CONVERSION AND COMPARISON OF THE MATHEMATICAL, THREE-DIMENSIONAL, FINITE-DIFFERENCE, GROUND-WATER FLOW MODEL TO THE MODULAR, THREE-DIMENSIONAL, FINITE-DIFFERENCE, GROUND-WATER FLOW MODEL FOR THE TESUQUE AQUIFER SYSTEM IN NORTHERN NEW MEXICO

By Amjad M.J. Umari and Timothy L. Szeliga

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CONVERSION FACTORS

For the use of readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply inch-pound unit	By	To obtain metric units
foot	0.3048	meter
mile	1.609	kilometer
cubic foot per second	0.02832	cubic meter per second

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929."

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ABSTRACT

The mathematical, three-dimensional, finite-difference, ground-water flow model of the Tesuque aquifer system in northern New Mexico was converted to run using the U.S. Geological Survey's modular ground-water-flow code. Results from the final versions of the predevelopment and 1947 to 2080 transient simulations of the two models are compared. A correlation coefficient of 0.9905 was obtained for the match in block-by-block constant-head fluxes and 0.9845 was obtained for the match in block-by-block head-dependent fluxes for predevelopment conditions. There are, however, significant differences in at least two specific cases. In the first case, a difference is associated with the net loss from the Pojoaque River and its tributaries to the aquifer. The net loss by the river is given as 1.134 cubic feet per second using the original ground-water model, which is 38.1 percent less than the net loss by the river of 1.8319 cubic feet per second computed by the new model in this study. In the second case, the large difference is computed for the transient decline in the hydraulic head of a model block near Tesuque Pueblo. The hydraulic-head decline by 2080 is, using the original model, 249 feet, which is 14.7 percent less than the hydraulic head of 292 feet computed by this study. In general, the differences between the two sets of results are not large enough to lead to different conclusions regarding the behavior of the system at steady state or when pumped.

INTRODUCTION

The U.S. Geological Survey was requested by the U.S. Bureau of Indian Affairs to evaluate the effects of that agency's plan for irrigation development within the Pojoaque basin on ground-water levels and streamflow. The results of that evaluation were presented by Hearne (1985). Hearne's (1985) three-dimensional model simulation of the Tesuque aquifer system used the model code developed by Posson and others (1980). The model code of Posson and others (1980) can no longer be easily used because the code is machine-dependent.

Purpose and Scope

In 1987, the U.S. Geological Survey, in cooperation with the U.S. Bureau of Indian Affairs, began the present investigation to determine if the Hearne (1985) model could be converted to use the model code developed by McDonald and Harbaugh (1984). The purpose of this report is to show the results of simulations of the original Hearne (1985) model and those of the same model converted to the McDonald and Harbaugh (1984) code. The scope of this report is limited to presenting these results and brief explanations of possible differences in results, if any. The data arrays needed to run the Hearne (1985) model using the McDonald and Harbaugh (1984) code are presented as a supplement to this report (Umari, 1989).

Geohydrologic Setting

The following brief summary of the geohydrology of the modeled area is taken from Hearne (1985, p. 3-4). A more complete description is available in Hearne (1985).

> The Tesuque Formation (Santa Fe Group), of Miocene age, underlies the central part of Española Basin (Kelley, 1978), including most of the Pojoaque River basin [fig. 1]. The Española Basin is one of several interconnected basins that form the Rio Grande depression. The eastern boundary of the basin is the Sangre de Cristo uplift. The western boundary is a complicated fault system, much of which has been covered by volcanic rocks of the Jemez Mountains. The basin is separated from the San Luis Basin to the north and from the Albuquerque Basin to the south by constrictions in the bedrock. * * * The principal aquifer underlying the Pojoaque River basin and vicinity is the Tesuque Formation, which is composed of interbedded layers of gravel, sand, silt, and clay with some intercalated volcanic ash beds. The degree of both sorting and cementation is variable, but the beds are typically poorly sorted and poorly cemented. Two important features of the Tesuque Formation are the dip of the beds and the lack of continuity of the individual beds. * * * Average dip of the beds is estimated to be between 5 and 10 degrees (Kelley, 1952, p. 111), and toward the west or northwest. * * * Except for the ash beds, the Tesuque Formation was deposited as coalescing alluvial fans [fig. 2]. * * * Miller and others (1963, p. 50) report that '* * * few beds can be traced more than a mile or two.' The predominantly north-trending faults further disrupt the continuity of individual beds of the Tesuque Formation [fig. 2]. * * * The thickness of the Tesuque Formation is unknown but has been estimated to exceed 3,700 feet in some places (Galusha and Blick, 1971, p. 44). Kelley (1978) estimated that the thickness of the Tesuque Formation may exceed 9,000 feet near the Rio Grande.

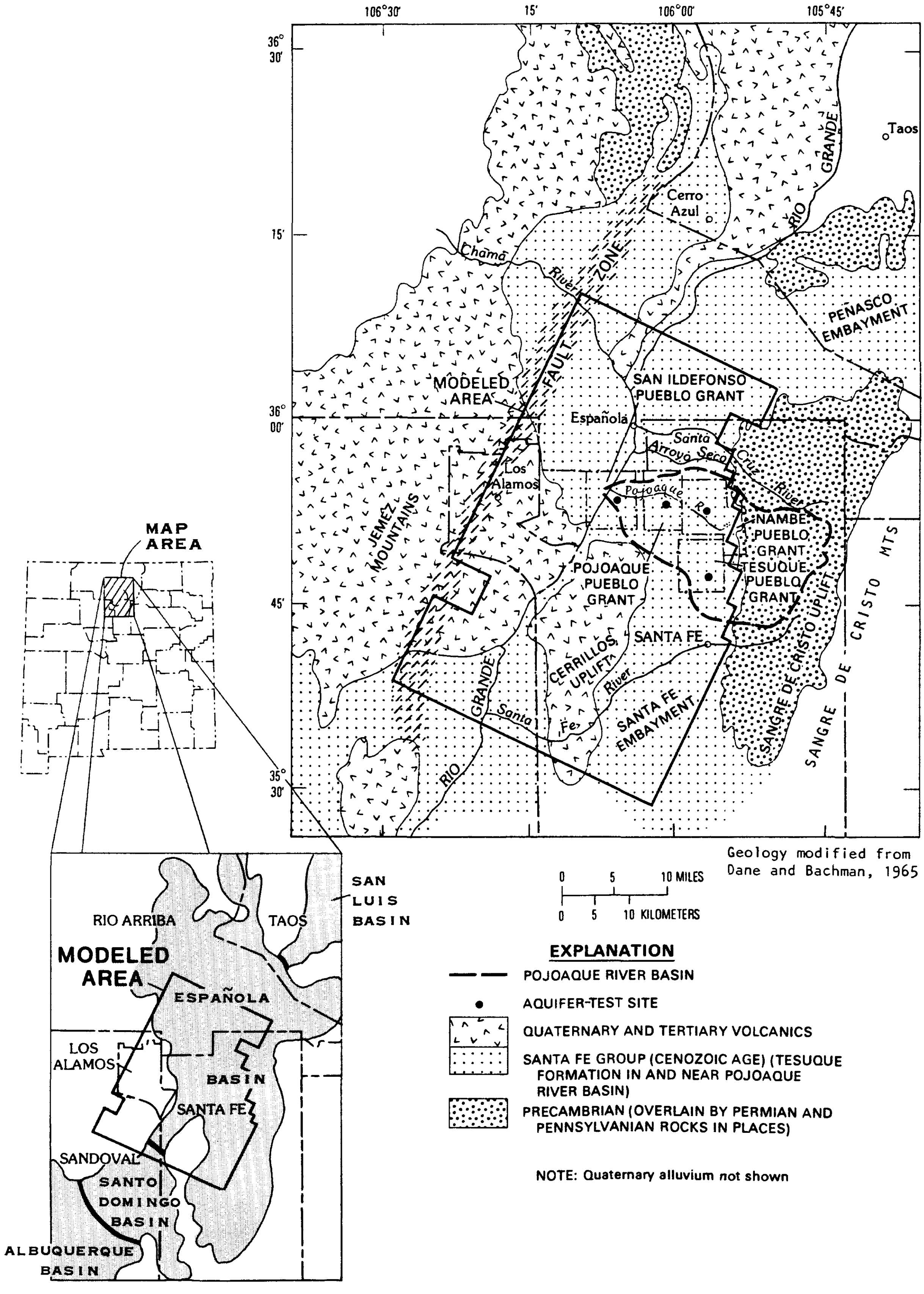


Figure 1.--Location of the modeled area (modified from Hearne, 1985).

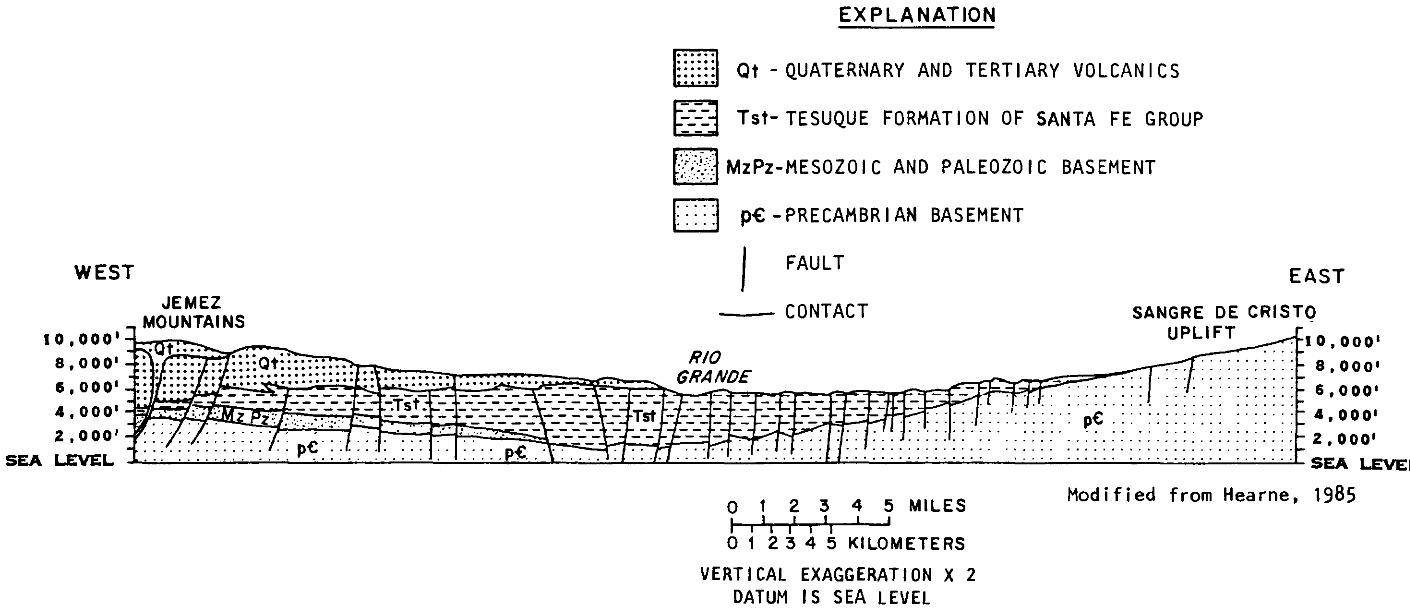


Figure 2.--Generalized east-west geologic section near Pojoaque River basin.

Structure Represented in the Model

The brief summary of the structure represented in the model is taken from Hearne (1985, p. 4-6).

> It is impractical to model each bed of the Tesuque aquifer system as a separate unit. This would require data on the hydrologic characteristics, the areal extent, and hydraulic connection through semiconfining beds to beds both above and below as well as connection along any fault to other permeable beds. The model presented in this report relies on the consistent heterogeneity of the Tesuque aquifer system. As a unit, the salient structural features are the areal boundaries, the thickness, and the strike and dip of the beds. * * * The model describes the Tesuque aquifer system as a network of contiguous but discrete cells aligned with the bedding planes in the Tesuque Formation. The bedding planes were assumed to strike N. 25 E. and dip to the northwest at about 8 degrees on the east side of the Rio Grande and about 4 degrees on the west side. The model grid was oriented with principal axes dipping to the northwest at 8 degrees east of the Rio Grande and at 4 degrees west of the Rio Grande with a strike of N. 25 E. [fig. 3]. * * * The irregular boundary to the east of the modeled area approximates the contact between the Tesuque Formation and the crystalline rocks of the Sangre de Cristo Mountains. The boundary to the west of the modeled area approximates a fault zone beneath the Jemez Mountains [fig. 1]. * * * The north and south boundaries do not approximate geologic boundaries but are sufficiently distant from the Pojoaque River basin that the boundary effects are negligible. * * * The assumed thickness of the Tesuque Formation in the Pojoaque River basin used in the model ranges from a few hundred feet along the mountain front to about 4,000 feet along the Rio Grande [fig. 4].

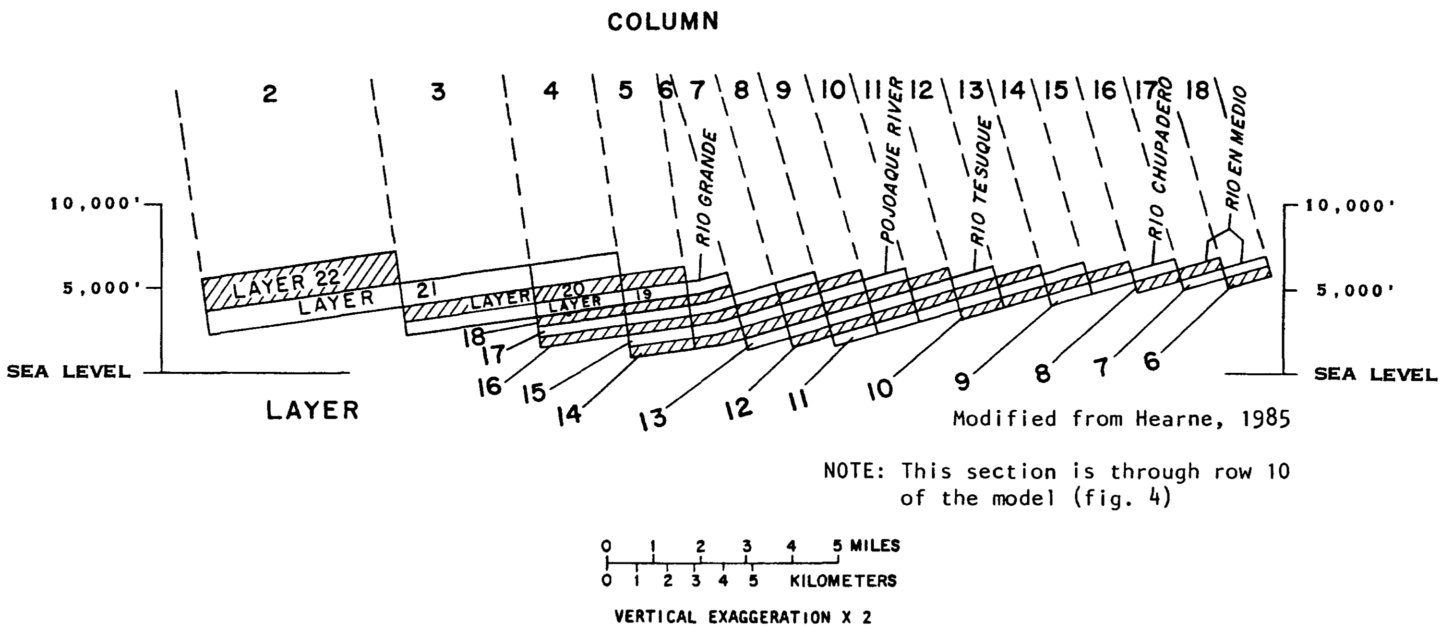


Figure 3.--Dip represented along row 10 of the model.

