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GEOLOGICAL SURVEY

SIMULATED CHANGES IN GROUND-WATER LEVELS RESULTING FROM PROPOSED PHOSPHATE MINING, WEST-CENTRAL FLORIDA -- PRELIMINARY RESULTS

By

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CONVERSION FACTORS

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

Multiply English unit	By	To obtain metric unit
	Length	
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
	Area	
square miles (mi^2)	2.590	square kilometers (km^2)
	Flow	
million gallons per day (Mgal/d)	0.04381	cubic meters per second (m^3/s)
	Transmissivity	
feet squared per day (ft^2/d)	0.0929	meters squared per day (m^2/d)
	Hydraulic Conductivity	
feet per day (ft/d)	0.3048	meters per day (m/d)
feet per second (ft/s)	0.3048	meters per second (m/s)
	Leakance Coefficient	
feet per day per foot [(ft/d)/ft]	1.0	meters per day per meter [(m/d)/m]
gallons per day per cubic foot [$(gal/d)/ft^3$]	0.1337	meters per day per meter [(m/d)/m]

SIMULATED CHANGES IN GROUND-WATER LEVELS RESULTING FROM PROPOSED PHOSPHATE MINING, WEST-CENTRAL FLORIDA -- PRELIMINARY RESULTS

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ABSTRACT

A digital model of two-dimensional ground-water flow was used to simulate projected changes in the Floridan aquifer potentiometric surface in 1985 and 2000, resulting from proposed ground-water developments by the phosphate mining industry in west-central Florida. The model was calibrated under steady-state conditions to simulate the September 1975 potentiometric surface. Under one development plan, existing phosphate mines in Polk County would continue to withdraw ground water at 1975 rates, until phased out as the ore is depleted; no new mines would be introduced. Preliminary results indicate that under this plan, maximum simulated recovery of the potentiometric surface is 11.9 feet by 1985 and 36.5 feet by 2000. Under an alternative plan, all proposed mines in Polk, Hardee, DeSoto, Hillsborough and Manatee Counties would begin operations, in addition to the continuation and phasing out of existing mines. Preliminary results indicate that the potentiometric surface would generally recover in Polk County and decline elsewhere in the modeled area. Maximum simulated recovery is 4.5 feet by 1985 and 29.6 feet by 2000; maximum simulated drawdown is 15.1 feet by 1985 and 14.4 feet by 2000. All results are preliminary and subject to revision as the investigation continues.

INTRODUCTION

Long-range projections of water use in west-central Florida suggest that substantial increases in ground-water withdrawals will occur for municipal supplies, irrigation, and phosphate mining. In the mid-1970's, principal interest was focused on the phosphate industry, whose mines and associated chemical plants each used millions of gallons of ground water per day for processing. In 1975, phosphate mining was confined to Polk County (fig. 1), but mining companies, through permit applications to regulatory agencies, were actively seeking to expand operations into Hardee, Hillsborough, DeSoto, and Manatee Counties over the next several decades, as the Polk County ore becomes depleted.

The proposed mining operations, especially when considered along with anticipated growing demands for ground water for municipal supplies and irrigation could have a major impact on the hydrology. In 1975, the U.S. Geological Survey entered into a cooperative agreement with the Southwest Florida Water Management District to determine the regional hydrologic effects of anticipated ground-water withdrawals by major users, including the phosphate industry, municipalities, and irrigators.

The objective of the first phase of this investigation was to determine the amount of change in the potentiometric surface of the Floridan aquifer to be expected as a result of proposed major ground-water developments in west-central Florida. A comprehensive report of the first phase will describe the regional hydrogeology and the projected changes in the potentiometric surface. In a later phase of the investigation, the potential effects of development on the saltwater-freshwater interface along coastal west-central Florida will be assessed.

This report presents some preliminary results of one aspect of the first phase of this investigation, namely, only those changes in the potentiometric surface that might be expected as the result of ground-water development by the phosphate industry. The purpose of releasing these preliminary findings is to provide timely results in support of an investigation by the U.S. Environmental Protection Agency. In 1976, the Environmental Protection Agency and its principal contractor, Texas Instruments, Inc., undertook the preparation of an Environmental Impact Statement on the current and projected development of the phosphate industry in central Florida.

