2          1          3       5110         15       1.5     93.6
       2          6          9      -2.32
       4          6          9       -3.1
       3          6          9       -6.2
       3          2          3       4015         15       1.5     93.6
       2          6          9      -7.74
       4          6          9      -4.64
       3          6          9     -19.58
       4          3          3       2190         15       1.5     93.6
       2          6          9     -13.92
       4          6          9     -10.05
       3          6          9     -22.38
       5          4          3       1460         15       1.5     93.6
       2          6          9     -15.47
       4          6          9     -12.53
       3          6          9     -31.96
       6          5          3       1825        15        1.5     93.6
       2          6          9     -13.92
       4          6          9     -13.92
       3          6          9     -37.95
       7          6          3        730         15       1.5     93.6
       2          6          9     -17.02
       4          6          9     -17.79
       3          6          9     -45.76
       8          7          3        730         15       1.5     93.6
       2          6          9     -20.11
       4          6          9     -18.56
       3          6          9     -54.26
       9          8          3       1825         50       1.5     93.6
       2          6          9     -20.11
       4          6          9     -30.17
       3          6          9     -59.30
      10          9          3        365         15       1.5     93.6
       2          6          9     -19.49
       4          6          9     -34.65
       3          6          9     -56.95
/*
//
```

Appendix III. Listing of computer code and data input for one-dimensional, finite-difference model used to solve for hydraulic conductivity of the Baton Rouge fault

```
C **** GENERAL IMPLICIT, FINITE-DIFFERENCE PROGRAM FOR ONE DIMENSIONAL
C      FLOW ACROSS BATON ROUGE FAULT. EB-780-B AND EB-781 VALUES FOR
C      HYDRAULIC HEAD USED AS INPUT ****
C
C DIMENSION ARRAYS
C
      DIMENSION A(40),B(40),C(40),D(40),H(40),PERM(40),R(40),SS(40),BETA
     #(40),GAMMA(40),G(40),KMH(40),KPH(40),KH(40),DX(40)
C
      REAL*8 A,B,C,D,R,BETA,GAMMA,G,KMH,KPH,KH
C READ IN PHYSICAL DIMENSIONS OF MODEL AND THETA PARAMETER
C
      READ(5,10) NX,THETA,DELT
   10 FORMAT(3G10.0)
C
C READ MULTIPLICATION FACTORS FOR SS PERM, AND DX
C
      READ(5,20) FACT1,FACT2,FACT3
   20 FORMAT(3G15.0)
C READ VALUES TO COMPUTE SS, PERM, AND DX
C
      READ(5,30) (SS(I),I=1,NX)
   30 FORMAT(20F4.0)
      READ(5,41) (PERM(I),I=1,NX),(DX(I),I=1,NX)
C
C  INITIALIZE HEADS
C
      READ(5,41) (H(I),I=1,NX)
   41 FORMAT(8G10.0)
C
C COMPUTE SS, PERM, AND DX
      DO 40 I=1,NX
         SS(I)=SS(I)*FACT1
         PERM(I)=PERM(I)*FACT2
         DX(I)=DX(I)*FACT3
   40 CONTINUE
C  WRITE INITIAL CONDITIONS
C
      WRITE(6,45) NX,THETA,DELT
   45 FORMAT(1H ,17HNUMBER OF NODES =,I3,3X,7HTHETA =,F5.2,3X,6HDELT =,F
     #5.2,1X,5HHOURS//)
      WRITE(6,46) (DX(I),I=1,NX)
   46 FORMAT(//,48X,21HGRID SPACING, DELTA X/(1H ,10F12.1,/))
      WRITE(6,47) (SS(I),I=1,NX)
   47 FORMAT(//,43X,33HSPECIFIC STORAGE OF AQUIFER (1/L)/(1H ,10(1PE11.3
     #,1X)/))
      WRITE(6,48) (PERM(I),I=1,NX)
   48 FORMAT(43X,36HAQUIFER HYDRAULIC CONDUCTIVITY (L/T)/4X,6HEB-781,6X,
     #5HFAULT,68X,7HEB-780B/(1H ,10(1PE11.3,1X)/))
      WRITE(6,49) (H(I),I=1,NX)
   49 FORMAT(48X,25HINITIAL HEAD DISTRIBUTION/3X,6HEB-781,6X,5HFAULT,61X
     #,7HEB-780B/(1H ,10(0PF8.2,3X)/))
C *** BEGIN TIME-DEPENDENT CALCULATIONS BY
C      READING VALUES OF HEAD AND DELT FOR EB-781 ***
      DTIME=0.0
   60 READ(5,70,END=999) H(1),TIME
   70 FORMAT(2G10.0)
C
C  ADD A COUNTER FOR TIME
      DTIME= TIME+DTIME
      YTIME=DTIME/365
      NM1=NX-1
      NTS=TIME*24/DELT
```

```
C  COMPUTE R(I) AND A, B, C TERMS FOR COEFFICIENT MATRIX
      A(1)=0.0
      B(1)=1.0
      C(1)=0.0
      DO 80 I=2,NM1
         R(I)=DELT/(SS(I)*DX(I))
         KMH(I)=2*PERM(I-1)*PERM(I)/(PERM(I-1)*DX(I)+PERM(I)*DX(I-1))
         KPH(I)=2*PERM(I)*PERM(I+1)/(PERM(I)*DX(I+1)+PERM(I+1)*DX(I))
         KH(I)=(KMH(I)+KPH(I))/2
         A(I)=-THETA*R(I)*KMH(I)
         B(I)=(1.+2*THETA*R(I)*KH(I))
         C(I)=-THETA*R(I)*KPH(I)
   80 CONTINUE
      R(NX)=DELT/(SS(NX)*DX(NX))
      A(NX)=-1.0
      B(NX)=1.0
      C(NX)=0.0
C
C  COMPUTE KNOWN HEAD MATRIX D FOR EACH DELT INCREMENT
      D(1)=H(1)
      D(NX)=0.0
      DO 500 M=1,NTS
      K=M
      DO 90 I=2,NM1
         D(I)=(1.-THETA)*R(I)*KMH(I)*H(I-1) + (1.-2*(1.-THETA)*R(I)*KH(I
     #   ))*H(I) + (1.-THETA)*R(I)*KPH(I)*H(I+1)
   90 CONTINUE
C
C COMPUTE H(I) VALUES FOR EACH DELT INCREMENT
C  THOMAS ALGORITHM FOR HEAD MATRIX SOLUTION
C  COMPUTE BETA(I), GAMMA (I), AND G(I)
C
      BETA(1)=B(1)
      GAMMA(1)=C(1)/BETA(1)
      G(1)=D(1)/BETA(1)
      DO 110 I=2,NX
         BETA(I)=B(I)-A(I)*GAMMA(I-1)
         GAMMA(I)=C(I)/BETA(I)
         G(I)=(D(I)-A(I)*G(I-1))/BETA(I)
  110 CONTINUE
C
C  COMPUTE HEAD FOR H(NX) NODE
C
      H(NX)=G(NX)
C
C COMPUTE REMAINING HEADS EXCEPT H(1) WHICH IS SPECIFIED AT EB-781.
C
      NM2=NX-2
      DO 120 I=1,NM2
         J=NX-I
         H(J)=G(J)-GAMMA(J)*H(J+1)
  120 CONTINUE
C
C USE NEW H(I) VALUES TO COMPUTE KNOWN HEAD MATRIX D FOR EACH DELT
C
  500 CONTINUE
C
C
      WRITE (6,140) DTIME,YTIME,TIME,K,(H(I),I=1,NX)
  140 FORMAT(//,11X,20HTOTAL ELAPSED TIME =,F7.2,1X,4HDAYS,2X,F8.5,1X,5H
     #YEARS//1X,21HSIZE OF TIME PERIOD =,F5.2,1X,4HDAYS,15X,17HHEAD DIST
     #RIBUTION,15X,19HNO. OF TIME STEPS =,I5,1X,2H**/3X,6HEB-781,6X,5HFA
     #ULT,27X,17H---- ------------,17X,7HEB-780B/(1H ,10(F8.2,3X)/))
C  READ ANOTHER HEAD FOR EB-781 AND COMPUTE NEW HEAD DISTRIBUTION
      GO TO 60
  999 STOP
      END
```

NUMBER OF NODES = 40 THETA = 1.00 DELT = 8.00 HOURS

GRID SPACING, DELTA X

600.0	600.0	600.0	600.0	600.0	600.0	600.0	600.0	600.0	600.0
600.0	600.0	600.0	600.0	600.0	600.0	1200.0	1800.0	2400.0	3000.0
3600.0	3600.0	3600.0	3600.0	4800.0	4800.0	4800.0	4800.0	4800.0	4800.0
4800.0	4800.0	6000.0	9000.0	12000.0	15000.0	18000.0	21000.0	24000.0	27000.0

SPECIFIC STORAGE OF AQUIFER (1/L)

1.940E-05	1.940E-05	1.940E-05	1.940E-05	1.940E-05	1.940E-05	1.940E-05	1.940E-05	1.940E-05	1.940E-05
1.940E-05	1.940E-05	1.940E-05	1.940E-05	1.940E-05	1.940E-05	1.940E-05	1.940E-05	1.940E-05	1.940E-05
1.940E-05	1.940E-05	1.940E-05	1.940E-05	1.940E-05	1.940E-05	1.940E-05	1.940E-05	1.940E-05	1.940E-05
1.940E-05	1.940E-05	1.940E-05	1.940E-05	1.940E-05	1.940E-05	1.940E-05	1.940E-05	1.940E-05	1.940E-05

AQUIFER HYDRAULIC CONDUCTIVITY (L/T)

EB-781 6.958E+00	FAULT 1.375E-03	5.917E+00	5.917E+00	5.917E+00	5.917E+00	5.917E+00	EB-780B 5.917E+00	5.917E+00	5.917E+00
5.917E+00	5.917E+00	5.917E+00	5.917E+00	5.917E+00	5.917E+00	5.917E+00	5.917E+00	5.917E+00	5.917E+00
5.917E+00	5.917E+00	5.917E+00	5.917E+00	5.917E+00	5.917E+00	5.917E+00	5.917E+00	5.917E+00	5.917E+00
5.917E+00	5.917E+00	5.917E+00	5.917E+00	5.917E+00	5.917E+00	5.917E+00	5.917E+00	5.917E+00	5.917E+00

INITIAL HEAD DISTRIBUTION

EB-781 -122.38	FAULT -117.83	8.41	8.43	8.47	8.51	8.55	EB-780B 8.58	8.58	8.58
8.58	8.58	8.58	8.59	8.59	8.59	8.60	8.60	8.60	8.60
8.60	8.60	8.61	8.61	8.61	8.62	8.62	8.62	8.62	8.62
8.62	8.63	8.63	8.63	8.63	8.63	8.63	8.63	8.63	8.63

Appendix IV-A. Data for detailed three-dimensional model of "2,000-foot" sand, calibration and verification runs