STEADY-STATE SIMULATION USING THE MODULAR MODEL CODE

The computer data arrays necessary to run the modular code for the steady-state simulation are presented in Umari (1989). Arrays used for the Posson code were converted to the format required by the modular code, preserving the elements of the mathematical model as described in Hearne (1985).

Simulated Steady-State Condition Water Surface

Contours for the steady-state hydraulic heads of the topmost active surface of the model, which represents the water table, are presented in figure 5. The contours in figure 5A were constructed using results from the modular version of the model. The contours in figure 5B were constructed from the original simulations using the Posson code (Hearne, 1985).

The steady-state water surfaces simulated using the two codes differ as much as 50 feet west of the Rio Grande. The water surface computed using the modular code is lower than the one presented in Hearne (1985).

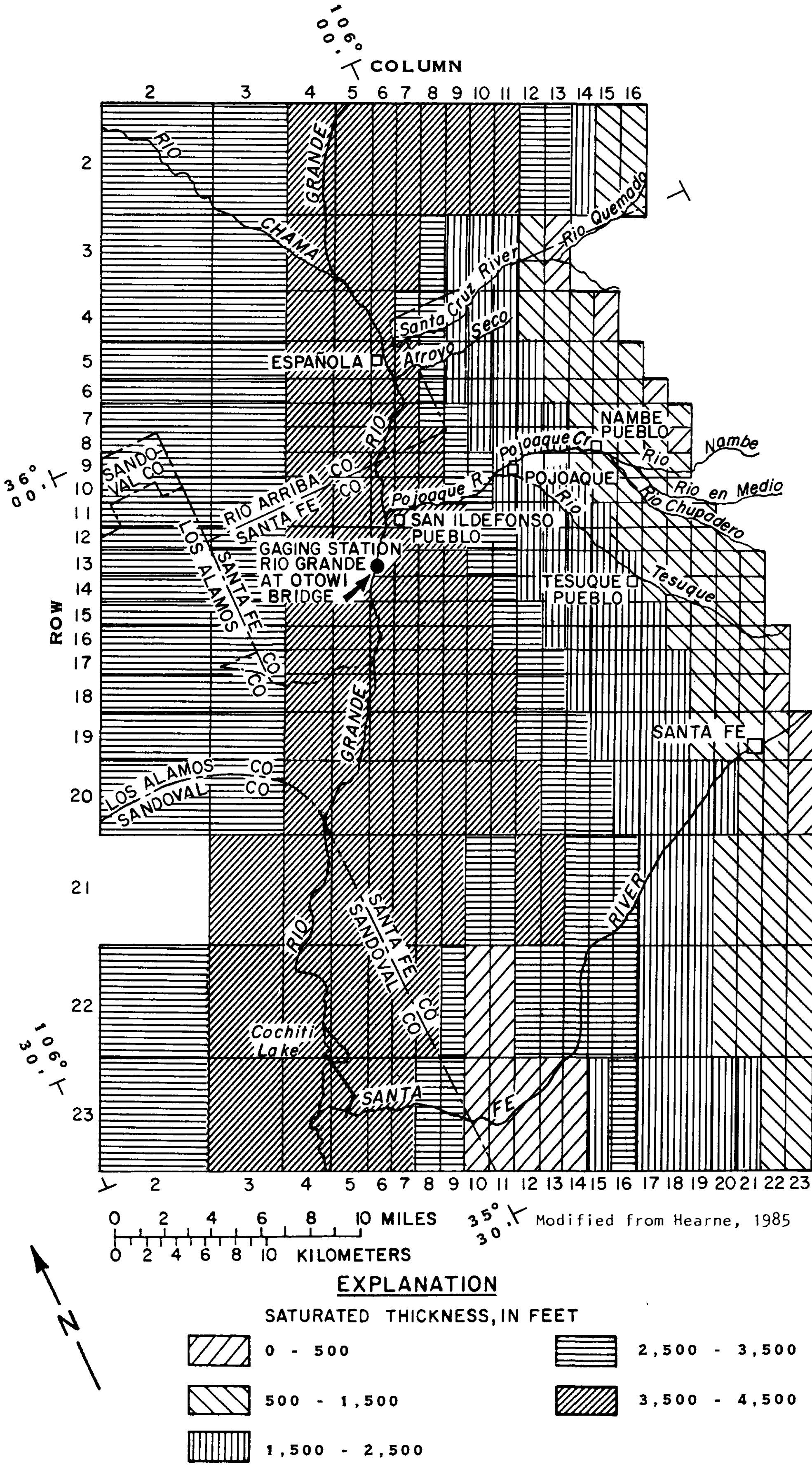
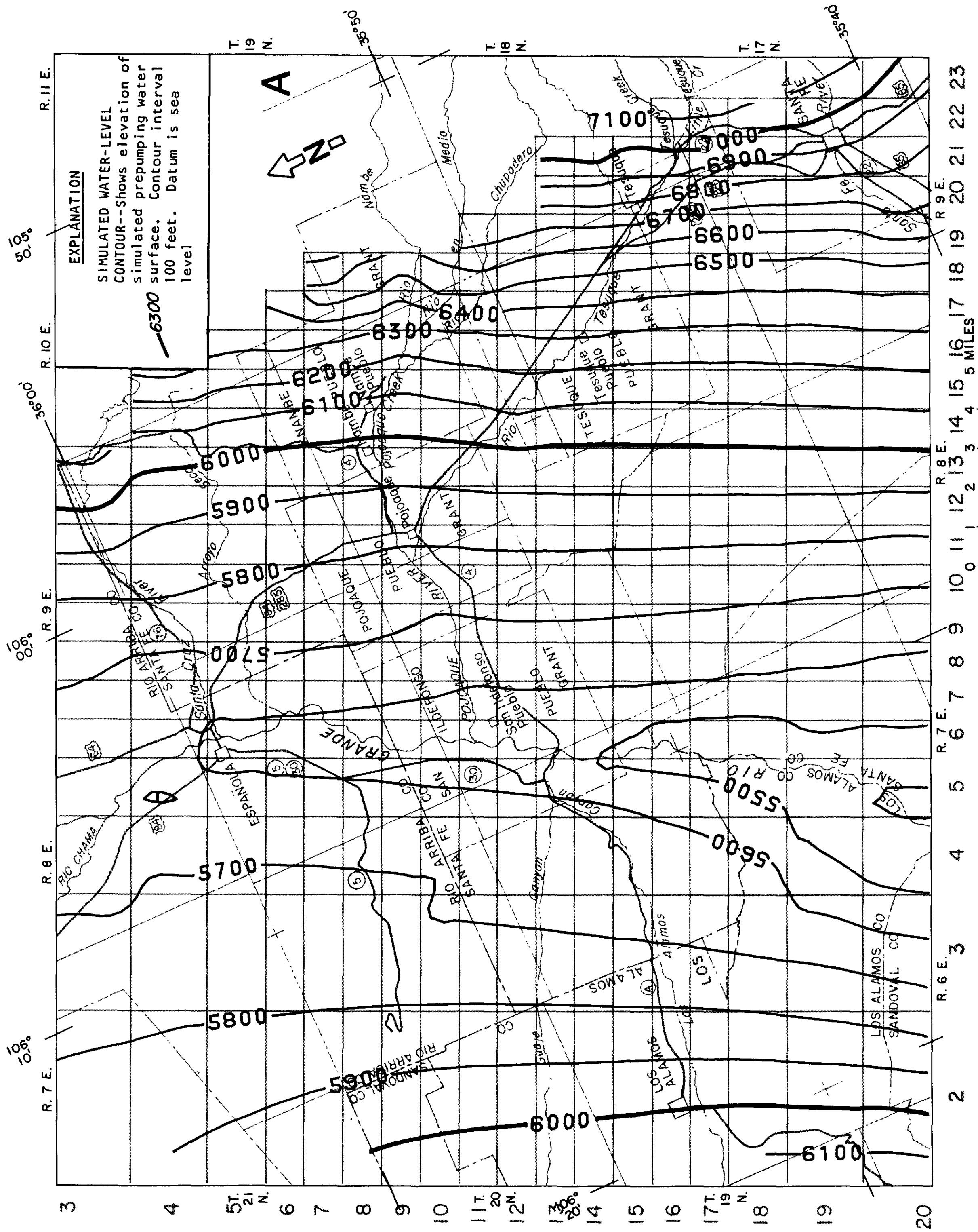


Figure 4.--Saturated thickness of the Tesuque Formation represented in the model and model grid.


EXPLANATION
6300 SIMULATED WATER-LEVEL CONTOUR--Shows elevation of simulated prepumping water surface. Contour interval 100 feet. Datum is sea level
A
N
5700
5800
5900
6000
6100
6200
6300
6400
6500
6600
6700
6800
6900
7000
7100
5500
5600
ESPAÑOLA
RIO CHAMA
Santa Cruz
RIO ARRIBA CO
SANTA FE CO
RIO GRANDE
POJOAQUE PUEBLO
SAN ILDEFONSO
San Ildefonso Pueblo
NAMBE PUEBLO
Nambe Pueblo
Pojoaque Creek
Tesuque Pueblo
TESUQUE PUEBLO GRANT
Chupadero
Tesuque Creek
Santa Fe River
LOS ALAMOS
LOS ALAMOS CO
SANDOVAL CO
R. 6 E.
R. 7 E.
R. 8 E.
R. 9 E.
R. 10 E.
R. 11 E.
T. 17 N.
T. 18 N.
T. 19 N.
T. 20 N.
T. 21 N.
ROW
COLUMN
5 MILES
KILOMETERS

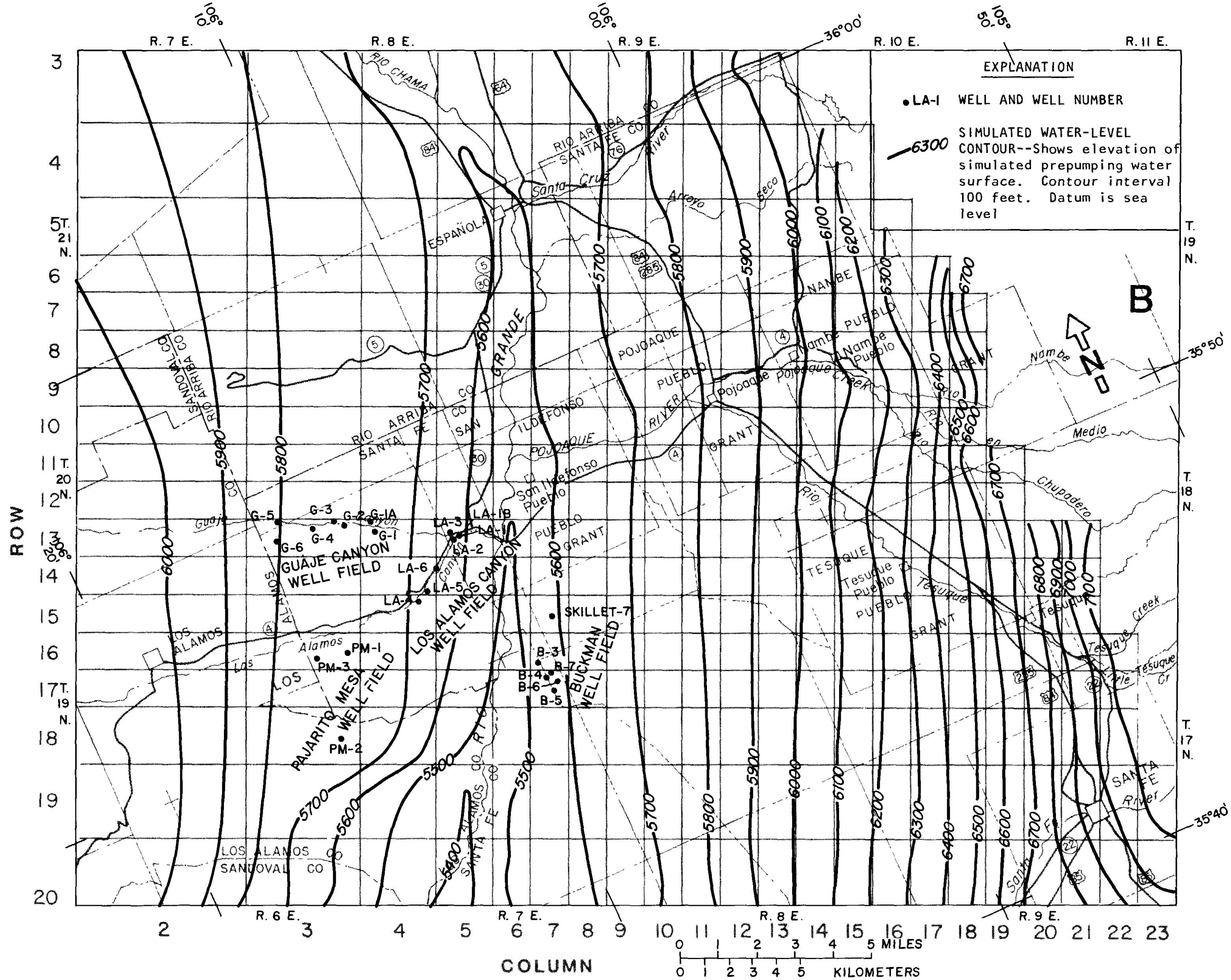


Figure 5.--Contours of steady-state water surface simulated by using:
A--this report; B--Hearne (1985, fig. 11).

Simulated Flows at Constant-Head Blocks

The flows at constant-head blocks simulated using the modular program are compared with those of Hearne (1985) in table 1. Positive numbers indicate flow into the aquifer (away from the rivers), whereas negative numbers indicate flow out of the aquifer (into the rivers). At the bottom of the table, net flow for the Santa Cruz and lower Santa Fe Rivers and the Rio Grande is given.