In view of the fact that the results in this report are preliminary, they are subject to revision as the investigation continues.

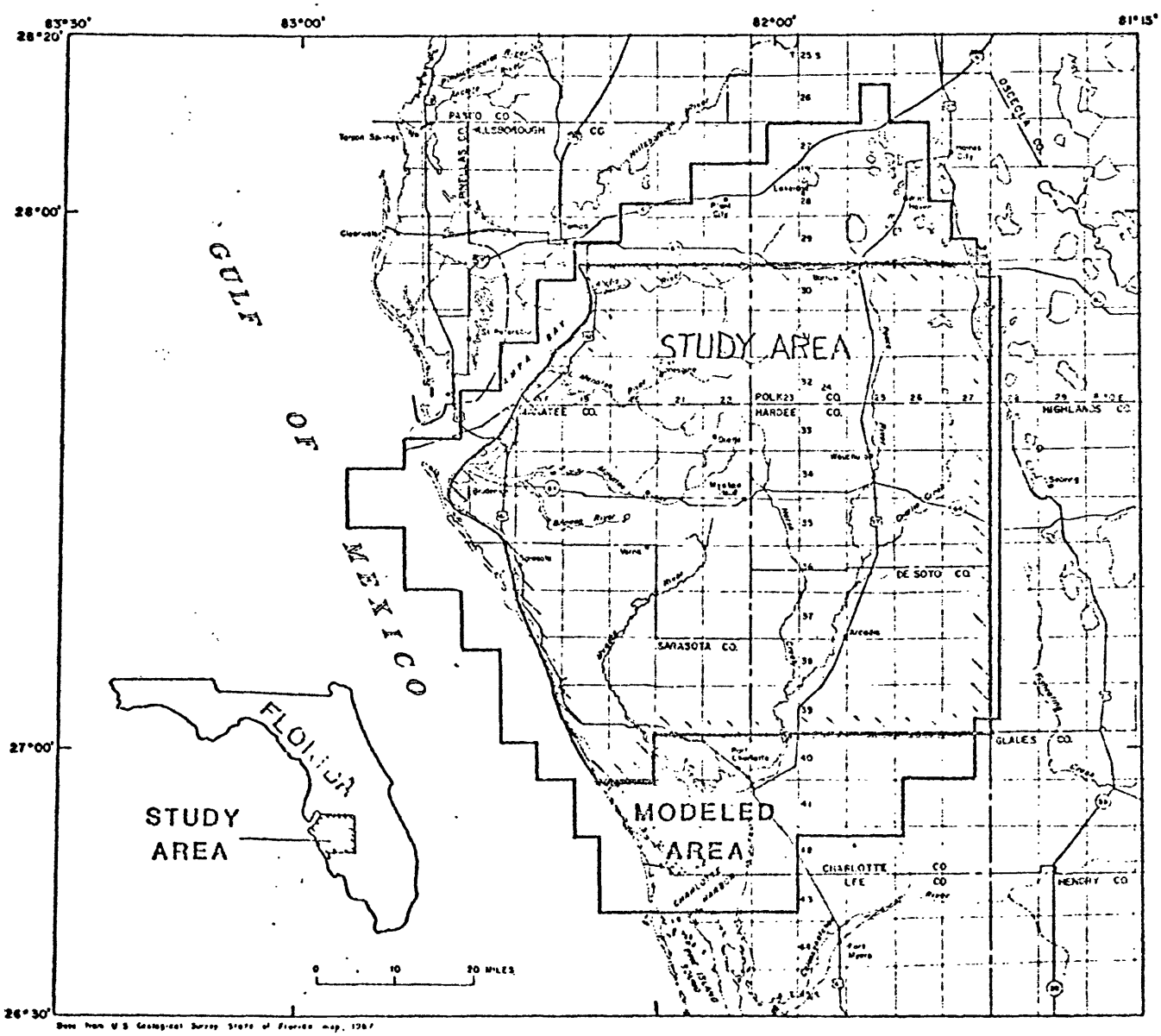


Figure 1. Location of study area and modeled area.