```
<<<<< DATA FOR CALIBRATION AND VERIFICATION RUN OF DETAILED FINITE DIFFERENCE
SIMULATION OF "2,000-FOOT" SAND OF BATON ROUGE >>>>>
      26          30           3          30          54          5
   HEAD MASS        DK2                              ITKR       ITLR
      28          50         .01           6

                                   (Four blank cards)

      0.0
      0.0
      0.0
 1.50E-04           1           1
  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  0   0   0   0   0   0   0   0   0   0
  0   0 400  -1  -1  -1  -1  -1  -1  -1 400 400 400 400 400 400  -1  -1  -1  -1
 -1 400 400  -1  -1 400 400 400 400   0
  0 400 400 400 400 400   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  1   1   1   1   1   1   1   1   1   0
  0   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  1   1   1   1   1   1   1   1   1   0
  0   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  1   1   1   1   1   1   1   1   1   0
  0   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  1   1   1   1   1   1   1   1   1   0
  0   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  1   1   1   1   1   1   1   1   1   0
  0   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  1   1   1   1   1   1   1   1   1   0
  0   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  1   1   1   1   1   1   1   1   1   0
  0   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  1   1   1   1   1   1   1   1   1   0
  0   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  1   1   1   1   1   1   1   1   1   0
  0   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  1   1   1   1   1   1   1   1   1   0
  0   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  1   1   1   1   1   1   1   1   1   0
  0   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  1   1   1   1   1   1   1   1   1   0
  0   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  1   1   1   1   1   1   1   1   1   0
  0   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  1   1   1   1   1   1   1   1   1   0
  0   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  1   1   1   1   1   1   1   1   1   0
  0   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  1   1   1   1   1   1   1   1   1   0
  0   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  1   1   1   1   1   1   1   1   1   0
  0   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  1   1   1   1   1   1   1   1   1   0
  0   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  1   1   1   1   1   1   1   1   1   0
  0   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  1   1   1   1   1   1   1   1   1   0
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180 185 100 130 180 180 100  50  50   0
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500 400 290 225 180 250 160  80  80   0
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300 265 420 300 200 340 340 380 300   0
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562 675 300 300 270 270 350 400 350   0
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550 590 200 260 300 220 300 300 250   0
  0 170 170 170 135 200 180 200 185 220 360 400 476 476 476 476 520 520 520 520
520 520 475 300 260 170 370 300 300   0
  0 170 170 175 175 200 280 300 310 260 330 300 350 390 420 440 400 425 465 450
443 415 410 380 254 200 210 210 210   0
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343 335 290 280 219 220 210 210 210   0
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225 251 260 200 190 160 250 250 250   0
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255 255 250 140 130 150 250 250 250   0
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120 150 220 150 120 150 200 200 200   0
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140 1.1 1.4 .70 .85 .55 .55 .55 .55   0
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175 175 220 140 310 150 150 150 150   0
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 50 190 207 160 255 110 100 100 100   0
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387 276 507 240 190 165 225 220 220   0
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 250 .72 .62 .71 1.0 .58 .58 .47 .47   0
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  81 130 170 170 150 130 220 250 300   0
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(Two blank cards)

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   0 .02 .02 .02 .02 .02 .02 .02 .02   2   2   2   2   2   2   2   2   2   2   2
   2   7   7  10  15  10  17   2   2   0
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2	7	2	2	2	2	.2	2	.7	0										
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2	2	2	2	2	7	7	2	.7	0										
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.2	.2	.2	.2	.2	7	7	2	.2	0										
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.4	.2	.2	.2	.2	7	7	2	.2	0										
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.4	.4	.4	2	7	7	7	2	.2	0										
0	.7	.7	.7	.7	.07	.07	.07	.07	.07	.07	.07	.14	.2	1	.4	.4	.4	.4	.4
1	1	1	2	7	7	7	2	.2	0										
0	.7	.7	.7	.7	.07	.07	.07	.07	.07	.07	.07	.07	.2	.4	.4	.4	.4	.4	.4
.4	1	1	2	7	7	7	2	.2	0										
0	.1	.1	.1	.1	.07	.07	.07	.07	.07	.07	.07	.07	.07	.4	.4	.4	.25	.25	.4
.4	.7	.7	.7	.7	2	.7	2	.2	0										
0	.1	.1	.1	.1	.07	.07	.07	.07	.07	.07	.07	.07	.07	.4	.4	.25	.1	.1	.4
.4	.4	.4	.4	.7	2	.7	2	.2	0										
0	.1	.1	.1	.1	.1	.1	.1	.1	.1	.05	.05	.05	.05	.4	.4	.25	.1	.1	.4
.4	.4	.4	.4	2	2	2	2	.2	0										
0	.1	.1	.1	.1	.1	.1	.1	.05	.05	.1	.1	.2	2	.08	.08	.08	.08	.08	.08
.08	2	.2	.2	2	2	2	2	.2	0										
0	.05	.05	.05	.05	.05	.05	.05	.2	.2	.2	.2	.2	2	2	2	2	2	2	2
2	.01	.01	.01	.01	.01	.01	.05	.05	0										
0	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	0										
0	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.7	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	0										
0	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	0										
0	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.2	.2	2	2	2	2	2	2	2
2	2	.7	.7	.7	.7	2	2	2	0										
0	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.2	.2	2	2	2	2	2	2	2
2	2	.7	.7	.7	.7	2	2	2	0										
0	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.2	.2	2	2	2	2	2	2	2
2	2	.7	.7	.7	.7	2	2	2	0										
0	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.2	.2	2	2	2	2	2	2	2
2	2	.7	.7	.7	.7	2	2	2	0										
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0										
2.226E-09				1		1													
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0										
0	10	10	10	10	10	10	10	10	10	.7	.7	.7	.7	.7	.7	.7	.7	.7	.7
.7	.7	.7	.7	.7	.7	.7	.7	.7	0										
0	10	10	10	10	10	10	10	10	2	2	2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	0										
0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	7	2	2	0										
0	.2	.2	.2	.2	.2	.2	.2	.2	.2	.2	2	2	2	2	2	2	2	2	2
2	.7	.7	.2	7	.2	.7	.2	.2	0										
0	.2	.2	.2	.2	.2	.2	.2	.2	.2	.2	2	2	2	2	2	2	2	2	2
2	.7	.7	.2	2	.2	.7	.2	.2	0										
0	.1	.1	.1	.1	.1	.1	.1	.1	.1	.2	2	2	2	2	2	2	2	2	2
2	.7	.7	.2	.2	.2	.7	.2	.2	0										
0	.1	.1	.1	.1	.1	.1	.07	.07	.1	.2	2	2	2	2	2	2	2	2	2
2	.7	.7	.2	.2	.2	.7	.02	.02	0										
0	.1	.1	.1	.1	.1	.1	.07	.07	.07	.1	2	2	2	2	2	2	2	2	2
2	2	2	2	.2	.2	.7	.02	.02	0										
0	.1	.1	.1	.1	.2	.2	.2	.2	.1	.07	7	7	7	7	7	2	2	2	2
2	2	2	2	.2	.2	.7	.02	.02	0										
0	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.7	.7	.7	.7	.7	.2	.1	.1	.1
.2	.2	.2	.2	.2	.2	.7	2	2	0										
0	.1	.1	.1	.1	.07	.07	.1	.1	.1	.1	.7	.7	1.2	1.2	1	.2	.2	.2	.2
.2	.2	.2	.2	.2	.2	.2	2	2	0										
0	.1	.1	.1	.07	.07	.07	.1	.1	.1	.1	.7	.7	.7	.7	.4	.2	.2	.2	.2
.3	.3	.3	.3	.2	.2	.2	2	2	0										
0	.1	.1	.1	.1	.07	.07	.1	.1	.1	.1	.7	.7	.7	.7	.7	.15	.15	.15	.2
.2	.3	.3	.7	.7	.2	2	2	2	0										
0	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.7	.7	.7	.9	.9	.2	.15	.5	.2
.2	.2	.2	.2	.2	.2	2	2	2	0										
0	.1	.1	.1	.1	.1	.1	.1	.1	.1	.08	.08	.08	.08	.7	.7	.2	.15	.15	.2
.2	.2	.2	.2	.2	.2	2	2	2	0										
0	.1	.1	.1	.1	.1	.1	.1	.05	.05	2	2	2	2	.08	.08	.08	.08	.08	.08
.08	2	2	2	2	.2	2	2	2	0										
0	.05	.05	.05	.05	.05	.05	.05	2	2	2	2	.7	.7	.7	2	2	2	2	2
2	.01	.02	.02	.02	.02	.01	.01	.01	0										
0	2	2	2	2	2	2	2	2	2	2	.7	.7	.7	.7	.7	2	2	2	2
2	2	2	2	2	2	2	2	2	0										