The Santa Cruz River and the Rio Grande are represented by constant-head blocks. Only the lower part of the Santa Fe River, referred to in table 1 as "Lower Santa Fe," is represented by constant-head blocks. The rest of the Santa Fe River is represented by constant-flux blocks.

A statistical computer package (P-STAT, Inc., 1986) was used to perform linear regression on the flows for the blocks in table 1. The modular-computed flows computed in this study are the dependent variable, and the flows computed by Hearne (1985) are the independent variable. The "Pearson correlation coefficient" is 0.9905, indicating a close correspondence between constant-head flows computed in this study and those presented in Hearne (1985).

Table 1.—Comparison of simulated steady-state flow rates, in cubic feet per second, at specified hydraulic-head boundaries computed by this study and Hearne (1985)

Layer	Row	Column	This study	Hearne (1985)	Difference, as percentage of this study
2	2	4	-0.8700	-0.8170	6.1
2	3	4	-0.7298	-0.6055	17.0
3	4	5	-1.1131	-1.1390	-2.3
3	19	5	-1.1828	-1.0344	12.6
3	20	5	-1.1476	-0.8202	28.5
3	21	4	-4.0719	-4.0078	1.6
3	22	4	-3.2591	-3.0804	5.5
3	23	4	-3.1799	-3.1699	0.3
3	23	5	-0.4635	-0.0793	82.9
4	5	6	-0.8006	-0.8328	-4.0
4	6	6	-0.3976	-0.3961	0.4
4	7	6	-0.4096	-0.4041	1.3
4	8	6	-0.4194	-0.4114	1.9
4	9	6	-0.4381	-0.4280	2.3
4	10	6	-0.4475	-0.4364	2.5

Table 1.—Comparison of simulated steady-state flow rates, in cubic feet per second, at specified hydraulic-head boundaries computed by this study and Hearne (1985)—Concluded

Layer	Row	Column	This study	Hearne (1985)	Difference, as percentage of this study
4	11	6	-0.4376	-0.4268	2.5
4	12	6	-0.4357	-0.4250	2.5
4	13	6	-0.4391	-0.4286	2.4
4	14	6	-0.5054	-0.4914	2.8
4	15	6	-0.5191	-0.5052	2.7
4	16	6	-0.5367	-0.5241	2.3
4	17	6	-0.5537	-0.5456	1.5
4	18	6	-1.0749	-1.1329	-5.4
4	23	6	-0.7391	-0.9872	-33.6
5	4	7	-0.9045	-0.8998	0.5
5	23	7	-0.5467	-0.6475	-18.4
6	4	8	-0.2016	-0.4804	-138.3
6	23	8	-0.6282	-0.6400	-1.9
7	4	9	-0.1795	-0.1299	27.6
7	23	9	-0.5634	-0.5167	8.3
8	4	10	0.5440	0.5394	0.8
8	23	10	-0.0857	-0.2130	-148.5
9	3	11	0.9671	0.9599	0.7
9	23	11	-0.0149	-0.0149	0.0
10	3	12	1.2692	1.2669	0.2
10	23	12	-0.0203	-0.0203	0.0
11	3	13	1.3591	1.3444	1.1
11	23	13	-0.0165	-0.0168	-1.8
12	22	14	-1.2901	-1.2114	6.1
		Net	-24.4838	-23.8092	2.8
		Santa Cruz	2.8538	2.6005	8.9
		Rio Grande	-22.9692	-22.0626	3.9
		Lower Santa Fe	-4.3684	-4.3471	0.5
		Total Santa Fe	2.8411	2.8624	0.7

Simulated Flows at Head-Dependent Flow Blocks

Flows at the head-dependent blocks (which represent the Pojoaque River and its tributaries) computed using the modular program are compared to those presented in Hearne (1985, table 8, p. 25) in table 2 using the same technique as described for table 1. The correlation coefficient is 0.9845, indicating close correspondence between the head-dependent flow values computed by this study and those presented in Hearne (1985). Even though the overall correspondence in block-by-block values is good, net flow into the aquifer (recharge) is 1.8319 cubic feet per second according to the modular simulation and 1.1340 cubic feet per second according to Hearne (1985).

COMBINED HISTORICAL AND FUTURE SIMULATIONS USING THE MODULAR MODEL CODE

In this report, "historical period" means 1947 to 1980. "Future period" means 1981 to 2080. The data arrays required to run the modular program for the combined historical-future run are presented in listings 7 through 14 of the report on model input values by Umari (1989).

Simulated Hydraulic Heads for 1947 to 1980

Figures 6 through 14 present drawdown (with respect to steady-state conditions) versus time for the historical period for simulations comparing the modular and Posson codes. Each figure is for a specific model block, which is indicated by a row, column, and layer number in the figure caption.

Layer numbers for the modular code start with 1 for the top layer and increase downward. In the Posson code, however, layer numbers start with 1 for the bottom layer and increase upward. Drawdown from every stress period, which range in duration from 1/25 of a year to 1 year, was used in the plotting of figures 6A through 14A. However, in figures 6B through 14B, reproduced from Hearne (1985), only one drawdown from each year was used in plotting.

Simulated Water Surface for 2030

Figure 15 presents contours of the hydraulic head in the topmost active surface of the model, which represents the water table for 2030, constructed using the modular model code of McDonald and Harbaugh (1984) and from figure 23 of Hearne (1985) using the model code of Posson and others (1980). The results presented in the figure are based on pumping according to the irrigation plan described in Hearne (1985). There is approximately 50 feet of difference in the predicted water-table elevations between the two simulations west of the Rio Grande.

Table 2.--Comparison of simulated steady-state flow rates, in cubic feet per second, at hydraulic-head-dependent boundaries computed by this study and Hearne (1985)

Row	Column	Layer	This study	Hearne (1985)	Difference, as percentage of this study
11	7	5	-0.2794	-0.2940	-5.2
11	8	6	-0.2315	-0.2370	-2.4
10	9	7	-0.2020	-0.1980	2.0
10	10	8	-0.1936	-0.1810	6.5
9	11	9	-0.1062	-0.0900	15.3
9	12	10	-0.0432	-0.0270	37.5
10	12	10	0.0319	0.0440	-37.9
9	13	11	-0.0408	-0.0160	60.8
11	13	11	0.0668	0.0830	-24.3
8	14	12	-0.0584	-0.0310	46.9
12	14	12	0.3640	0.3630	0.3
9	15	13	-0.1186	-0.1010	14.8
12	15	13	0.3417	0.3410	0.2
9	16	14	-0.2930	-0.2870	2.0
10	16	14	-0.0032	0.0000	100.0
13	16	14	0.2797	0.2720	2.8
9	17	15	-0.3295	-0.3010	8.6
10	17	15	0.0124	0.0390	-214.5
11	17	15	0.0000	0.0000	0.0
14	17	15	0.2930	0.2720	7.2
9	18	16	-0.8163	-1.0050	-23.1
10	18	16	0.6714	0.5510	17.9
11	18	16	0.5360	0.5360	0.0
14	18	16	-0.0464	-0.0780	-68.1
11	19	17	0.7244	0.6390	11.8
15	19	17	0.1190	0.0640	46.2

Table 2.—Comparison of simulated steady-state flow rates, in cubic feet per second, at hydraulic-head-dependent boundaries computed by this study and Hearne (1985)—Concluded

Row	Column	Layer	This study	Hearne (1985)	Difference, as percentage of this study
15	20	18	0.1371	0.0660	51.9
16	21	19	-0.0850	-0.2620	-208.2
16	22	20	0.5486	0.4190	23.4
17	22	20	0.5530	0.5530	0.0
		Net	1.8319	1.1340	38.1
		Recharge	4.6790	4.2420	9.3
		Discharge	-2.8471	-3.1080	9.2

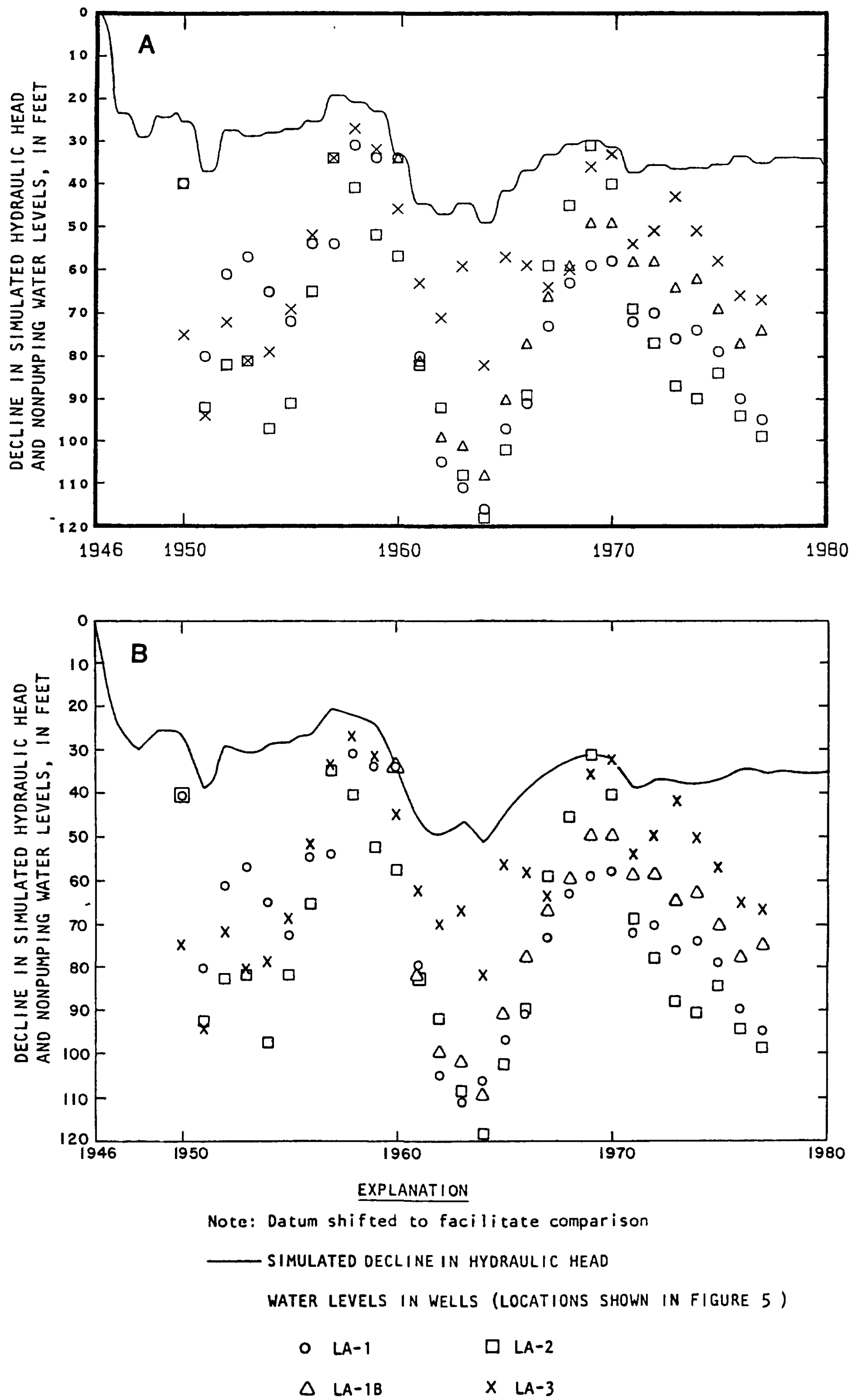


Figure 6.--Comparison between decline in hydraulic head and declines in nonpumping water levels measured in wells LA-1, LA-1B, LA-2, and LA-3 simulated at: A--row 13, column 5, layer 4; B--row 13, column 5, layer 19 (Hearne, 1985, fig. 12).

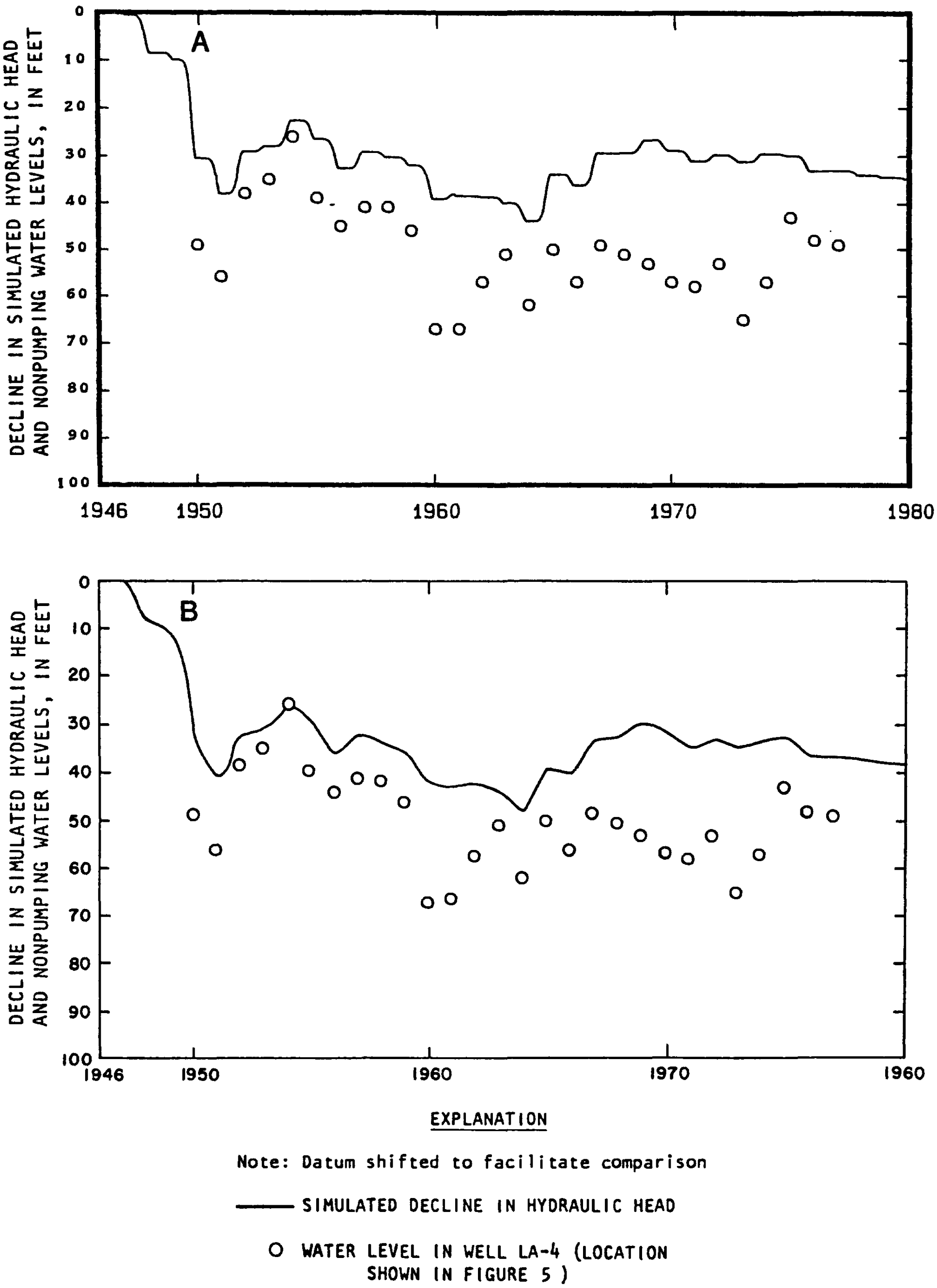


Figure 7.--Comparison between decline in hydraulic head and declines in nonpumping water levels measured in well LA-4 simulated at: A--row 15, column 4, layer 3; B--row 15, column 4, layer 20 (Hearne, 1985, fig. 13).