The study area for the Geological Survey investigation is a 3,530 mi^2 area in west-central Florida, south and east of Tampa (fig. 1). The area includes all of Hardee, DeSoto, Manatee, and Sarasota Counties, the southeastern part of Hillsborough County, and the southwestern part of Polk County. Projected changes in the potentiometric surface were simulated by calibrating and applying a digital model of the ground-water flow system, based on interpretations of the regional hydrogeology. The modeled area covers about 5,854 mi^2, as shown in figure 1. The stratigraphic nomenclature used in this report was determined from several sources and may not necessarily follow the usage of the U.S. Geological Survey.

HYDROGEOLOGY

Ground water occurs beneath the study area in two principal aquifers, the surficial aquifer and the Floridan aquifer. Ground water in the surficial aquifer is unconfined, and ground water in the Floridan aquifer is confined. Recharge to and discharge from the Floridan aquifer is principally by leakage through a confining bed that separates the Floridan aquifer from the overlying surficial aquifer.

The surficial aquifer underlies most of the study area and consists predominantly of fine-to-very-fine sand and clayey sand. The aquifer includes deposits commonly referred to as surficial sand, terrace sand, phosphorite, Caloosahatchee Marl (Pleistocene and Pliocene), and parts of the Bone Valley Formation (Pliocene).

The principal sources of ground water in the study area are the transmissive zones in the Floridan aquifer. The Floridan aquifer was originally defined by Parker (Parker and others, 1955, p. 189) to include all or parts of the Lake City Limestone (Eocene), Avon Park Limestone (Eocene), Ocala Limestone (Eocene), Suwannee Limestone (Oligocene), Tampa Limestone (Miocene), and "permeable parts of the Hawthorn Formation that are in hydrologic contact with the rest of the aquifer". This definition is closely followed in this report, except for differences in the identity of the top and base of the aquifer.

Confining beds bound the Floridan aquifer above and below. As used in this report, the upper confining bed of the Floridan aquifer is the full clastic-carbonate sequence between the surficial aquifer and the Floridan aquifer. This sequence includes, in different parts of the study area, all or part of the Bone Valley Formation, Tamiami Formation (Pliocene), Hawthorn Formation (Miocene), and Tampa Limestone. Although these formations commonly contain permeable zones, well yields are generally substantially less than those from the underlying carbonate section of the Floridan aquifer. Thus, for purposes of this report, the carbonate-clastic section can be appropriately considered as a single confining unit overlying the Floridan aquifer. The base of the Floridan aquifer, as used here, occurs where the amounts of intergranular anhydrite and gypsum, usually 5 to 15 percent, become sufficiently great with depth to result in a very low porosity and permeability. In this report, this hydrologically significant lithologic change is considered to correspond to the top of the Lake City Limestone.

DESCRIPTION OF HYDROLOGIC MODEL

The digital simulation model computes hydraulic head changes in time and space in an aquifer system in response to applied hydraulic stresses. The model utilizes a finite-difference method in which differential equations of ground-water flow are solved numerically. The equations require that hydraulic properties, boundaries, and stresses be defined for the area modeled. The digital model of two-dimensional flow used in this study was described by Trescott, Pinder and Larson (1976).

A 13,608 mi^2 area of west-central Florida and the adjoining Gulf of Mexico was subdivided into a rectangular finite-difference grid within which the model area was defined (fig. 2). Block sizes range from 2 mi by 2 mi to 10 mi by 10 mi. The node at the center of each block is designated by row and column number; for example, the node at row 20, column 5 is expressed as 20-5.

Within the gridded area, model boundaries were selected to coincide as closely as possible with hydrologic boundaries. Two types of boundaries can be represented by the model: constant flux and constant head (Trescott, Pinder, and Larson, 1976). A constant flux may be finite or it may be zero (no-flow). For the steady-state calibration, the modeled area was defined by a no-flow boundary (fig. 2); in the transient analysis, nodes immediately inside this boundary were designated constant-head. No finite-flux boundary was used in this model.