Appendix IV-A.--Continued

0	2	2	2	2	2	2	2	2	2	2	2	.7	.7	.7	2	2	2	2	2
2	2	2	2	2	2	2	2	2	0										
0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	0										
0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	0										
0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	0										
0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	0										
0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	0										
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0										
		1		1			1												
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0										
0	40	40	30	30	40	50	35	40	40	40	50	50	50	50	50	50	50	50	50
60	60	75	85	100	100	60	50	50	0										
0	50	50	35	30	40	50	40	40	40	40	50	50	50	50	50	50	50	60	60
60	70	85	100	110	100	60	50	50	0										
0	90	90	1	65	50	50	80	80	80	80	100	100	100	100	100	100	100	130	140
160	160	140	110	244	150	80	40	40	0										
0	70	75	75	75	175	75	30	80	125	100	75	60	50	60	75	85	110	125	135
150	200	120	75	250	120	140	150	150	0										
0	50	50	35	185	50	50	75	120	150	120	100	140	160	190	200	230	250	350	400
280	275	130	200	310	175	250	200	200	0										
0	100	100	125	135	50	85	100	100	50	120	130	240	250	225	190	300	320	350	400
450	500	350	350	240	100	275	175	175	0										
0	110	120	130	275	300	75	105	100	200	180	75	190	230	90	100	250	330	300	250
220	300	100	135	100	195	125	30	50	0										
0	110	115	165	200	320	350	255	170	200	140	120	130	155	130	105	97	150	100	100
180	175	137	100	80	55	125	125	125	0										
0	115	115	165	50	80	200	165	150	180	87	87	90	70	65	70	90	115	125	165
180	195	120	68	75	125	125	200	200	0										
0	115	115	100	60	135	300	210	135	210	125	87	100	125	210	280	230	185	160	95
150	210	150	100	80	65	75	200	200	0										
0	70	70	80	120	105	100	90	120	140	140	160	200	190	135	200	240	210	175	165
195	220	165	150	60	50	50	175	175	0										
0	70	70	150	125	115	100	80	135	140	135	225	400	150	135	175	200	175	150	140
140	140	120	110	100	50	100	200	200	0										
0	180	220	210	100	100	100	100	130	120	145	250	450	150	110	100	80	100	65	50
50	75	75	75	120	175	60	130	200	0										
0	180	220	220	100	100	105	100	200	150	220	150	250	150	120	75	60	58	42	75
75	60	41	110	120	130	200	200	200	0										
0	200	210	180	65	95	120	145	155	160	250	175	180	140	65	65	110	150	50	100
100	110	110	125	120	80	120	175	200	0										
0	150	150	220	105	120	135	135	120	150	215	175	150.	175	260	300	250	220	50	80
70	120	150	150	135	80	150	175	200	0										
0	50	40	200	105	110	100	100	120	165	220	250	210	250	275	400	150	150	80	300
220	240	80	200	140	90	150	220	220	0										
0	35	35	100	100	120	165	85	100	165	230	250	250	330	420	500	260	175	150	210
230	120	70	200	140	120	210	230	230	0										
0	30	30	60	160	175	185	150	125	165	300	400	500	350	300	200	69	100	135	300
475	300	120	170	100	250	220	250	250	0										
0	30	30	70	180	190	270	195	140	160	170	300	200	200	215	120	80	100	170	230
220	280	130	130	65	290	250	250	250	0										
0	120	120	150	170	190	260	230	165	150	150	150	100	130	130	140	130	100	150	170
150	120	100	100	100	100	150	180	180	00										
0	150	150	160	180	200	250	230	150	160	160	150	100	120	130	140	130	100	150	170
150	130	120	100	100	130	150	150	150	0										
0	160	160	170	190	200	250	230	150	160	160	150	110	130	130	140	130	100	150	170
150	130	120	100	100	200	150	150	150	0										
0	160	160	170	190	200	250	230	150	160	160	150	110	130	130	140	130	100	150	170
150	130	120	100	100	200	150	150	150											
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0										
		1		1			1												
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0										
0	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
15	15	15	15	15	15	15	15	15	0										
0	100	50	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
15	15	15	15	15	15	15	15	15	0										
0	250	15	1	1	50	80	100	80	50	75	110	120	120	120	120	110	110	100	90
90	120	130	120	100	15	85	85	85	0										
0	70	1	1	35	50	80	40	85	100	100	100	120	120	75	65	45	35	45	50
100	130	130	120	120	1	65	1	1	0										
0	40	40	80	105	40	85	100	100	205	150	120	110	75	50	25	35	45	50	30
67	100	175	175	100	150	150	60	60	0										
0	50	50	75	120	65	175	160	200	150	220	100	140	130	130	140	150	155	140	140
200	300	250	200	1	175	250	150	150	0										
0	75	75	75	125	90	150	70	175	220	145	60	200	275	185	210	200	215	200	185
300	425	285	200	130	1	120	150	150	0										

```
  0  70  70 140  75  75 100  50  85 160 120 130 140 150 175 175 150 200 175 260
250 220 270 115 100  55 120 150 150   0
  0  75  75 165  60  72 160  80 265 130  75 225 275 300 370 120 200 220 225 230
235 200 100 115 100 350 110 140 140   0
  0  75  75 200 140 120 175 100 320 100 140 250 280 300 250 190 135 150 120 150
150 110  85 100 115 200  85  80 100   0
  0  85  85 150 200 130 120 130 275 100 150 250 250 175 185 140 175 200 200 115
 85  60  75 215 100 275 120 120 120   0
  0 105 105 220 250 250 100 170 190 105  80 435 350 400 520 135 150 175 240 200
140 125 135  60  75 299 125 135 135   0
  0 110 110 320 135 200 105 200 175 110 175 330 200 600 350 100 175 190 275 235
200 200 100  80 100 300 140 140 140   0
  0 100 100 275 125 200 125 175 150 125 175 225 275 200 130  75 275 150 250 215
210 215  85 140 230 300 150 150 150   0
  0  80  80 200 150 165 150 165 100 120 200  70 190 175  80 140 260 140 250 235
230 220  85 150 300 260 100 150 150   0
  0  70  70  50 155 120 130 150 165 130 110 200 230 200 120 120 130 160 240 180
150 200 100  80 300 190 200 170 150   0
  0  60  60  80 160 230 110 130 250 220 100 210 215 165  75 140 185 200 250 250
 60  60  60  80 160 100 175 150 150   0
  0  50  50  90 210 165 100 140 170 200 150 200 200 200 200 220 200 250 265 175
185 185 225 165 220  80 200 150 150   0
  0  45  45  80 220 300 360 280 275 300 220 230 270 275 230 260 120  60  50 100
160 220 160  80 200  80 130 150 150   0
  0  40  40 100 250 350 450 430 500 320 190 200 210 200 190 230 275 200 180 175
160 300 200  50 100 130 170 160 160   0
  0  60  60 120 250 350 420 420 400 300 200 200 240 240 210 230 250 275 200 220
220 250 210 100 100 320 260 220 150   0
  0  60  60 120 220 320 420 420 370 280 240 220 240 250 250 250 250 250 250 250
250 250 190 120 100 250 220 220 180   0
  0  50  50 120 250 350 400 420 400 280 260 250 240 250 250 250 250 250 250 250
250 250 175 100 100 250 220 220 180   0
  0  50  50 140 250 320 380 400 360 300 250 240 245 245 250 250 250 250 250 250
250 250 200 150 100 240 240 230 200   0
  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  0   0   0   0   0   0   0   0   0   0
 1.50F-05
     5280           1
       40          27          18          12           9           6           5           5
      4.5           4           3           3           2         1.5           1           1
        1           1           1         1.5        2.25       3.375      5.0625        7.59
    11.39       17.08          24          36          54          54
     5280           1
       18          12           9           9           6           6           6           5
    3.375        2.25           2         1.5           1           1           1           1
        1           1         1.5         2.5        3.75         5.5        8.25          12
       18          27
        1           1
      200         200         280
   .99863
        1           0           1         730          10         1.5         104
        2          15          16      -0.668
        2           1           2        1460          10         1.5       206.2
        2          19          14       -1.08
        2          15          16      -1.403
        3           2           5        2555          10         1.5      360.73
        2          19          14       -1.08
        2          15          16      -1.996
        2          15          17       -.371
        2           9          17       -.387
        2          12          15       -.387
        4           3           7        1095          10         1.5       154.6
        2          19          14        -.51
        2          14          18      -1.671
        2          15          16      -3.387
        2          15          17       -.371
        2           9          17       -.387
        2          12          15       -.387
        3          14          18        -1.7
        5           4           8        3650          10         1.5      515.31
        2          19          14        -.51
        2          14          18      -1.857
        2          15          16      -3.387
        2          15          17       -.542
        2          15          18       -.124
        2           9          17       -.542
        2          12          15       -.387
        3          14          18       -1.80
        6           5          12         365          10         1.5      51.531
        2          19          14        -.65
        2          12          16      -4.377
        2          14          18      -3.404
        2          15          16      -1.702
        2          15          17       -.542
        2          15          18       -.124
```