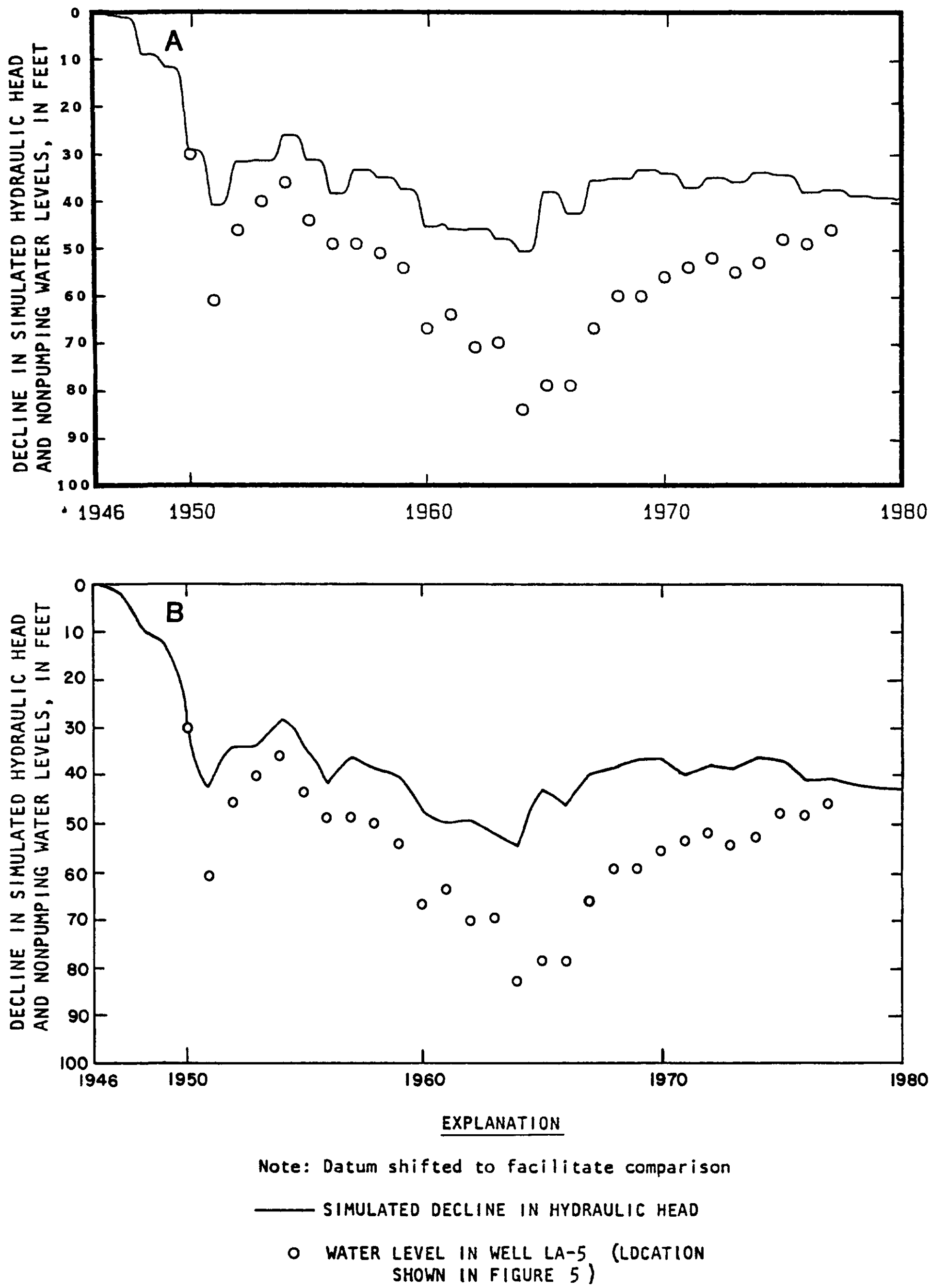


Figure 8.--Comparison between decline in hydraulic head and declines in nonpumping water levels measured in well LA-5 simulated at: A--row 14, column 4, layer 3; B--row 14, column 4, layer 20 (Hearne, 1985, fig. 14).

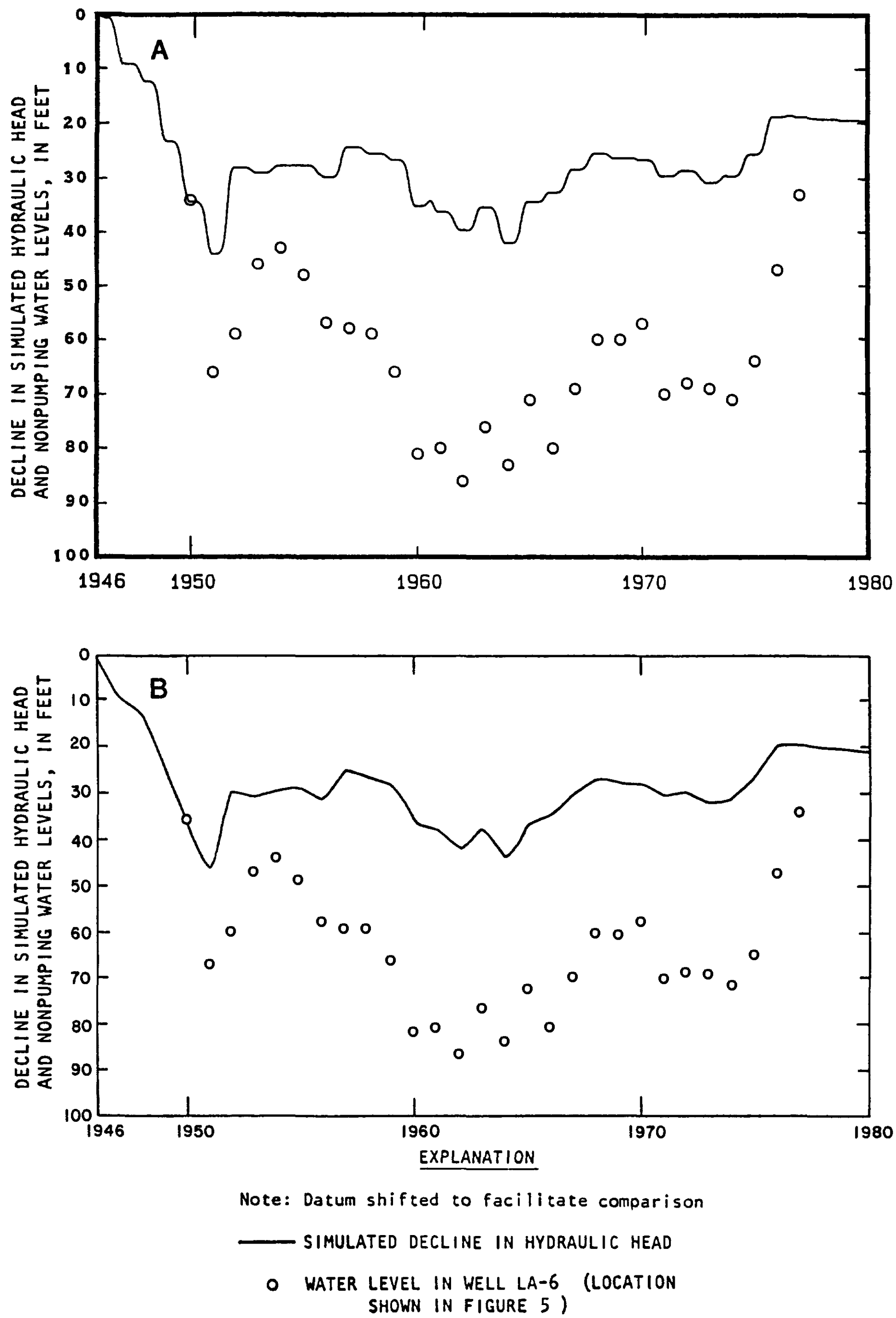


Figure 9.--Comparison between decline in hydraulic head and declines in nonpumping water levels measured in well LA-6 simulated at: A--row 14, column 5, layer 4; B--row 14, column 5, layer 19 (Hearne, 1985, fig. 15).

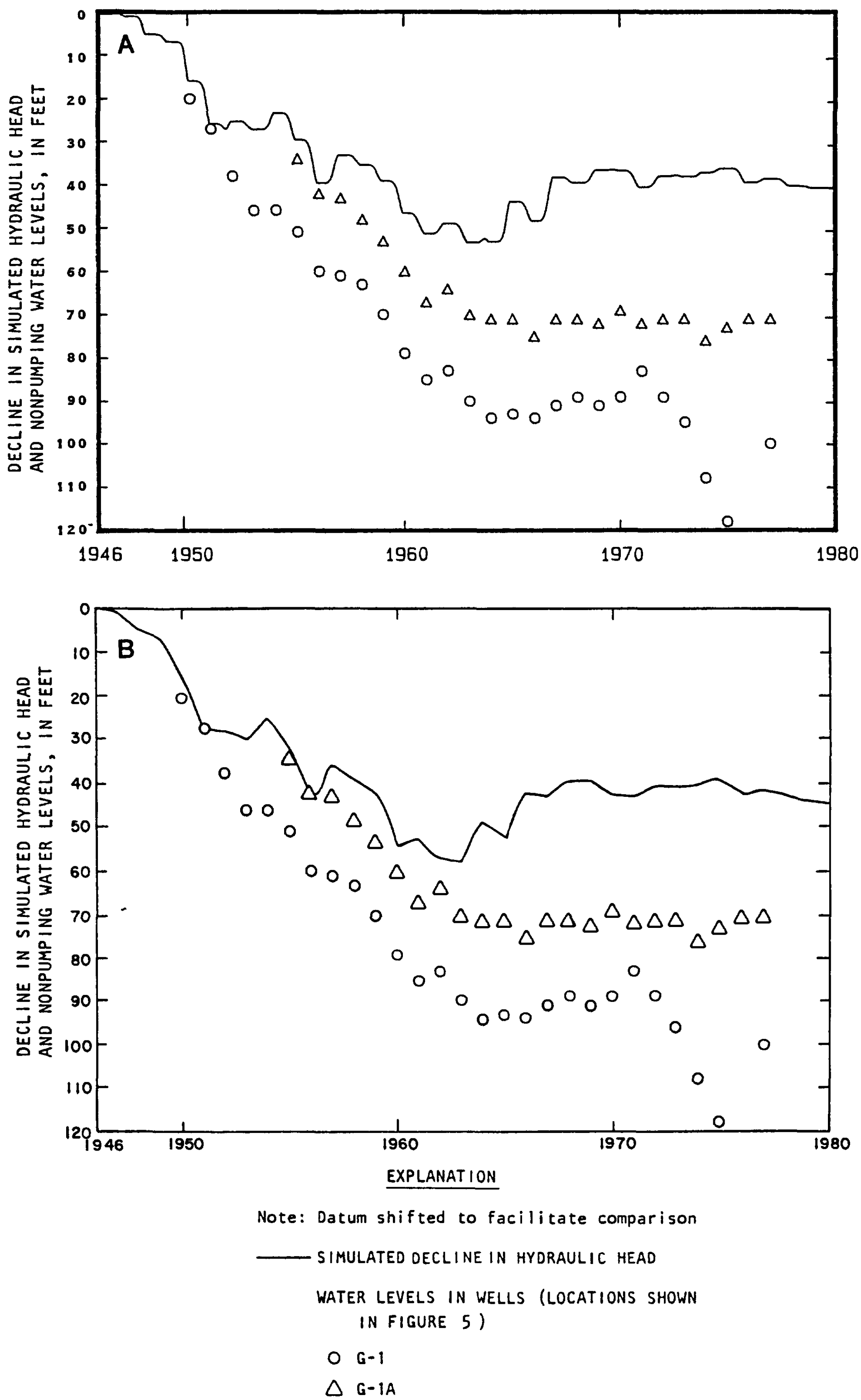


Figure 10.--Comparison between decline in hydraulic head and declines in nonpumping water levels measured in wells G-1 and G-1A simulated at: A--row 13, column 4, layer 3; B--row 13, column 4, layer 20 (Hearne, 1985, fig. 16).