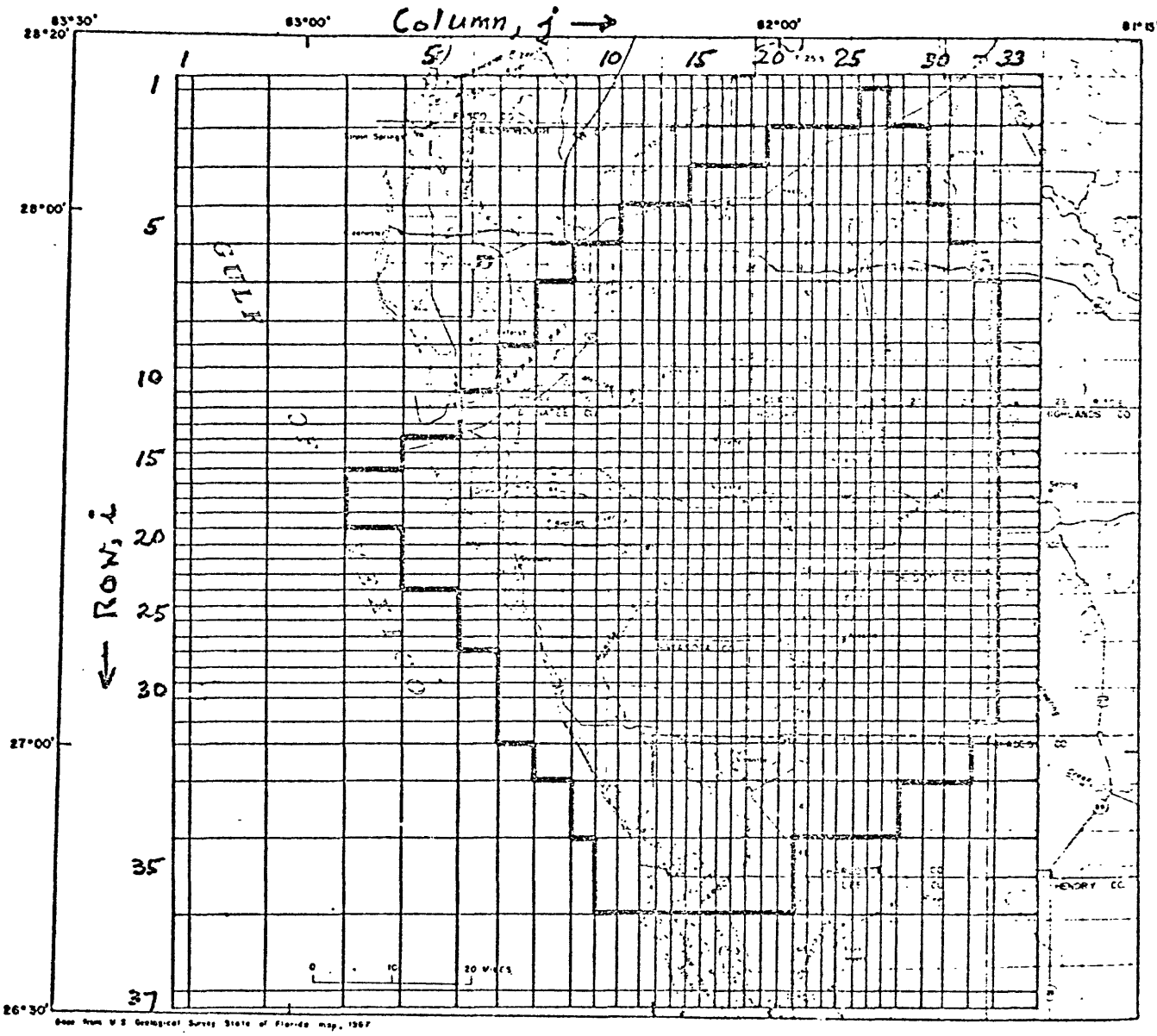


Figure 2. Grid network and boundary of modeled area.

Major assumptions made in the model analysis are as follows:

1. Ground-water movement in the Floridan aquifer occurs in a horizontal plane in a single-layer, isotropic medium.

2. Water moves vertically into or out of the Floridan aquifer through the upper confining bed. No leakage occurs through the lower confining bed.

3. The head in the surficial aquifer does not change in response to any imposed stress.

The ground-water flow system in the study area is shown schematically in figure 3. Regionally, the system approximates the assumed conditions, although locally, deviations occur. Most wells in the area are finished as open hole and tap most of the thickness of the Floridan aquifer. An upper confining bed overlies the Floridan aquifer throughout the area, and aquifer discharge and recharge occur principally as vertical leakage through this confining bed. Aquifer tests have shown the lower confining bed (Lake City Limestone) to be relatively impermeable. The seasonal range of fluctuation of the water table in the surficial aquifer is generally less than a few feet, and in the study area the water table is virtually unaffected by withdrawals from the Floridan aquifer.