Appendix IV-A.--Continued

2	9	17	-.542			
2	11	19	-.02			
2	12	15	-.387			
3	14	18	-1.90			
3	12	16	-2.61			
3	10	12	-.064			
7	6	15	365	10	1.5	51.531
2	5	27	-17.36			
2	19	14	-.65			
2	12	16	-9.903			
2	13	16	-.093			
2	14	18	-3.996			
2	15	16	-.695			
2	15	18	-.124			
2	9	17	-.542			
2	11	19	-.02			
2	9	23	-.124			
2	12	15	-.387			
3	14	18	-1.99			
3	11	18	-.36			
3	12	16	-2.61			
3	10	12	-.064			
8	7	21	730	10	1.5	103.062
2	4	26	-.31			
2	5	27	-22.26			
2	19	14	-.65			
2	12	16	-11.729			
2	13	16	-1.244			
2	14	18	-4.064			
2	15	16	-.3			
2	15	18	-.124			
2	15	19	-.856			
2	9	17	-.658			
2	11	19	-.03			
2	9	23	-.140			
2	12	15	-.387			
1	12	16	-1.78			
3	11	18	-1.08			
3	14	18	-2.03			
1	12	17	-4.11			
3	12	16	-2.61			
3	12	22	-.01			
3	12	18	-.35			
3	10	12	-.064			
9	8	26	1095	10	1.5	154.6
2	4	26	-.31			
2	5	27	-19.7			
2	19	14	-.65			
2	18	15	-.175			
2	12	16	-12.009			
2	13	16	-1.742			
2	14	18	-2.724			
2	15	16	-.995			
2	15	18	-.124			
2	15	19	-2.025			
2	9	17	-.774			
2	11	19	-.034			
2	9	23	-.155			
2	10	18	-.016			
2	10	19	-.016			
2	12	15	-.387			
1	14	18	-.33			
1	12	16	-2.81			
1	12	17	-7.11			
1	15	19	-1.48			
3	12	16	-2.61			
3	12	22	-.03			
3	12	18	-.7			
3	10	12	-.064			
3	11	18	-1.08			
3	14	18	-1.36			
10	11	30	365	10	1.5	51.531
2	4	26	-.5			
2	5	27	-19.7			
2	19	14	-.22			
2	18	15	-.175			
2	12	16	-11.139			
2	13	16	-1.857			
2	14	18	-3.3			
2	15	16	-1.547			
2	15	18	-.124			
2	15	19	-3.094			
2	9	17	-.774			
2	11	19	-.034			
2	9	23	-.155			

2	10	18	-.016			
2	10	19	-.016			
2	11	15	-.051			
2	12	15	-.387			
1	14	18	-.05			
1	12	16	-3.33			
1	12	17	-7.11			
1	15	19	-1.55			
3	13	17	-.19			
3	11	18	-1.08			
3	12	16	-2.61			
3	12	22	-.03			
3	12	18	-.95			
3	10	12	-.064			
3	13	26	-.62			
3	15	19	-1.67			
3	14	18	-2.01			
11	10	33	1825	10	1.5	257.66
2	4	26	-.6			
2	5	27	-12.8			
2	19	14	-.22			
2	18	15	-.175			
2	11	16	-.155			
2	12	16	-10.288			
2	13	16	-2.087			
2	14	18	-4.023			
2	15	16	-2.166			
2	15	18	-.124			
2	15	19	-4.023			
2	9	17	-1.006			
2	11	19	-.04			
2	9	23	-.155			
2	10	18	-.019			
2	10	19	-.019			
2	11	15	-.051			
2	12	15	-.387			
2	12	23	-.28			
1	14	18	-.65			
1	12	16	-3.93			
1	12	17	-6.64			
1	15	19	-1.60			
3	13	17	-.19			
3	12	16	-2.61			
3	15	19	-3.75			
3	12	22	-.03			
3	12	18	-1.09			
3	11	16	-.02			
3	10	12	-.064			
3	13	26	-.7			
3	11	18	-1.08			
3	14	18	-3.68			
12	11	38	1095	10	1.5	154.6
2	4	26	-.77			
2	5	27	-12.8			
2	19	14	-.22			
2	18	15	-.2			
2	11	16	-.135			
2	12	16	-10.363			
2	13	16	-4.789			
2	14	18	-3.17			
2	15	16	-2.706			
2	15	18	-.157			
2	15	19	-1.637			
2	11	19	-.052			
2	9	23	-.155			
2	10	18	-.022			
2	10	19	-.020			
2	11	15	-.049			
2	12	21	-.005			
2	12	15	-.388			
2	12	23	-.46			
3	10	15	-.52			
3	10	12	-.064			
3	13	17	-.19			
3	11	18	-1.08			
3	12	22	-.03			
3	12	18	-1.04			
3	11	22	-.02			
1	7	26	-.32			
1	12	16	-4.58			
1	15	19	-1.64			
1	14	18	-.63			
1	12	17	-6.91			
1	12	19	-.92			
1	9	19	-.01			