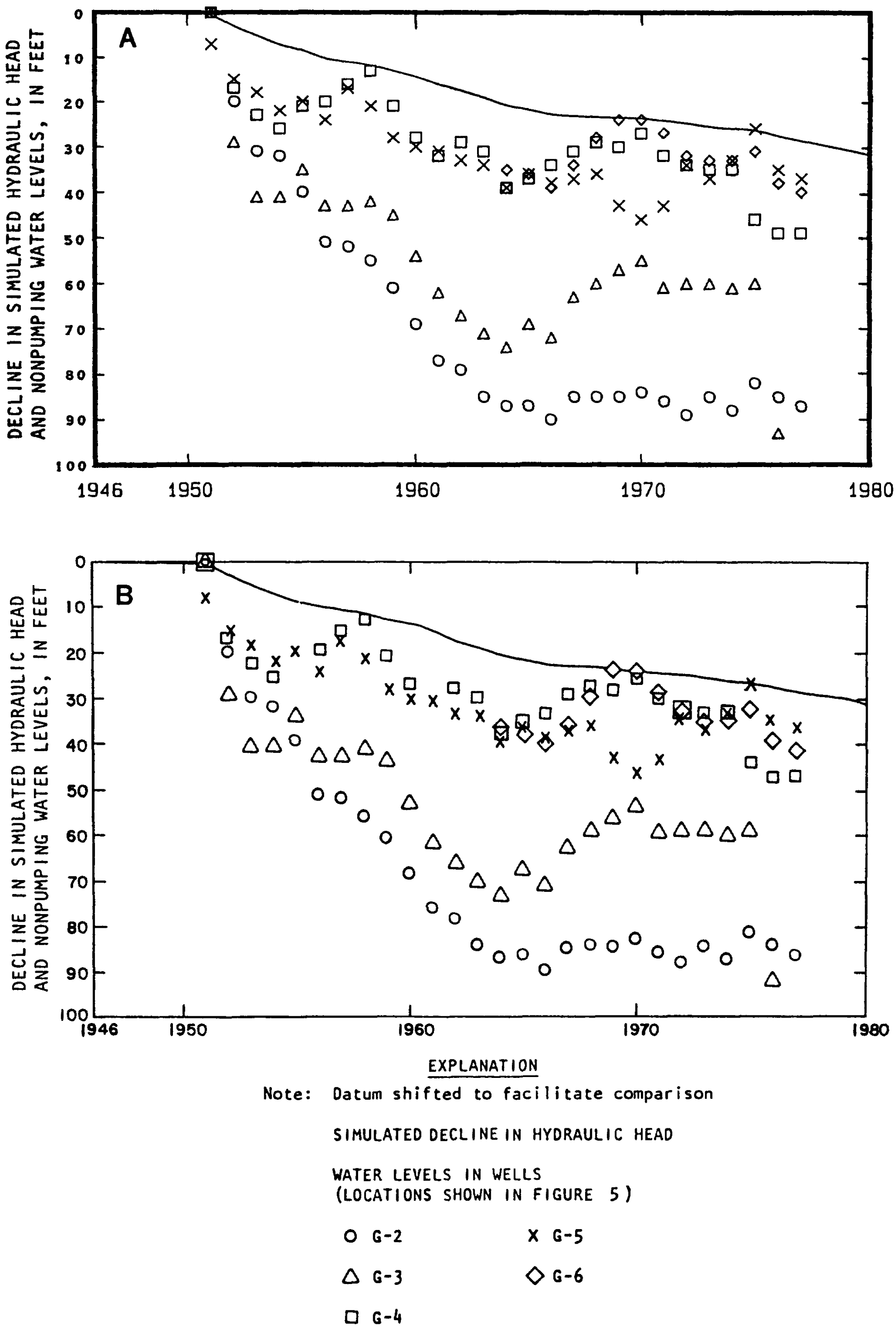


Figure 11.--Comparison between decline in hydraulic head and declines in nonpumping water levels measured in wells G-2, G-3, G-4, G-5, and G-6 simulated at: A--row 13, column 3, layer 2; B--row 13, column 3, layer 21 (Hearne, 1985, fig. 17).

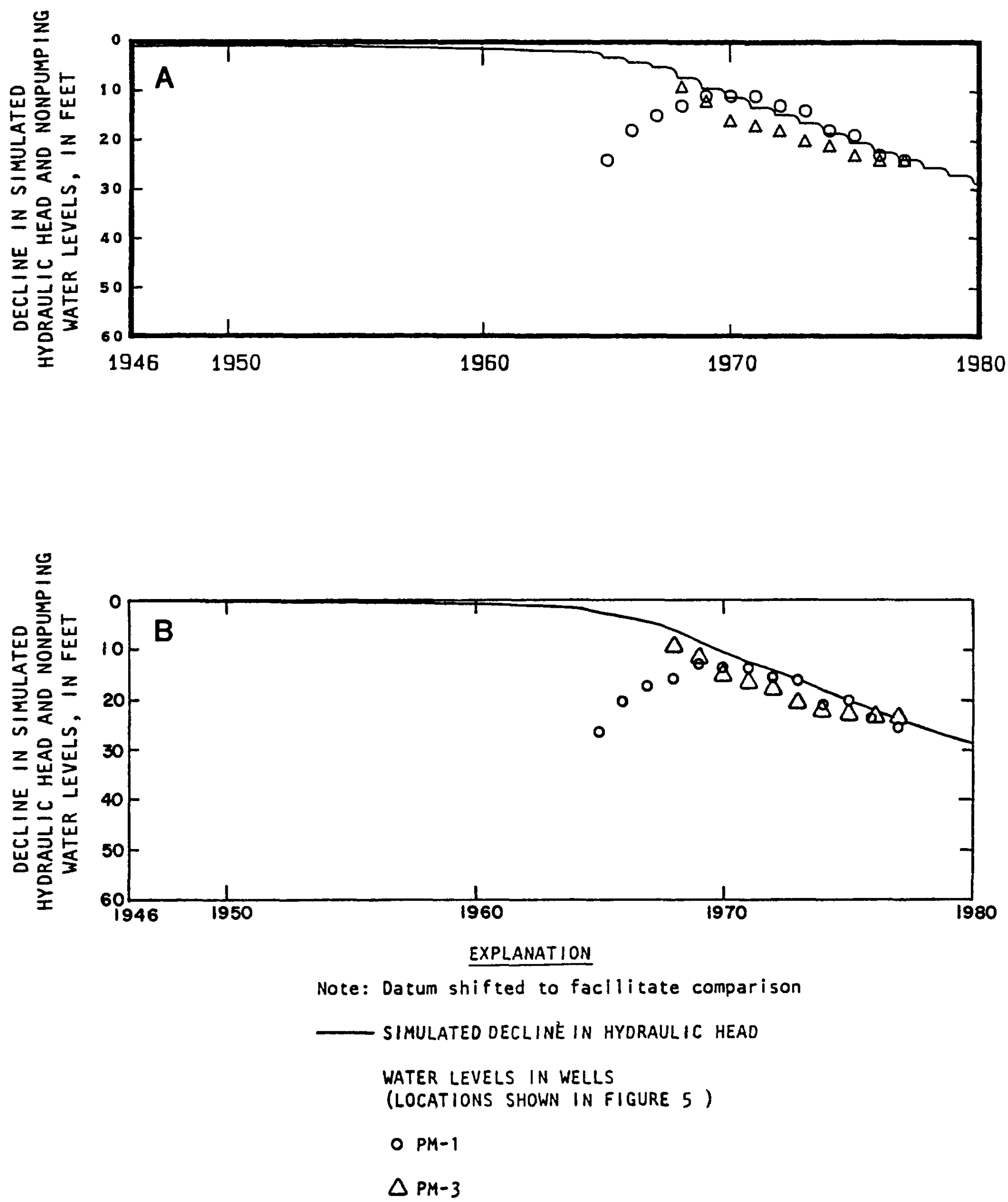


Figure 12.--Comparison between decline in hydraulic head and declines in nonpumping water levels measured in wells PM-1 and PM-3 simulated at: A--row 16, column 3, layer 2; B--row 16, column 3, layer 21 (Hearne, 1985, fig. 18).

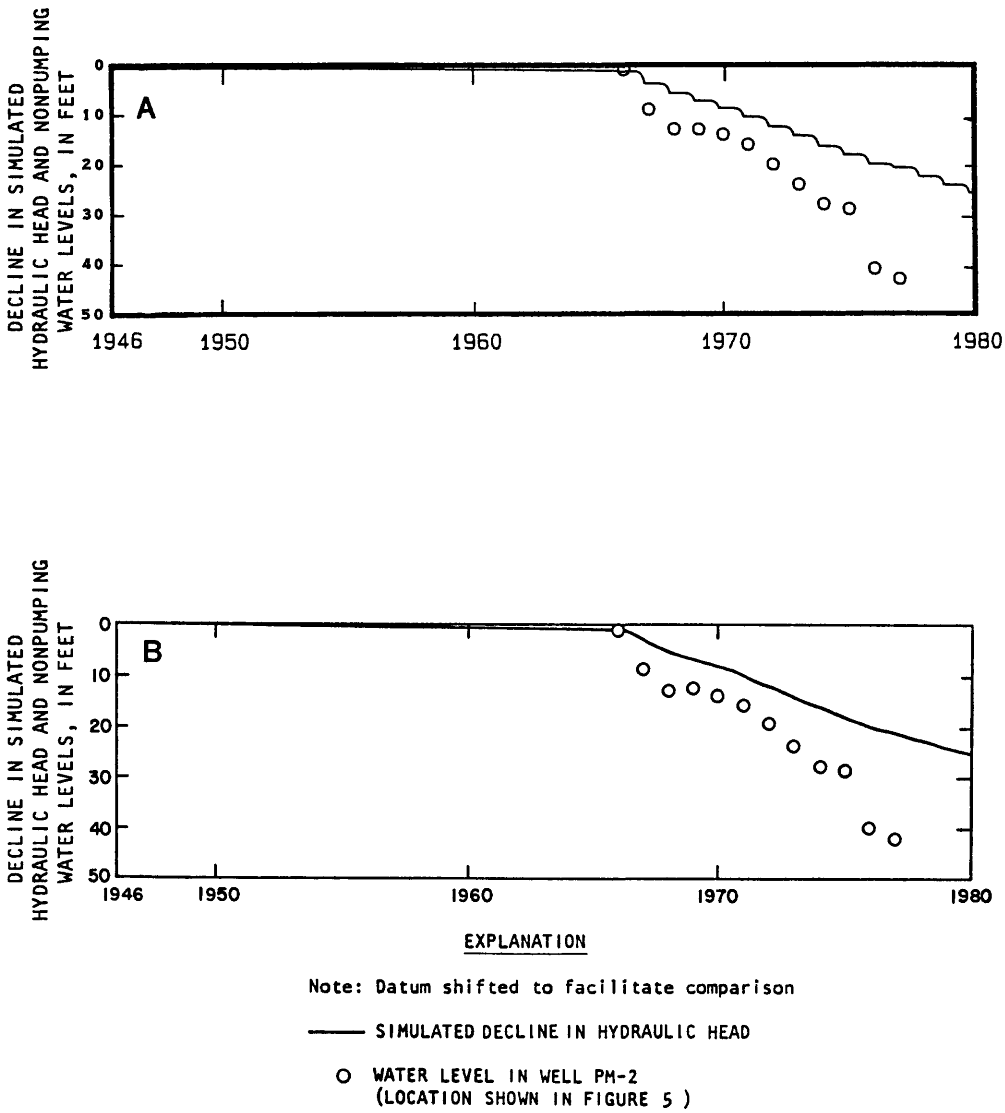


Figure 13.--Comparison between decline in hydraulic head and declines in nonpumping water levels measured in well PM-2 simulated at: A--row 13, column 5, layer 4; B--row 18, column 3, layer 21 (Hearne, 1985, fig. 19).

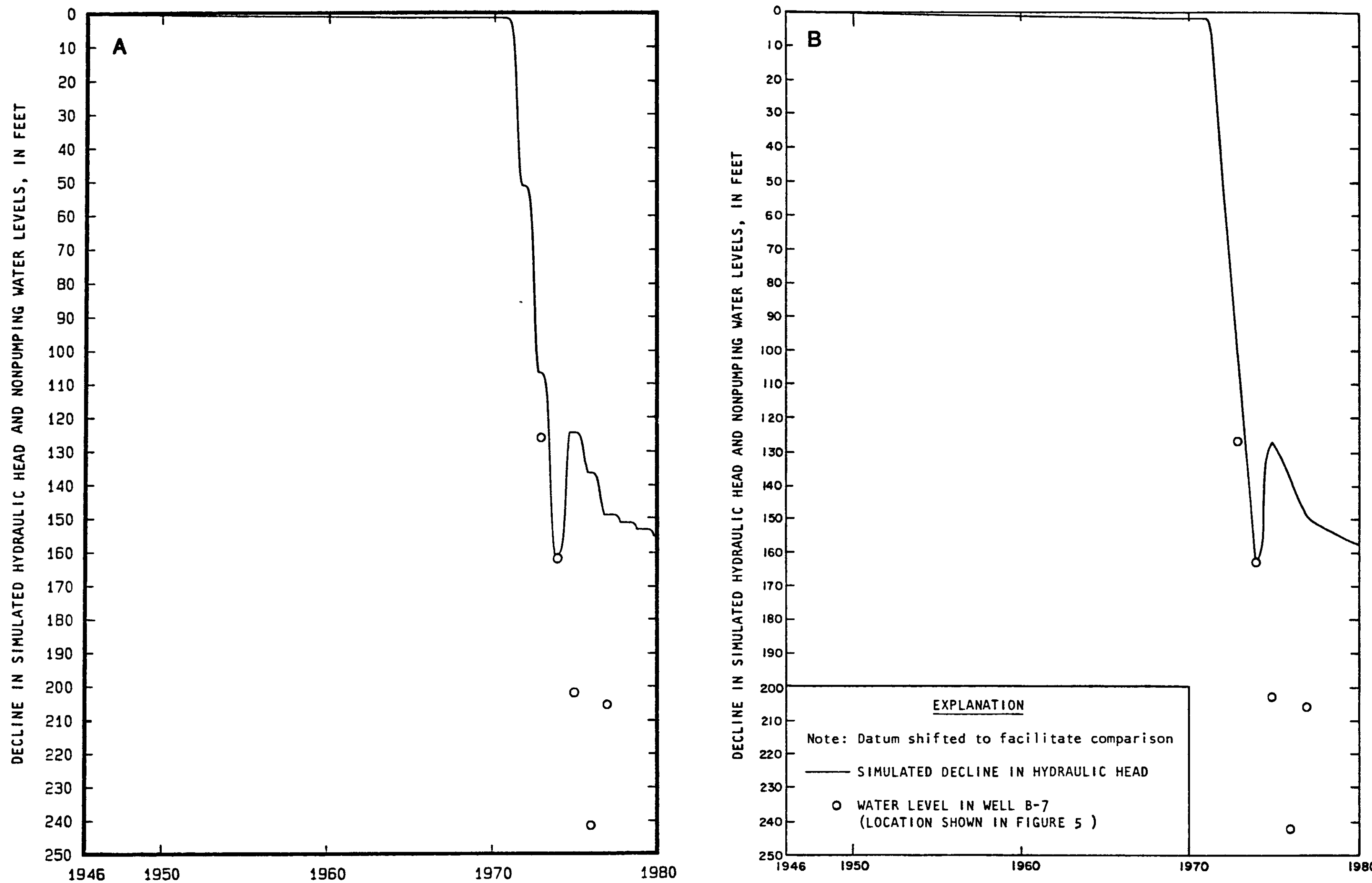
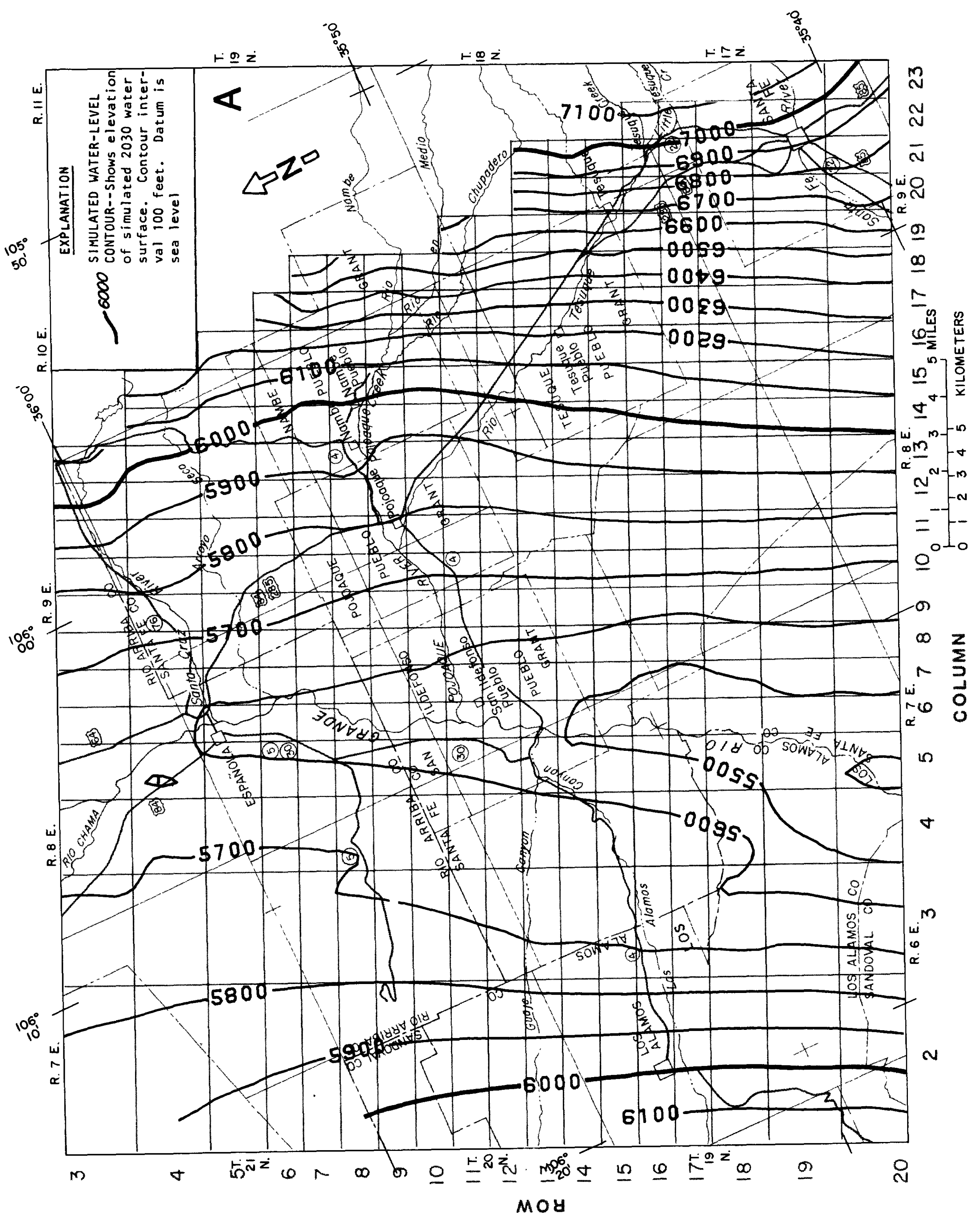