3	13	26	-.77			
3	12	16	-2.61			
3	11	16	-.03			
3	15	19	-3.35			
3	14	18	-3.81			
13	12	41	730	10	1.5	104
2	4	26	-.62			
2	5	27	-13.34			
2	19	14	-.35			
2	10	17	-.015			
2	12	16	-11.607			
2	13	16	-9.399			
2	13	17	-1.341			
2	14	18	-3.515			
2	15	16	-2.666			
2	15	18	-.173			
2	15	19	-1.578			
2	11	19	-.011			
2	10	18	-.022			
2	10	19	-.022			
2	11	15	-.026			
2	12	21	-.006			
2	12	15	-.388			
2	18	15	-.544			
2	11	23	-.01			
2	12	23	-.65			
2	11	24	-.06			
1	7	26	-.27			
1	12	16	-4.58			
1	15	19	-1.58			
1	14	18	-0.67			
1	12	17	-6.49			
1	12	19	-1.73			
1	9	19	-.07			
3	10	15	-.84			
3	13	17	-.19			
3	11	18	-1.08			
3	16	21	-.05			
3	12	22	-.05			
3	13	23	-.009			
3	12	18	-.59			
3	10	12	-.064			
3	13	26	-.85			
3	12	16	-2.61			
3	15	19	-3.15			
3	14	18	-4.22			
3	11	22	-.07			
14	13	44	730	10	1.5	104
2	4	26	-.62			
2	5	27	-12.5			
2	19	14	-.35			
2	10	17	-.015			
2	12	16	-10.66			
2	12	17	-2.30			
2	13	16	-11.649			
2	13	17	-2.941			
2	14	18	-2.567			
2	15	16	-3.871			
2	15	18	-.175			
2	15	19	-1.604			
2	10	18	-.023			
2	10	19	-.022			
2	11	15	-.028			
2	12	21	-.006			
2	12	15	-.388			
2	18	15	-.746			
2	13	10	-.005			
2	11	23	-.02			
2	12	23	-.75			
2	11	24	-.07			
2	10	25	-.04			
1	7	26	-.27			
1	12	16	-4.59			
1	15	19	-1.45			
1	14	18	-0.69			
1	12	17	-3.26			
1	12	19	-2.24			
1	9	19	-.07			
3	10	15	-.87			
3	12	17	-1.33			
3	13	17	-.19			
3	11	18	-1.08			
3	11	22	-.11			
3	16	21	-.19			
3	12	22	-.07			

3	13	23	-.016			
3	12	18	-.02			
3	10	12	-.064			
3	13	26	-.85			
3	12	16	-2.61			
3	15	19	-3.11			
3	14	18	-4.4			
15	14	45	730	10	1.5	104
2	4	26	-.62			
2	5	27	-10.0			
2	10	26	-.77			
2	19	14	-.4			
2	10	17	-.057			
2	12	16	-9.05			
2	12	17	-7.40			
2	13	17	-3.197			
2	13	16	-10.096			
2	14	18	-1.341			
2	15	16	-4.188			
2	15	18	-.217			
2	15	19	-3.234			
2	10	18	-.017			
2	10	19	-.011			
2	12	21	-.012			
2	12	15	-.422			
2	18	15	-.393			
2	13	10	-.008			
2	11	23	-.03			
2	12	23	-.85			
2	11	24	-.102			
2	10	25	-.125			
3	10	15	-.83			
3	9	14	-.23			
3	11	18	-1.08			
3	12	16	-2.61			
3	16	21	-.09			
3	12	22	-.29			
3	13	23	-.05			
3	10	12	-.064			
3	11	22	-.11			
3	10	16	-.01			
1	10	26	-.77			
1	7	26	-.27			
1	12	16	-4.39			
1	12	17	-3.16			
1	12	19	-3.79			
1	15	19	-2.02			
1	14	18	-.52			
1	9	19	-.80			
3	13	26	-.85			
3	12	17	-1.38			
3	15	19	-3.78			
3	14	18	-5.7			
16	15	45	730	10	1.5	104
2	4	26	-.62			
2	5	27	-10.0			
2	10	26	-.77			
2	19	14	-.4			
2	10	17	-.057			
2	12	16	-9.05			
2	12	17	-7.40			
2	13	17	-3.197			
2	13	16	-10.096			
2	14	18	-1.341			
2	15	16	-4.188			
2	15	18	-.217			
2	15	19	-3.234			
2	10	18	-.017			
2	10	19	-.011			
2	12	21	-.012			
2	12	15	-.422			
2	18	15	-.393			
2	13	10	-.008			
2	11	23	-.03			
2	12	23	-.85			
2	11	24	-.102			
2	10	25	-.125			
3	10	15	-.83			
3	9	14	-.23			
3	11	18	-1.08			
3	12	16	-2.61			
3	16	21	-.09			
3	12	22	-.29			
3	13	23	-.05			
3	10	12	-.064			

Appendix IV-A.--Continued

3	11	22	-.11			
3	10	16	-.01			
1	10	26	-.77			
1	7	26	-.27			
1	12	16	-4.39			
1	12	17	-3.16			
1	12	19	-3.79			
1	15	19	-2.02			
1	14	18	-.52			
1	9	19	-.80			
3	13	26	-.85			
3	12	17	-1.38			
3	15	19	-3.78			
3	14	18	-5.7			
17	16	44	730	10	1.5	104
2	4	26	-.89			
2	5	27	-8.00			
2	10	26	-.77			
2	19	14	-.4			
2	10	17	-0.065			
2	12	16	-8.02			
2	12	17	-8.19			
2	13	16	-11.617			
2	13	17	-4.861			
2	14	18	-1.147			
2	14	19	-1.060			
2	15	16	-3.883			
2	15	18	-.224			
2	15	19	-3.492			
2	10	18	-.034			
2	12	21	-.012			
2	12	15	-.309			
2	18	15	-.487			
2	13	10	-.008			
2	11	23	-.03			
2	12	23	-.9			
2	11	24	-.148			
2	10	25	-.141			
1	10	26	-2.32			
1	7	26	-.27			
1	12	16	-3.47			
1	12	17	-3.30			
1	15	19	-3.25			
1	12	19	-3.75			
1	9	19	-.11			
3	10	15	-.84			
3	9	14	-.62			
3	11	18	-1.08			
3	12	16	-2.61			
3	16	21	-.21			
3	12	22	-.33			
3	13	23	-.01			
3	10	12	-.064			
3	13	26	-1.49			
3	11	22	-.11			
3	12	17	-1.13			
3	10	16	-.01			
3	15	19	-3.93			
3	14	18	-5.11			
18	17	46	730	10	1.5	104
2	5	27	-6.86			
2	4	26	-.8			
2	10	26	-1.0			
2	13	16	-12.672			
2	10	17	-.065			
2	11	16	-.302			
2	12	16	-7.59			
2	12	17	-8.53			
2	13	17	-5.722			
2	14	18	-1.786			
2	14	19	-1.673			
2	15	16	-4.032			
2	15	18	-.224			
2	15	19	-3.449			
2	10	18	-.034			
2	12	15	-.309			
2	18	15	-.534			
2	13	10	-.008			
2	11	23	-.04			
2	12	23	-.92			
2	11	24	-.191			
2	10	25	-.155			
1	10	26	-2.32			
1	7	26	-.27			
1	12	16	-4.13			

Appendix IV-A.--Continued

1	12	17	-4.46			
1	15	19	-4.08			
1	12	19	-3.29			
1	14	16	-.40			
1	9	22	-.11			
1	9	15	-.33			
3	13	26	-1.49			
3	10	15	-.89			
3	12	17	-.89			
3	9	14	-0.57			
3	11	18	-1.08			
3	12	16	-1.95			
3	14	18	-6.89			
3	15	19	-3.90			
3	16	21	-.1			
3	11	17	-1.13			
3	12	22	-.12			
3	11	22	-.33			
3	13	23	-.005			
3	10	12	-.064			
3	10	16	-.01			
19	18	54	1095	10	1.5	154.6
2	4	26	-.77			
2	10	26	-1.5			
2	12	27	-1.5			
2	16	28	-3.6			
2	8	12	-6.238			
2	10	17	-.065			
2	11	16	-.460			
2	12	16	-8.76			
2	12	17	-12.07			
2	13	16	-14.1			
2	13	17	-7.494			
2	14	18	-1.784			
2	14	19	-1.778			
2	15	16	-3.797			
2	15	17	-1.245			
2	15	18	-.224			
2	15	19	-4.087			
2	10	18	-.037			
2	12	15	-.309			
2	18	15	-3.014			
2	13	10	-.008			
2	11	23	-.05			
2	12	23	-.93			
2	11	24	-.232			
2	10	23	-.181			
1	10	26	-2.32			
1	7	26	-.27			
1	12	27	-.75			
1	12	17	-3.86			
1	12	16	-6.13			
1	15	19	-3.87			
1	14	16	-2.			
1	12	19	-3.68			
1	9	22	-.11			
1	9	15	-.33			
3	13	26	-.58			
3	16	28	-.4			
3	10	27	-.4			
3	10	15	-2.			
3	12	17	-0.95			
3	9	14	-0.61			
3	11	18	-0.57			
3	12	16	-1.67			
3	14	18	-5.87			
3	15	19	-3.92			
3	16	21	-.35			
3	11	17	-1.15			
3	12	22	-.27			
3	14	21	-.34			
3	11	22	-.27			
3	13	23	-.03			
3	10	12	-.064			
3	9	13	-.15			
3	10	16	-.01			
20	19	56	365	10	1.5	51.6
2	4	26	-.65			
2	10	26	-1.8			
2	12	27	-1.7			
2	16	28	-4.			
2	8	12	-9.359			
2	10	17	-.042			
2	10	22	-.127			
2	11	16	-.577			

Appendix IV-A.--Continued

2	12	16	-8.			
2	12	17	-11.94			
2	13	16	-14.748			
2	13	17	-8.284			
2	14	18	-1.355			
2	14	19	-1.569			
2	15	16	-5.158			
2	15	17	-1.502			
2	15	18	-.224			
2	15	19	-3.066			
2	10	18	-.037			
2	12	15	-.309			
2	18	15	-3.386			
2	13	10	-.008			
2	11	23	-.05			
2	12	23	-.94			
2	11	24	-.278			
2	10	25	-.217			
1	18	15	-1.235			
1	10	26	-2.32			
1	7	26	-.27			
1	12	27	-.8			
1	12	17	-2.83			
1	12	16	-7.65			
1	15	19	-3.74			
1	14	16	-1.57			
1	12	19	-3.56			
1	9	22	-.11			
1	9	15	-.33			
3	13	26	-.58			
3	16	28	-.4			
3	10	27	-.4			
3	10	15	-2.55			
3	12	17	-1.27			
3	9	14	-.7			
3	11	18	-.32			
3	12	16	-1.38			
3	14	18	-5.23			
3	15	19	-3.46			
3	16	21	-.56			
3	11	17	-1.67			
3	12	22	-.39			
3	14	21	-2.08			
3	11	22	-.15			
3	13	23	-.03			
3	10	12	-.064			
3	9	13	-.15			
3	10	16	-.01			
21	20	56	365	10	1.5	51.6
2	4	26	-.58			
2	10	26	-2.01			
2	12	27	-1.75			
2	16	28	-4.4			
2	8	12	-9.359			
2	14	21	-1.464			
2	10	17	-.042			
2	10	22	-.424			
2	11	16	-.418			
2	12	16	-7.91			
2	12	17	-12.49			
2	13	16	-15.413			
2	13	17	-8.267			
2	14	18	-1.861			
2	14	19	-1.725			
2	15	16	-5.281			
2	15	17	-1.457			
2	15	18	-.224			
2	15	19	-3.19			
2	12	15	-.309			
2	18	15	-3.541			
2	13	10	-.008			
2	11	23	-.05			
2	12	23	-.96			
2	11	24	-.302			
2	10	25	-.232			
1	18	15	-1.275			
1	10	26	-2.32			
1	7	26	-.27			
1	12	27	-.85			
1	12	17	-2.28			
1	12	16	-8.05			
1	15	19	-3.87			
1	14	16	-1.24			
1	12	19	-3.37			
1	9	22	-.11			

1	9	15	-.34			
3	13	26	-.65			
3	16	28	-.46			
3	10	27	-.46			
3	10	15	-2.64			
3	12	17	-1.41			
3	9	14	-.32			
3	11	18	-.32			
3	12	16	-.78			
3	14	18	-7.31			
3	15	19	-4.51			
3	16	21	-.43			
3	11	17	-1.18			
3	12	22	-.46			
3	14	21	-1.87			
3	11	22	-.15			
3	13	23	-.08			
3	10	12	-.064			
3	9	13	-.15			
3	10	16	-.01			
22	21	57	365	10	1.5	51.6
2	4	26	-.51			
2	10	26	-2.01			
2	12	27	-1.86			
2	16	28	-4.95			
2	13	26	-.23			
2	8	12	-10.233			
2	14	21	-1.204			
2	10	17	-.002			
2	10	22	-.541			
2	11	16	-3.2			
2	12	16	-7.90			
2	12	17	-12.12			
2	13	16	-14.85			
2	13	17	-8.19			
2	14	18	-1.78			
2	14	19	-2.02			
2	15	16	-5.68			
2	15	17	-1.21			
2	15	18	-.224			
2	15	19	-3.11			
2	12	15	-.309			
2	18	15	-3.931			
2	13	10	-.008			
2	11	23	-.08			
2	12	23	-1.			
2	11	24	-.325			
2	10	25	-.248			
1	18	15	-1.443			
1	10	26	-2.48			
1	12	27	-.93			
3	13	26	-.65			
3	10	27	-.46			
3	16	28	-.46			
1	12	17	-2.38			
1	12	16	-7.82			
1	15	19	-3.67			
1	14	16	-1.19			
1	12	19	-3.72			
1	9	14	-.34			
1	9	22	-.13			
1	9	15	-.34			
3	10	15	-2.68			
3	12	17	-1.41			
3	9	14	-.32			
3	11	18	-.32			
3	12	16	-.85			
3	14	18	-7.57			
3	15	19	-5.04			
3	16	21	-.45			
3	11	17	-1.09			
3	12	22	-.45			
3	14	21	-1.53			
3	11	22	-.15			
3	13	23	-.06			
3	10	12	-.064			
3	10	16	-.01			
3	9	13	-.15			
23	22	57	365	10	1.5	51.6
2	4	26	-.51			
2	10	26	-2.01			
2	12	27	-1.86			
2	16	28	-4.95			
2	13	26	-.23			
2	8	12	-10.233			

2	10	17	-.002			
2	14	21	-1.097			
2	10	22	-.696			
2	11	16	-3.26			
2	12	16	-7.21			
2	12	17	-12.56			
2	13	16	-15.47			
2	13	17	-7.97			
2	14	18	-1.72			
2	14	19	-1.56			
2	15	16	-6.93			
2	15	17	-1.36			
2	15	18	-.224			
2	15	19	-3.10			
2	12	15	-.309			
2	18	15	-3.931			
2	13	10	-.008			
2	11	23	-.08			
2	12	23	-1.05			
2	11	24	-.348			
2	10	25	-.263			
1	18	15	-1.443			
1	10	26	-2.48			
1	12	27	-.93			
3	13	26	-.65			
3	10	27	-.46			
3	16	28	-.46			
1	12	17	-2.84			
1	12	16	-7.42			
1	15	19	-2.94			
1	14	16	-1.31			
1	12	19	-3.86			
1	9	14	-.34			
1	9	22	-.17			
1	9	15	-.34			
3	10	15	-2.02			
3	12	17	-1.41			
3	9	14	-.32			
3	11	18	-.32			
3	12	16	-.85			
3	14	18	-7.34			
3	15	19	-5.95			
3	16	21	-.92			
3	11	17	-1.11			
3	12	22	-.26			
3	14	21	-1.40			
3	11	22	-.15			
3	13	23	-.07			
3	10	12	-.064			
3	9	13	-.15			
3	10	16	-.01			
24	23	57	365	10	1.5	51.6
2	4	26	-.51			
2	10	26	-2.01			
2	12	27	-1.86			
2	16	28	-4.95			
2	13	26	-.23			
2	8	12	-10.233			
2	10	17	-.002			
2	14	21	-1.314			
2	10	22	-.696			
2	11	16	-3.14			
2	12	16	-6.92			
2	12	17	-11.50			
2	13	16	-14.23			
2	13	17	-7.18			
2	14	18	-1.73			
2	14	19	-1.67			
2	15	16	-6.19			
2	15	17	-0.63			
2	15	18	-.224			
2	15	19	-3.04			
2	12	15	-.309			
2	18	15	-3.931			
2	13	10	-.008			
2	11	23	-.08			
2	12	23	-1.08			
2	11	24	-.376			
2	10	25	-.269			
1	18	15	-1.07			
1	10	26	-2.48			
1	12	27	-.93			
3	13	26	-.65			
3	10	27	-.46			
3	16	28	-.46			

Appendix IV-A.--Continued

1	12	17	-2.38			
1	12	16	-7.72			
1	15	19	-3.06			
1	14	16	-1.57			
1	12	19	-3.88			
1	9	14	-.32			
1	9	22	-.25			
1	9	15	-.34			
3	10	15	-2.52			
3	12	17	-1.41			
3	9	14	-.29			
3	11	18	-.32			
3	12	16	-1.10			
3	14	18	-7.39			
3	15	19	-5.87			
3	16	21	-.89			
3	11	17	-1.07			
3	12	22	-.34			
3	14	21	-2.86			
3	11	22	-.15			
3	13	23	-.07			
3	10	12	-.064			
3	9	13	-.15			
3	10	16	-.01			
25	24	57	365	10	1.5	154.6
2	4	26	-.51			
2	10	26	-2.2			
2	12	27	-2.			
2	16	28	-5.49			
2	13	26	-.30			
2	8	12	-9.554			
2	10	17	-.002			
2	14	21	-1.807			
2	10	22	-.774			
2	11	16	-.784			
2	12	16	-6.14			
2	12	17	-12.95			
2	13	16	-14.206			
2	13	17	-7.238			
2	14	18	-1.527			
2	14	19	-1.556			
2	15	16	-6.054			
2	15	17	-.883			
2	15	18	-.224			
2	15	19	-3.541			
2	12	15	-.309			
2	18	15	-3.272			
2	13	10	-.008			
2	11	23	-.08			
2	12	23	-1.10			
2	11	24	-.395			
2	10	25	-.294			
1	18	15	-1.196			
1	10	26	-2.65			
1	12	27	-1.3			
1	12	16	-6.67			
1	12	17	-2.59			
1	12	19	-4.47			
1	14	16	-1.01			
1	15	19	-2.49			
1	9	14	-.34			
1	9	22	-.16			
1	9	15	-.13			
3	13	26	-.75			
3	10	27	-.6			
3	16	28	-.52			
3	10	15	-3.06			
3	12	17	-1.			
3	9	14	-.3			
3	11	18	-.39			
3	12	16	-.899			
3	14	18	-7.74			
3	15	19	-6.89			
3	16	21	-1.26			
3	11	17	-1.12			
3	12	22	-.13			
3	14	21	-4.09			
3	11	22	-.21			
3	13	23	-.14			
3	10	12	-.064			
3	9	13	-.09			
3	10	16	-.01			
26	25	58	365	10	1.5	51.6
2	4	26	-.55			
2	10	26	-2.4			