Figure 14.--Comparison between decline in hydraulic head and declines in nonpumping water levels measured in well B-7 simulated at: A--row 17, column 7, layer 6; B--row 17, column 7, layer 17 (Hearne, 1985, fig. 20).


EXPLANATION
SIMULATED WATER-LEVEL CONTOUR--Shows elevation of simulated 2030 water surface. Contour interval 100 feet. Datum is sea level
6000
A
N
0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS
COLUMN
ROW
5500
5600
5700
5800
5900
6000
6100
6200
6300
6400
6500
6600
6700
6800
6900
7000
7100
RIO ARRIBA CO
SANTA FE CO
LOS ALAMOS CO
SANDOVAL CO
ESPAÑOLA
RIO CHAMA
RIO GRANDE
NAMBE PUEBLO
POJOAQUE PUEBLO
TESUQUE PUEBLO
SAN ILDEFONSO PUEBLO
Santa Cruz
Pojoaque Creek
Tesuque
Chupadero
Nambe
Medio
Santa Fe River
Los Alamos
Guaje
Canyon
R. 6 E.
R. 7 E.
R. 8 E.
R. 9 E.
R. 10 E.
R. 11 E.
T. 17 N.
T. 18 N.
T. 19 N.
T. 20 N.
T. 21 N.
35°40'
35°50'
36°00'
105° 50'
106° 00'
106° 10'
106° 20'

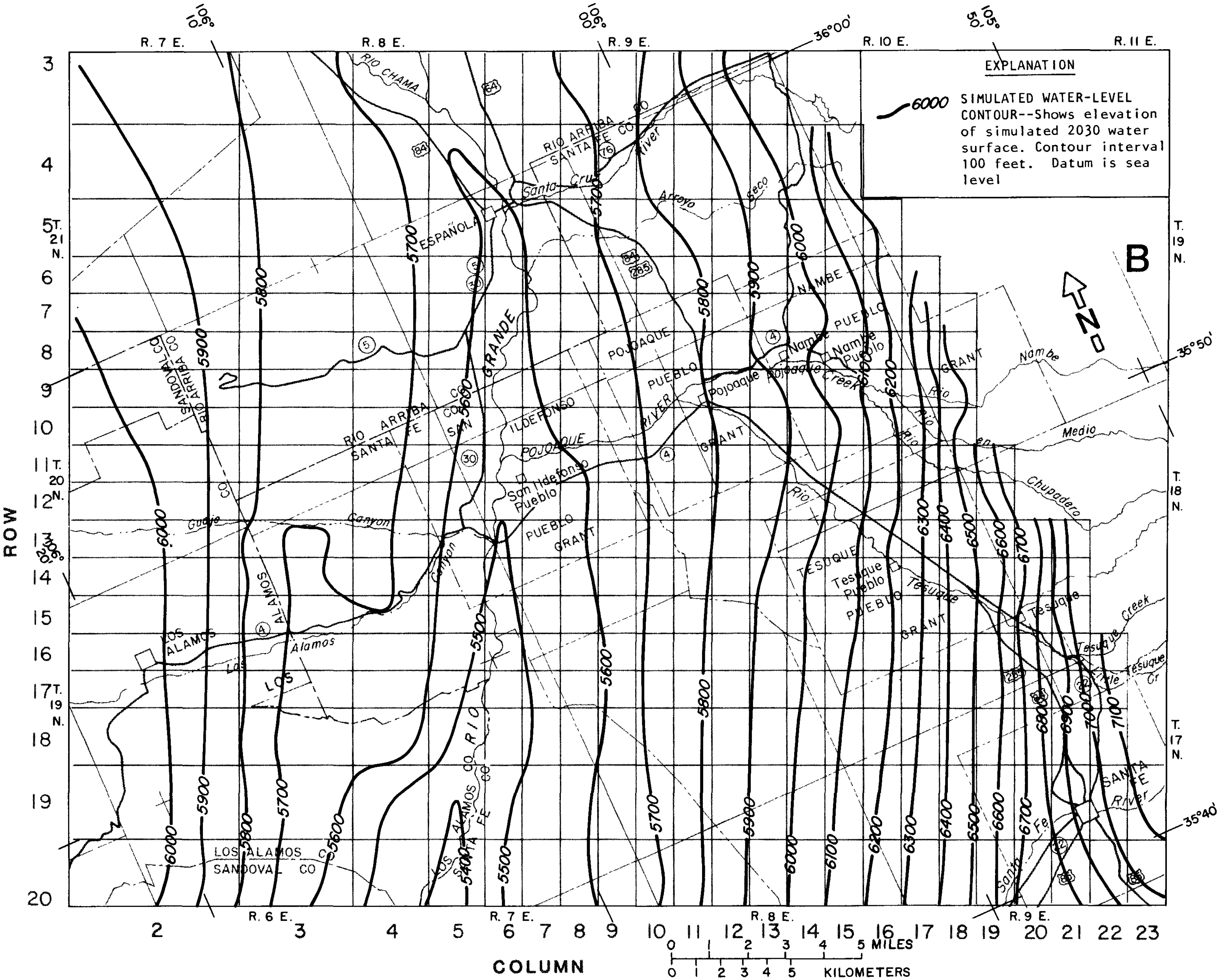


Figure 15.--Contours of simulated water surface in 2030 assuming irrigation using: A--this report; B--Hearne (1985, fig. 23).

Simulated Hydraulic Heads for 1947 to 2080

Figures 16 through 23 are plots of simulated decline (with respect to steady-state conditions) versus time for the combined "historical-future period" of 1947 to 2080. The agreement between the simulated decline in hydraulic head shown in figures 16A through 23A and their counterparts 16B through 23B from Hearne (1985) is good for all but figure 23. This figure indicates a large (approximately 43-foot) difference in simulated hydraulic-head decline in 2080 for the model block indicated.

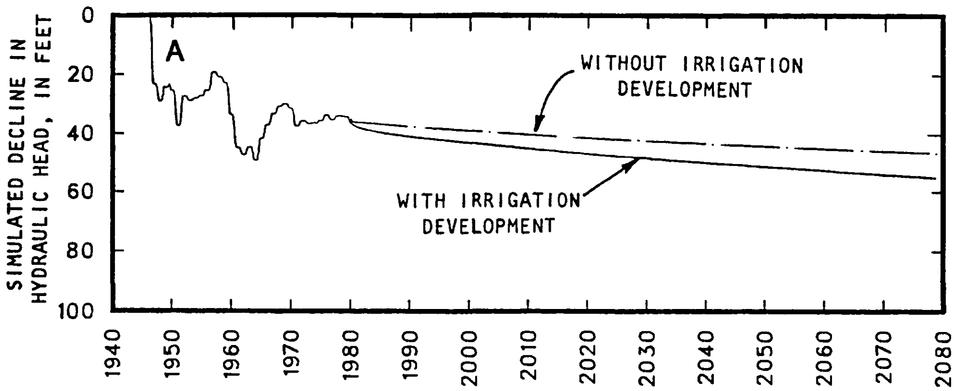
Effect of Withdrawals on Flow to Rivers

The simulated effect on flows to the Rio Grande and the Santa Cruz, Santa Fe, and Pojoaque Rivers in 1946 (steady state), 1980, and 2030 for the modular and Posson results is compared in table 3. If only the name of the river and the year appear on a line, then the amount shown is a net figure--positive for flow into the aquifer and negative for flow away from the aquifer. If a line contains the word "discharge," the amount is only the negative component of the net figure above it. "Recharge" indicates only the positive component of the net figure.

The 20.93 cubic feet per second of flow to the Rio Grande in 2030 with irrigation is not totally a computer-simulated number; 0.85 cubic foot per second of the total represents irrigation-return flow that is not taken into consideration by the model because it takes place in constant-head blocks representing the Rio Grande. The procedure for arriving at this discharge rate of 20.93 is the same one followed by Hearne (1985).

The correlation coefficient for the comparison of the simulations using the modular and Posson codes is 0.9929. This indicates good overall correspondence between aggregate flow numbers.

For the Pojoaque River, the annotation "with evapotranspiration" indicates that the quantity of flow is the sum of the net head-dependent flow between the river and the aquifer plus the evapotranspiration of -1.1 cubic feet per second, which is simulated as specified flux. The largest discrepancies between the results obtained in this study and those of Hearne (1985) are associated with the Pojoaque River, which is simulated in both models as a head-dependent boundary.



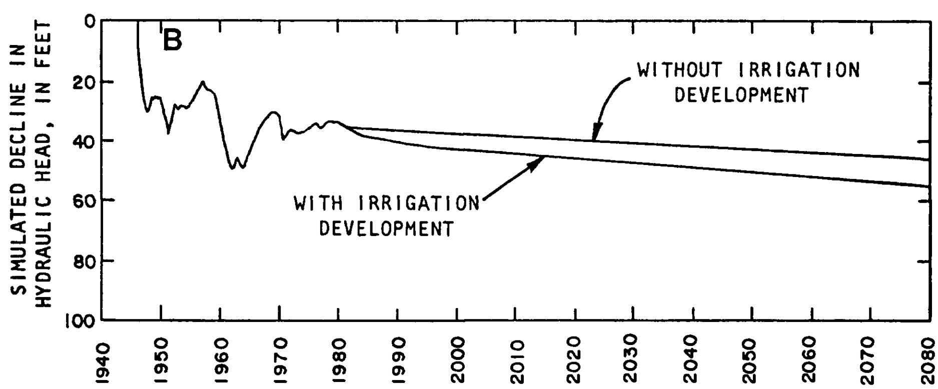
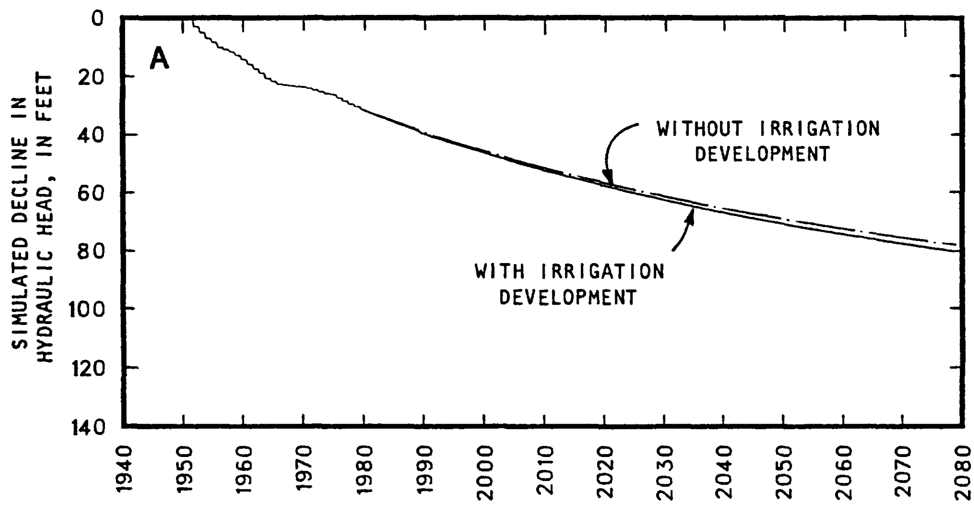


Figure 16.--Simulated decline in hydraulic head near Los Alamos Canyon well field: A--row 13, column 5, layer 4; B--row 13, column 5, layer 19 (Hearne, 1985, fig. 26).



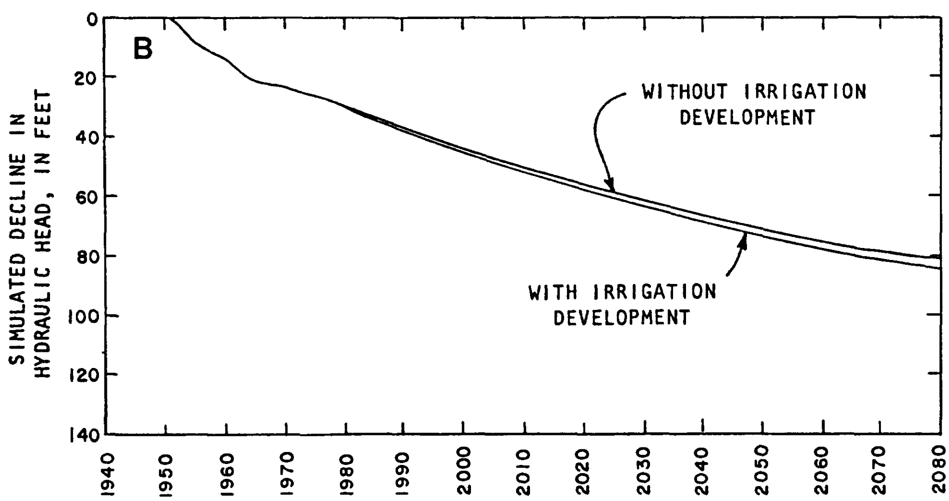


Figure 17.--Simulated decline in hydraulic head near Guaje Canyon well field: A--row 13, column 3, layer 2; B--row 13, column 3, layer 21 (Hearne, 1985, fig. 27).