Appendix IV-A.--Continued

2	12	27	-2.2			
2	16	28	-6.0			
2	13	26	-.33			
2	8	12	-8.557			
2	10	17	-.002			
2	14	21	-1.634			
2	10	22	-.928			
2	11	16	-.729			
2	12	16	-7.74			
2	12	17	-10.91			
2	13	16	-13.823			
2	13	17	-7.07			
2	14	18	-1.052			
2	14	19	-1.238			
2	15	16	-5.870			
2	15	17	-.823			
2	15	18	-.224			
2	15	19	-3.481			
2	12	15	-.309			
2	18	15	-2.981			
2	13	10	-.008			
2	11	23	-.12			
2	12	23	-1.12			
2	11	24	-.418			
2	10	25	-.309			
1	18	15	-1.126			
1	10	26	-2.8			
1	12	27	-1.55			
1	12	16	-6.05			
1	12	17	-2.46			
1	12	19	-4.2			
1	14	16	-1.56			
1	15	19	-2.79			
1	9	14	-.42			
1	9	22	-.15			
1	9	15	-.13			
3	17	22	-.387			
3	13	26	-.8			
3	10	27	-.7			
3	16	28	-.6			
3	10	15	-3.08			
3	12	17	-.97			
3	9	14	-.28			
3	11	18	-.39			
3	12	16	-1.02			
3	14	18	-7.			
3	15	19	-6.24			
3	16	21	-1.37			
3	11	17	-1.32			
3	12	22	-.18			
3	14	21	-3.74			
3	11	22	-.21			
3	10	12	-.064			
3	9	13	-.11			
3	10	16	-.01			
3	13	23	-.23			
27	26	59	365	10	1.5	51.6
2	4	26	-.6			
2	10	26	-2.60			
2	12	27	-2.4			
2	16	28	-6.5			
2	13	26	-.36			
2	8	12	-10.452			
2	14	21	-1.737			
2	10	17	-.001			
2	10	22	-.764			
2	11	16	-.843			
2	12	16	-7.48			
2	12	17	-10.63			
2	13	16	-13.058			
2	13	17	-6.605			
2	14	18	-1.085			
2	14	19	-1.208			
2	15	16	-6.259			
2	15	17	-1.378			
2	15	18	-.224			
2	15	19	-2.721			
2	12	15	-.309			
2	18	15	-2.952			
2	13	10	-.008			
2	11	23	-.12			
2	12	23	-1.16			
2	11	24	-.441			
2	10	25	-.325			
1	18	15	-1.10			

1	10	26	-3.1			
1	12	27	-1.7			
1	12	16	-7.18			
1	12	17	-2.75			
1	12	19	-4.4			
1	14	16	-1.58			
1	15	19	-2.14			
1	9	14	-.57			
1	9	22	-.18			
1	9	15	-.15			
1	15	22	-1.60			
3	13	26	-1.			
3	10	27	-.77			
3	16	28	-.66			
3	10	15	-2.89			
3	12	17	-.78			
3	9	14	-.43			
3	11	18	-.39			
3	12	16	-.998			
3	14	18	-7.26			
3	15	19	-4.81			
3	16	21	-1.4			
3	11	17	-1.38			
3	12	22	-.17			
3	14	21	-3.09			
3	11	22	-.22			
3	13	23	-.36			
3	10	12	-.064			
3	9	13	-.13			
3	10	16	-.01			
3	17	22	-1.31			
28	27	60	365	10	1.5	51.6
2	4	26	-.6			
2	10	26	-2.60			
2	12	27	-2.4			
2	16	28	-6.5			
2	13	26	-.36			
2	8	12	-13.912			
2	19	14	-.25			
2	17	14	-.3			
2	10	22	-.727			
2	11	16	-.834			
2	12	16	-6.66			
2	12	17	-10.197			
2	13	16	-12.10			
2	13	17	-5.73			
2	14	18	-2.242			
2	14	19	-1.728			
2	15	16	-5.945			
2	15	17	-1.17			
2	15	18	-.229			
2	15	19	-3.666			
2	12	15	-.309			
2	18	15	-3.102			
2	13	10	-.008			
2	11	23	-.14			
2	12	23	-1.16			
2	11	24	-.450			
2	10	25	-.340			
2	14	21	-.905			
1	10	26	-3.1			
1	12	27	-1.7			
1	12	16	-6.888			
1	12	17	-1.923			
1	12	19	-4.258			
1	14	16	-1.496			
1	15	19	-2.522			
1	9	14	-.467			
1	9	22	-.097			
1	9	15	-.171			
1	15	22	-1.796			
1	18	15	-.988			
3	13	26	-1.			
3	10	27	-.77			
3	16	28	-.66			
3	10	15	-3.034			
3	12	17	-1.259			
3	9	14	-.579			
3	11	18	-.39			
3	12	16	-.846			
3	14	18	-7.810			
3	15	19	-4.957			
3	16	21	-1.465			
3	11	17	-1.037			
3	12	22	-.34			
3	14	21	-3.264			
3	11	22	-.031			
3	13	23	-.36			
3	10	12	-.064			
3	9	13	-.147			
3	10	16	-.01			
3	17	22	-1.143			

/*
//

Appendix IV-B.--Instructions for additional data inputs to the three-dimensional model (Trescott, 1975) for the simulation of transient leakage from confining layers resulting from modifications by Tracy (in Posson and others, 1980)

The object deck is stored at the U.S. Geological Survey, Computer Center, Reston, Va., on SYS1.LOADLIB; PROG=K755. Computer storage required for execution of program is 530K.

Page numbers listed below refer to those in documentation of three-dimensional model by Trescott, 1975.

Group I: Title, Simulation Options and Problem Dimensions p. III-1

Card	Columns	Format	Variable	Definition
3	51-60	I10	MODE	Number of transient-leakage modes (exponential terms), less than 10.
4	56-59	A4	ITL	Code ITLR to specify transient-leakage option. Also specify ITKR option.
4	61-64	A4	IPARM	Code PARM for simulations used for parameter estimation.

Group III: Array Data (include parameter card where applicable) p. III-5

Data Set	Columns	Format	Variable	Definitions
5	1-80	20F4.0	TK(I,J,K)	Same as documentation; read in blank card for each TK, KO-1 layer entries.
8A	1-80	20F4.0	RATE(I,J,K)	Vertical hydraulic conductivity for each confining layer. KO-1 layer entries; either use parameter card singularly or with matrix of values.
8B	1-80	20F4.0	ZCB(I,J,K)	Thickness of confining layer.
8C	1-80	8F10.0	SS(K)	Specific storage of confining layer. Code a separate value for each layer (KO-1 layers) with a parameter card, a single value for all layers, or one card with all values of specific storage and a parameter card.
12	1-10	F10.0	WMAX	Maximum iteration parameter; code value of .99863.

Appendix V.--Instructions for data input to parameter-estimation program by Tracy (written commun., April 1980)

Variable	Columns	Format	Description
ID(I,J,K)	1-80	80I1	Identification matrix; enter a nonzero value (i.e. 1), where an observed water level or drawdown exists in the model.
H(I,J,K)	1-80	8F10.4	Observed values of hydraulic head or drawdown; start each row with a new card, include blank cards for inactive rows and rows where no observations exist.
NP, JP(I)	1-80	16I5	(one card) NP is the number of parameters used for parameter estimation of the model. JP(I) is the number corresponding to the perturbation run whose parameter is to be tested by the parameter-estimation program.

Base-parameter heads* are stored on direct-access disk files (UNIT 04) upon execution of base-parameter run. These values are read off the disk and used in the parameter estimation program.

Perturbation-run drawdowns* are stored on direct-access disk files (UNIT 03) upon execution of perturbation runs. These are also read off the disk and used in the parameter-estimation program.