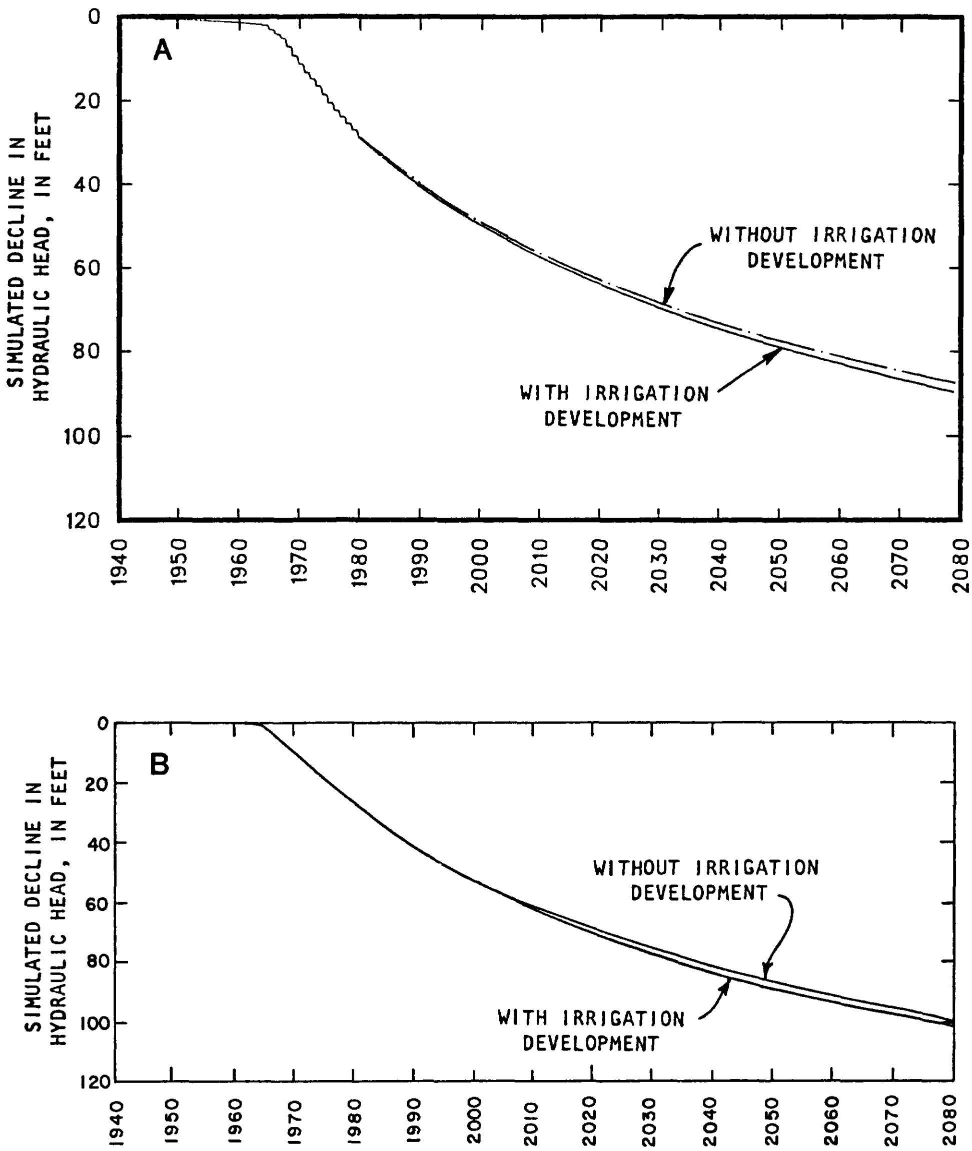


Figure 18.--Simulated decline in hydraulic head near Pajarito Mesa well field: A--row 16, column 3, layer 2; B--row 16, column 3, layer 21 (Hearne, 1985, fig. 28).

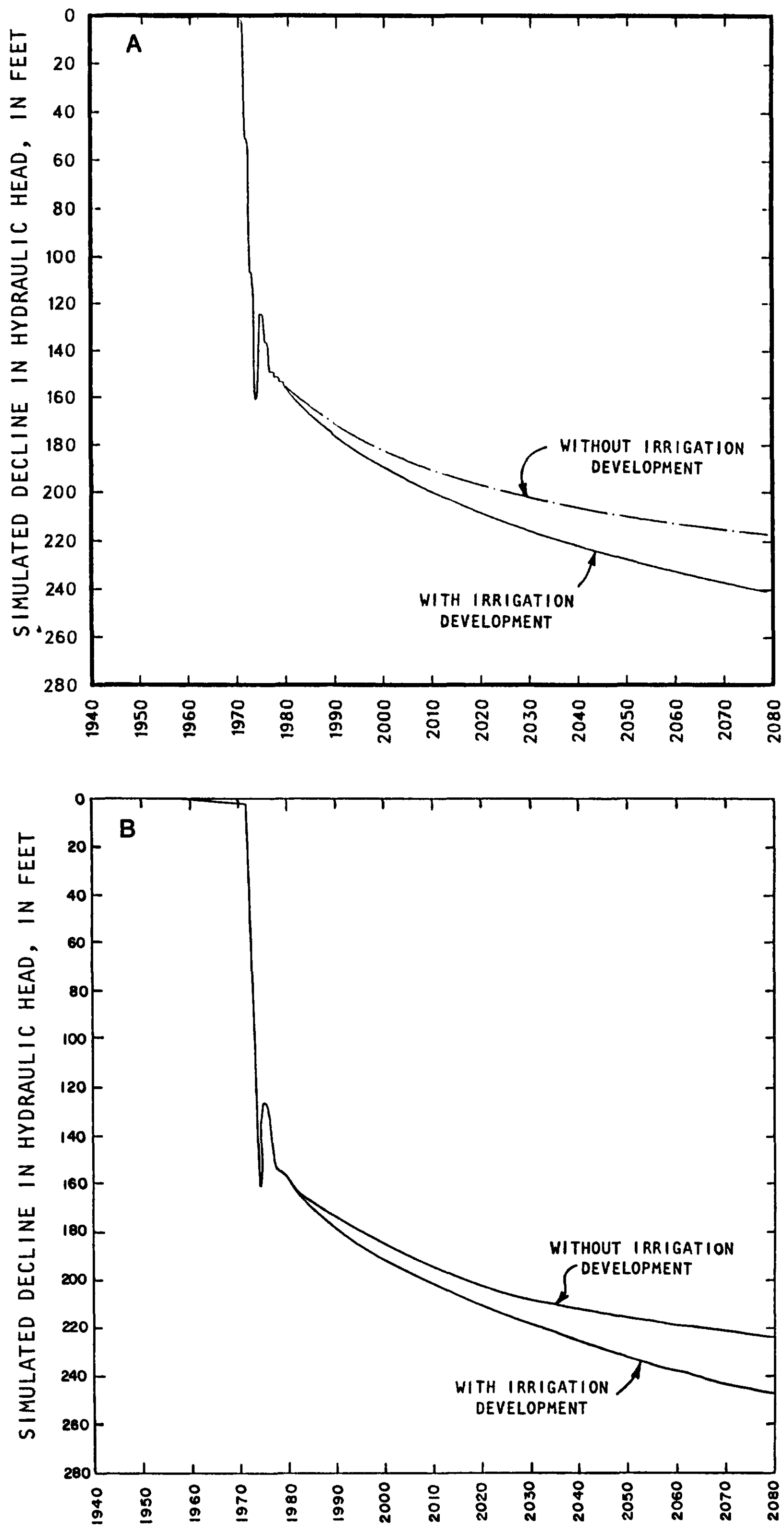
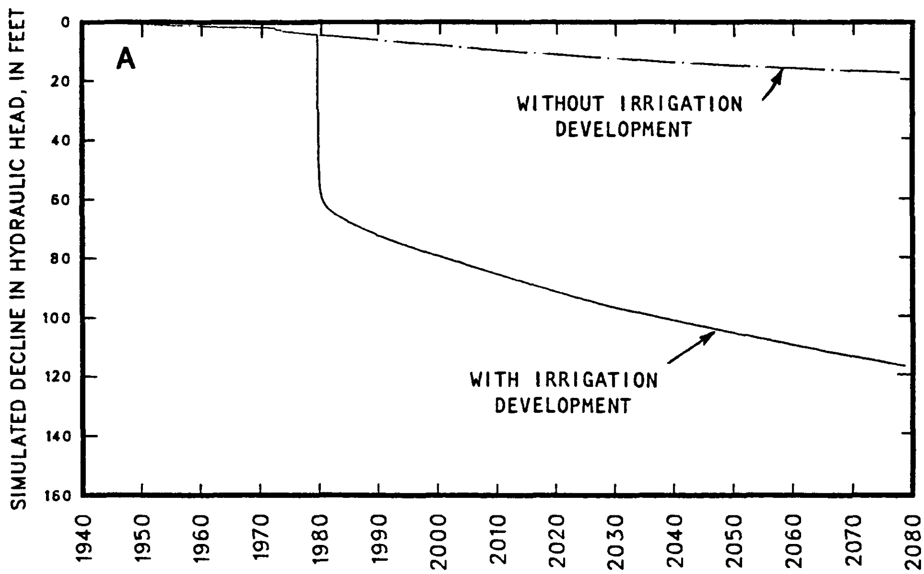


Figure 19.--Simulated decline in hydraulic head near Buckman well field: A--row 17, column 7, layer 6; B--row 17, column 7, layer 17 (Hearne, 1985, fig. 29).



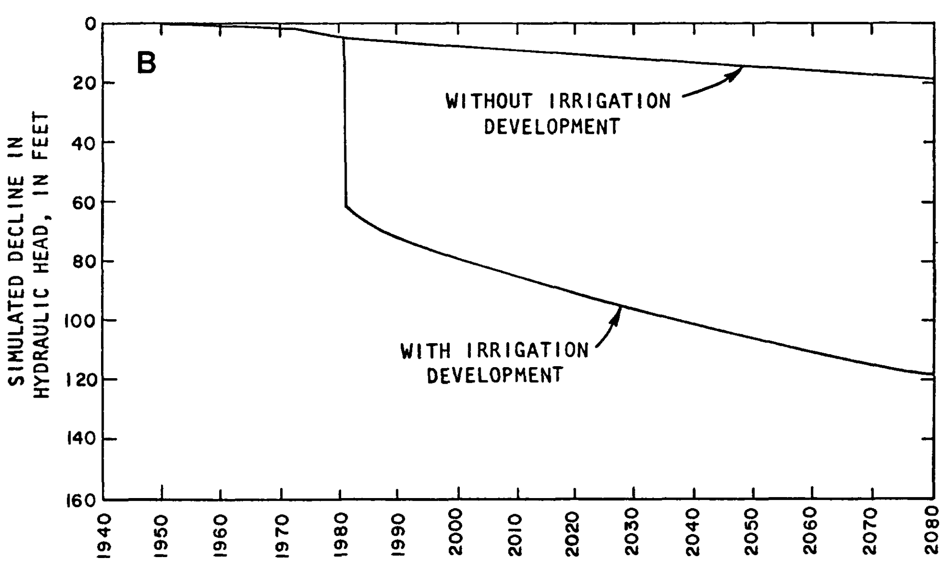


Figure 20.--Simulated decline in hydraulic head near San Ildefonso Pueblo: A--row 11, column 7, layer 6; B--row 11, column 7, layer 17 (Hearne, 1985, fig. 30).

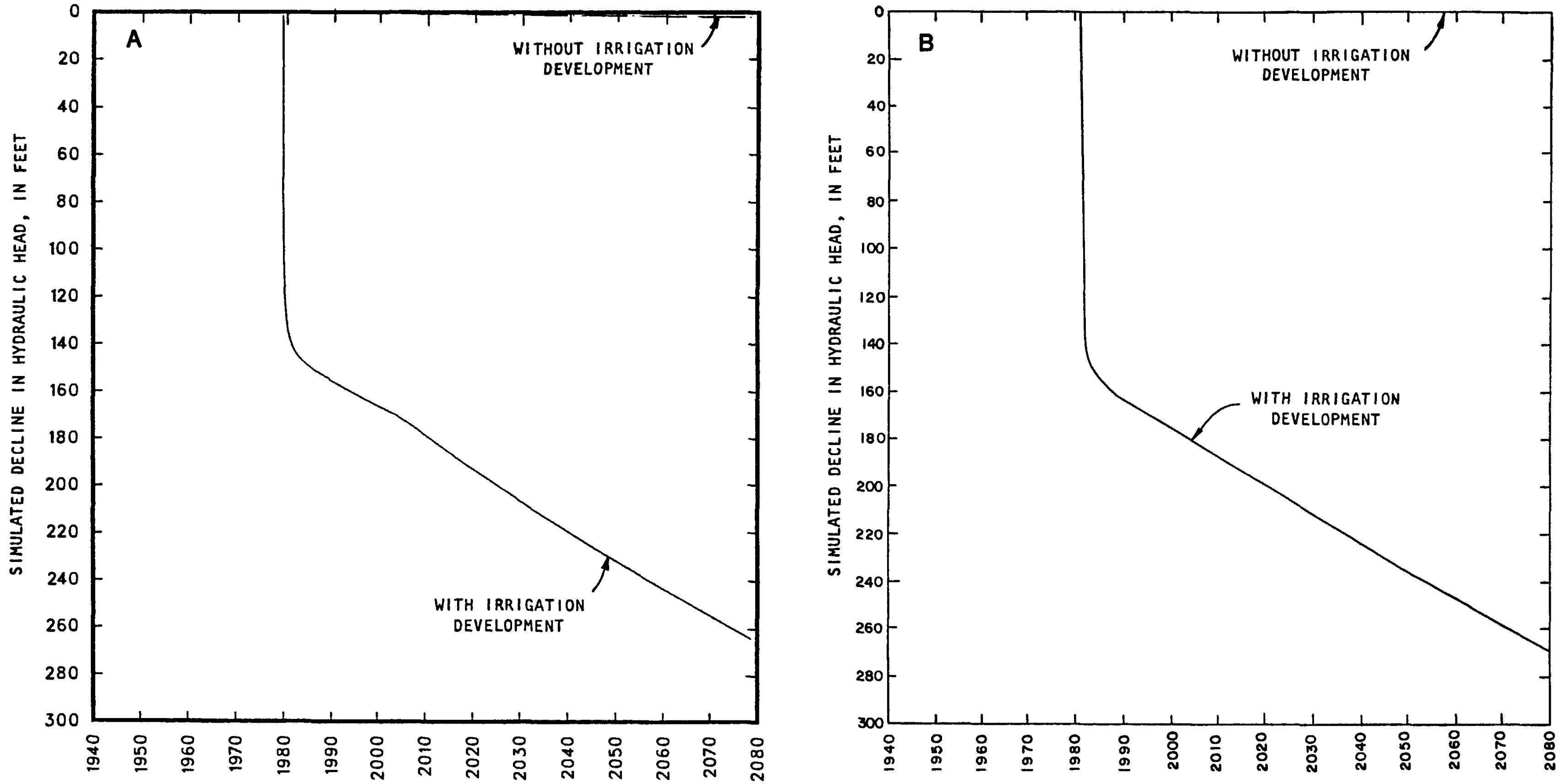


Figure 21.--Simulated decline in hydraulic head near Pojoaque Pueblo: A--row 9, column 12, layer 11; B--row 9, column 12, layer 12 (Hearne, 1985, fig. 31).

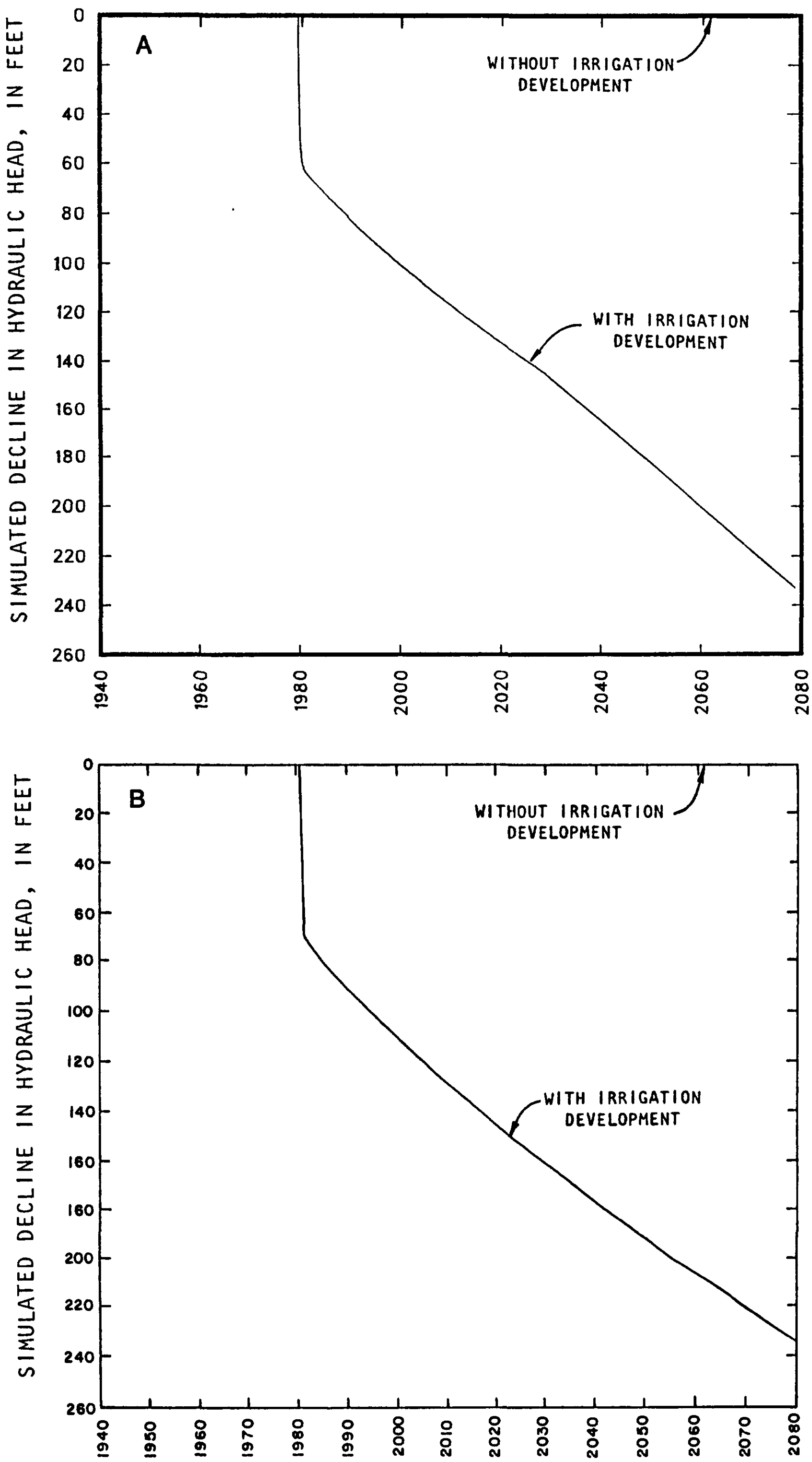


Figure 22.--Simulated decline in hydraulic head near Nambe Pueblo: A--row 8, column 16, layer 15; B--row 8, column 16, layer 8 (Hearne, 1985, fig. 32).

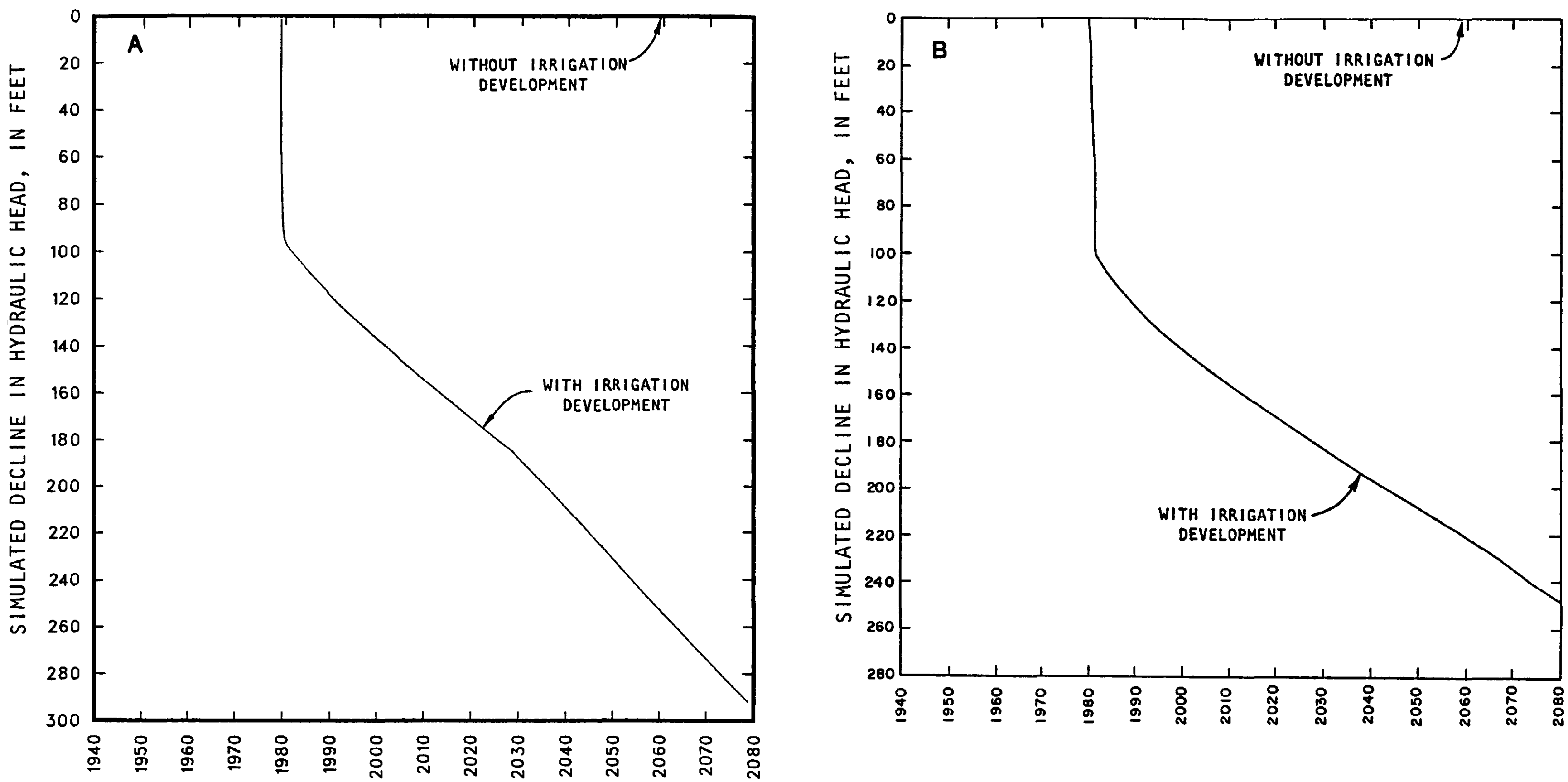


Figure 23.--Simulated decline in hydraulic head near Tesuque Pueblo: A--row 14, column 18, layer 17; B--row 14, column 18, layer 6 (Hearne, 1985, fig. 33).

Table 3.—**Comparison of simulated effect on flow to the rivers, in cubic feet per second, computed by this study and Hearne (1985)**

	This study	Hearne (1985)	Absolute difference
Rio Grande, 1946	-22.97	-22.06	0.91
Rio Grande, 1980	-21.98	-21.04	0.94
Rio Grande, 2030			
(with irrigation)	-20.93	-20.14	0.79
Rio Grande, 2030			
(without irrigation)	-21.05	-20.07	0.98
Santa Cruz, 1946	2.85	2.61	0.24
Santa Cruz, 1980	2.88	2.65	0.23
Santa Cruz, 2030			
(with irrigation)	3.95	3.73	0.22
Santa Cruz, 2030			
(without irrigation)	2.95	2.74	0.21
Santa Fe, 1946	2.84	2.86	0.02
Discharge	-4.37	-4.35	0.02
Santa Fe, 1980			
Discharge	-4.36	-4.34	0.02
Santa Fe, 2030			
(with irrigation)			
Discharge	-4.24	-4.21	0.03
Santa Fe, 2030			
(without irrigation)			
Discharge	-4.32	-4.28	0.04
Pojoaque, 1946	1.83	1.14	0.69
Discharge	-2.85	-3.11	0.26
Recharge	4.68	4.25	0.43

Table 3.--Comparison of simulated effect on flow to the rivers, in cubic feet per second, computed by this study and Hearne (1985)--Concluded

	This study	Hearne (1985)	Absolute difference
Pojoaque, 1946	1.83	1.14	0.69
With evapotranspiration	0.73	0.04	0.69
Pojoaque, 1980	1.74	1.19	0.55
With evapotranspiration	0.64	0.09	0.55
Pojoaque, 2030			
(with irrigation)	3.60	3.59	0.01
With evapotranspiration	2.50	2.49	0.01
Pojoaque, 2030			
(without irrigation)	2.07	1.41	0.66
With evapotranspiration	0.97	0.31	0.66

POSSIBLE SOURCES OF DIFFERENCE BETWEEN POSSON AND MODULAR RESULTS

Results from the Posson version and the modular version generally are similar. In some instances, however, there are differences. These instances are: (1) differences in the steady-state contours west of the Rio Grande presented in figure 5; (2) differences in flow into the aquifer for head-dependent blocks representing the Pojoaque River (tables 2 and 3); (3) differences in the contours west of the Rio Grande for 2030 presented in figure 15; and (4) differences of 43 feet in the predicted drawdown for 2080 for the model block represented in figure 23.

One possible explanation for these differences is that the mathematical formulation of the head-dependent flow boundary (which was used to represent the Pojoaque River) in the Posson code is "explicit" and requires obtaining the steady-state solution transiently (Posson and others, 1980, p. 15). In an explicit solution, the hydraulic head at the head-dependent blocks is first assumed. Using the assumed values, the flows at these blocks are then computed and imposed as boundary conditions. The set of equations representing the model is then solved for the unknown heads, including those at the head-dependent blocks. These newly computed heads at the head-dependent blocks are then used to compute flows at these blocks, and the process is repeated until the heads converge.

For the modular simulation, the formulation is implicit (McDonald and Harbaugh, 1984). In an implicit formulation, the equations representing the model are modified to include the dependence of the flows at the head-dependent blocks on the hydraulic heads at these blocks. The system of equations needs to be solved only once to obtain the final head distribution. This difference in formulation probably affects the results, but an investigation of the extent of the difference directly attributable to this difference was beyond the scope of this study.

Another possible source of differences in model results is the different methods required to supply the modular and Posson programs with values of vertical hydraulic conductivity. The modular program requires an array of values (vertical hydraulic conductivity divided by the layer thickness) that had to be computed separately before supplying them as model arrays. VCONT, a parameter needed for the modular code, had to be computed from the horizontal conductivity and the anisotropy ratio given for the Posson version of the model.

A possible source for the difference in the contours presented in figures 5 and 15 is the large size of the blocks on the west side of the Rio Grande. The large surface area of these blocks tends to amplify any differences that may exist between the two versions of the model.

In general, there is no one-to-one mapping of all the parameters used in the Posson code to the parameters used in the modular code. Hydrologic and mathematical judgment had to be exercised to perform a conversion of individual parameters or groups of parameters of the Posson code to parameters required for the modular code.

CONCLUSIONS

Computer array files in the format required by the modular code were constructed that represent the mathematical model of the Tesuque aquifer system. The results from the modular version of the model are similar to those of the original ground-water flow model. The overall correspondence of the results is evidenced by correlation coefficients of 0.9905, 0.9845, and 0.9929 for comparison of the constant-head, head-dependent, and aggregate weir flows, respectively, computed by the two versions of the model.

There are differences between some results. There is approximately 50 feet of difference in contoured water-table elevations west of the Rio Grande both for steady state and 2030.

There is a difference in the computed flows between the aquifer and the Pojoaque River, which is formulated as a head-dependent flow boundary. The net flow into the aquifer from the Pojoaque River is presented as 1.134 cubic feet per second in the original model, which is 38.1 percent less than the 1.8319 cubic feet per second computed in this study. Also, there is 43 feet of difference in the simulated head decline in 2080 for a block near Tesuque Pueblo.

One potentially significant source for the difference in results both for the Pojoaque River and the whole model is the different ways in which the modular and Posson codes formulate the head-dependent flow boundary. In general the difference between the two sets of results is not large enough to lead to different conclusions regarding the behavior of the system at steady state or when pumped.

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