The 'Sensitivity' computed in the parameter-estimation program reflects the percent increase in parameters used in the perturbation runs. In statement 6 of the program, the Sensitivity is multiplied by the reciprocal of the percent increase in parameters (in decimal form). Thus, for a 20-percent increase in parameters the sensitivity is multiplied by 5.00. (See statement 6 of program.)

* The terms 'heads' and 'drawdowns' are used to differentiate between the storage of results from the base run and subsequent perturbation runs. These terms are defined by the three-dimensional program of Trescott (1975). Modifications to the computer code of Trescott (1975) were made to allow storage of heads and drawdowns on different unit numbers (03 and 04) for use in the parameter-estimation program. This program can be modified to allow input of heads and drawdowns by card images instead of input from disks.

```
C***
      REAL*8 H,PM,S,SO,HO,HC,HCC,A,B,C,D1,S1
      DIMENSION ID(26,30,3),H(26,30,3),AM(11),PM(11)
      DIMENSION  S(49,5),HO(49),HC(49),B(5),A(5,5)
      DIMENSION  SO(49,5),JP(5),HCC(49)
      DIMENSION C(5,5)
      NPT=4
      NCC=31
      NOT=49
      NR=26
      NC=30
      NL=3
      VAR = 1.
      DO 1 K=1,NL
      DO 1 I=1,NR
1     READ 2,(ID(I,J,K),J=1,NC)
2     FORMAT (80I1)
C***  READ OBSERVED HEADS ***
      DO 3 K=1,NL
      DO 3 I=1,NR
3     READ 4, (H(I,J,K),J=1,NC)
4     FORMAT (8F10.4)
      WRITE (6,41)
41    FORMAT (1X,4HOBS.10X,1HK,8X,1HI,8X,1HJ,4X,14HOBSERVED HEADS//)
      NO = 0
      DO 5 K=1,NL
      DO 5 I=1,NR
      DO 5 J=1,NC
      IF(ID(I,J,K).EQ.0) GO TO 5
      NO = NO + 1
      HO(NO) = H(I,J,K)
      WRITE (6,42) NO,K,I,J,HO(NO)
42    FORMAT(1X,I3,10X,3(I2,7X),G11.4)
5     CONTINUE
      PRINT 10,NO,NOT
      IF (NO.NE.NOT) STOP
C***  READ HEADS FROM BASE PARAMETER RUN ***
      READ(4) H,AM
      NO = 0
      DO 7 K=1,NL
      DO 7 I=1,NR
      DO 7 J=1,NC
      IF (ID(I,J,K).EQ.0) GO TO 7
      NO = NO + 1
      HC(NO) = H(I,J,K)
```

```
7       CONTINUE
C***    READ PERTURBATION DRAWDOWNS ***
        DO 9 L=1,NPT
        READ(3) H,AM
        NO = 0
        DO 8 K=1,NL
        DO 8 I=1,NR
        DO 8 J=1,NC
        IF (ID(I,J,K).EQ.0) GO TO 8
        NO = NO + 1
C***    COMPUTE SENSITIVITY:  HC'S ARE NEGATIVE BASE-PARAM. HEADS,
C***    H(I,J,K)'S ARE DRAWDOWNS.
        SO(NO,L)=HC(NO)+H(I,J,K)
8       CONTINUE
9       CONTINUE
        DO 500 KT=1,NCC
        READ(5,10,END=999) NP,(JP(I),I=1,NP)
        DO 6 I=1,NOT
        DO 6 J=1,NP
        K=JP(J)
C***    A 20% INCREASE IN BASE PARAMETERS WAS USED IN THESE RUNS
6       S(I,J) = SO(I,K)*5.00
10      FORMAT (16I5)
        PRINT 20,KT,NP,(JP(I),I=1,NP)
20      FORMAT (' COMBO NO.',I3,',',I4,' PARAMETERS, NUMBERS',9I5)
15      FORMAT (8F10.4)
        DO 30 I=1,NOT
        DO 25 J=1,NP
25      S(I,J) = -S(I,J)
30      PRINT 50,HO(I),HC(I),(S(I,J),J=1,NP)
40      FORMAT (8F10.4)
50      FORMAT (8(1X,G11.4))
        SS=0.
        DO 60 I=1,NOT
        D1 = HO(I) - HC(I)
60      SS=SS+D1*D1
        PRINT 70,SS
70      FORMAT (4H SS=,G11.4)
        DO 75 I=1,NP
        B(I)=0.
        DO 75 J=1,NP
75      A(I,J)=0.
        DO 90 I=1,NP
        DO 90 J=1,NP
        IF (J.LT.I) GO TO 90
```

```
      S1=0.
      DO 80 K=1,NOT
80    S1=S1+S(K,I)*S(K,J)
      A(I,J-I+1) = S1
90    CONTINUE
      DO 100 I=1,NP
      DO 100 K=1,NOT
100   B(I)=B(I)+(HO(K)-HC(K))*S(K,I)
      DO 110 I=1,NP
110   PRINT 50,(A(I,J),J=1,NP),B(I)
      DO 111 J=1,NP
      DO 111 I=J,NP
      K=I-J+1
      C(I,J)=A(J,K)
111   C(J,I)=C(I,J)
      CALL BSOLVE (A,B,NP)
      DO 112 J=1,NP
      DO 112 I=J,NP
      K=I-J+1
112   C(I,J)=A(J,K)*A(J,1)
      DO 380 I=1,NP
380   C(I,I)=1./A(I,1)
      NM1=NP-1
      DO 430 K=1,NM1
      K1=K+1
      DO 400 I=K1,NP
      SUM=0.
      I1=I-1
      DO 390 J=K,I1
390   SUM=SUM+C(I,J)*C(J,K)
      C(K,I)=-SUM
400   C(I,K)=-SUM*C(I,I)
      DO 420 J=1,K
      SUM=C(K,J)
      DO 410 I=K1,NP
410   SUM=SUM+C(I,J)*C(K,I)
      C(K,J)=VAR*SUM
420   C(J,K)=C(K,J)
430   CONTINUE
      DO 450 J=1,NP
      C(NP,J)=VAR*C(NP,J)
450   C(J,NP)=C(NP,J)
      PRINT 15
      PRINT 520
      DO 460 I=1,NP
```

```
460    PRINT 15,(C(I,J),J=1,NP)
       DO 510 J=1,NP
       TEMP=C(J,J)**.5
       DO 505 I=J,NP
       C(I,J)=C(I,J)/(C(I,I)**.5*TEMP)
505    C(J,I) = C(I,J)
510    CONTINUE
       PRINT 15
       PRINT 530
       DO 550 I=1,NP
550    PRINT 15, (C(I,J),J=1,NP)
530    FORMAT (1X,'CORRELATION MATRIX')
520    FORMAT (1X,'VARIANCE - COVARIANCE MATRIX')
       DO 120 I=1,NP
120    PRINT 50,(A(I,J),J=1,NP),B(I)
       DO 140 K=1,NOT
       S1=0.
       DO 130 I=1,NP
130    S1=S1+B(I)*S(K,I)
140    HCC(K)=HC(K)+S1
       PRINT 50,HCC
       SS=0.
       DO 150 I=1,NOT
       D1=HO(I)-HCC(I)
       HCC(I)=D1
150    SS=SS+D1*D1
       PRINT 70,SS
       PRINT 50,HCC
500    CONTINUE
999    STOP
       END
C***
C***
       SUBROUTINE BSOLVE (A,B,N)
       REAL*8 A,B,C
       DIMENSION A(5,5),B(5)
       M=N
C**
C**   UPPER TRIANGULARIZATION
C**
       IF (N.EQ.1) GO TO 65
       NM1=N-1
       DO 30 K=1,NM1
       I=K
       DO 20 J=2,M
```

```
      I=I+1
      IF(A(K,J).EQ.0.) GO TO 20
      C=A(K,J)/A(K,1)
      L=0
      DO 10 JJ=J,M
      L=L+1
      IF(A(K,JJ).NE.0.) A(I,L)=A(I,L)-C*A(K,JJ)
10    CONTINUE
      A(K,J)=C
      B(I)=B(I)-C*B(K)
20    CONTINUE
30    B(K)=B(K)/A(K,1)
C**
C** BACK SUBSTITUTION
C**
      B(N)=B(N)/A(N,1)
      I=N
40    I=I-1
      IF(I.LE.0) GO TO 60
      L=I
      DO 50 J=2,M
      L=L+1
      IF(A(I,J).NE.0.) B(I)=B(I)-A(I,J)*B(L)
50    CONTINUE
      GO TO 40
60    RETURN
65    B(1)=B(1)/A(1,1)
      RETURN
      END
/*
```