MODEL CALIBRATION

The calibration procedure is a means of demonstrating how realistic the model is, by comparing computations of the model with actual field observations. In this study, the model was calibrated under steady-state conditions, in which a simulated potentiometric surface was compared to the observed September 1975 potentiometric surface, shown on figure 4, which was assumed to approximate steady-state conditions.

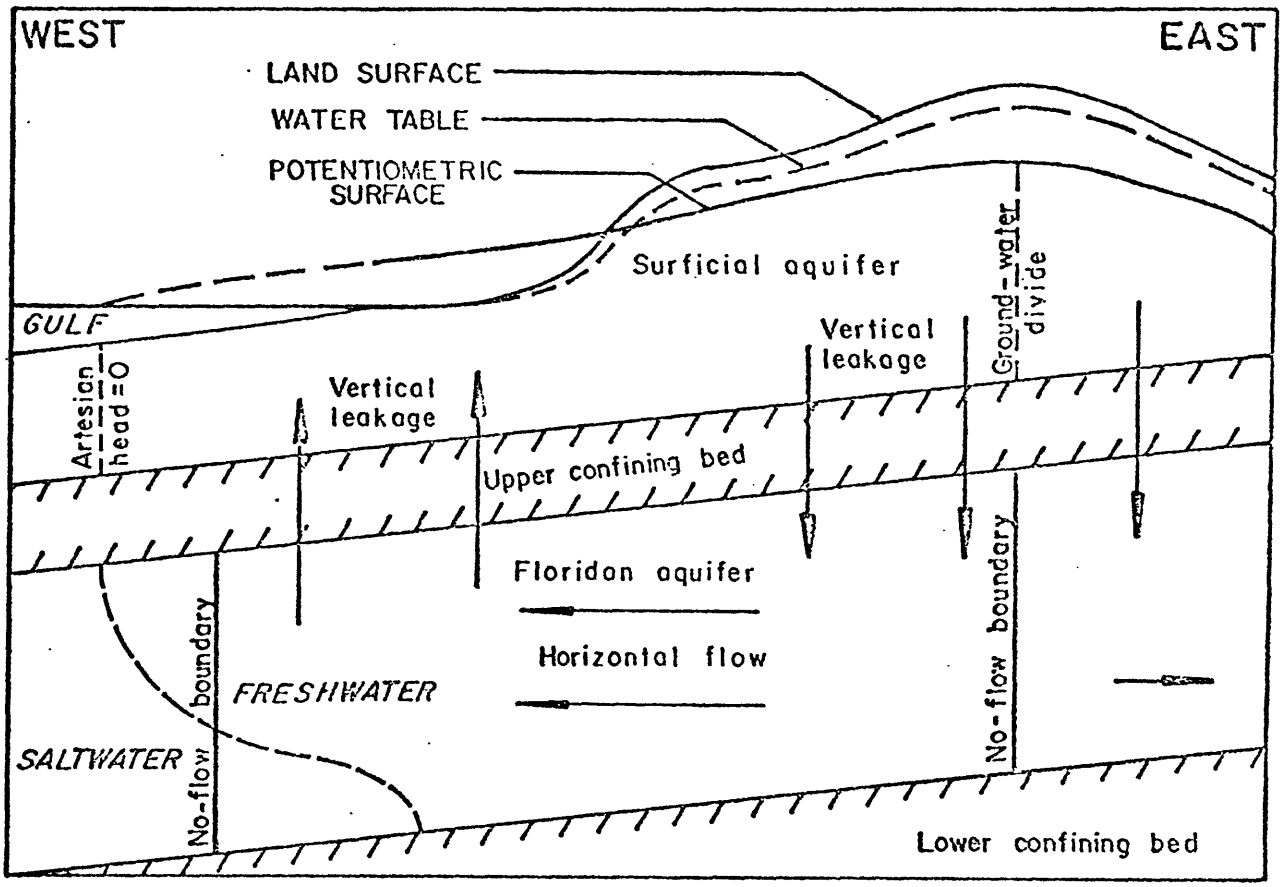


Figure 3. Generalized steady-state flow model. (Not to scale)

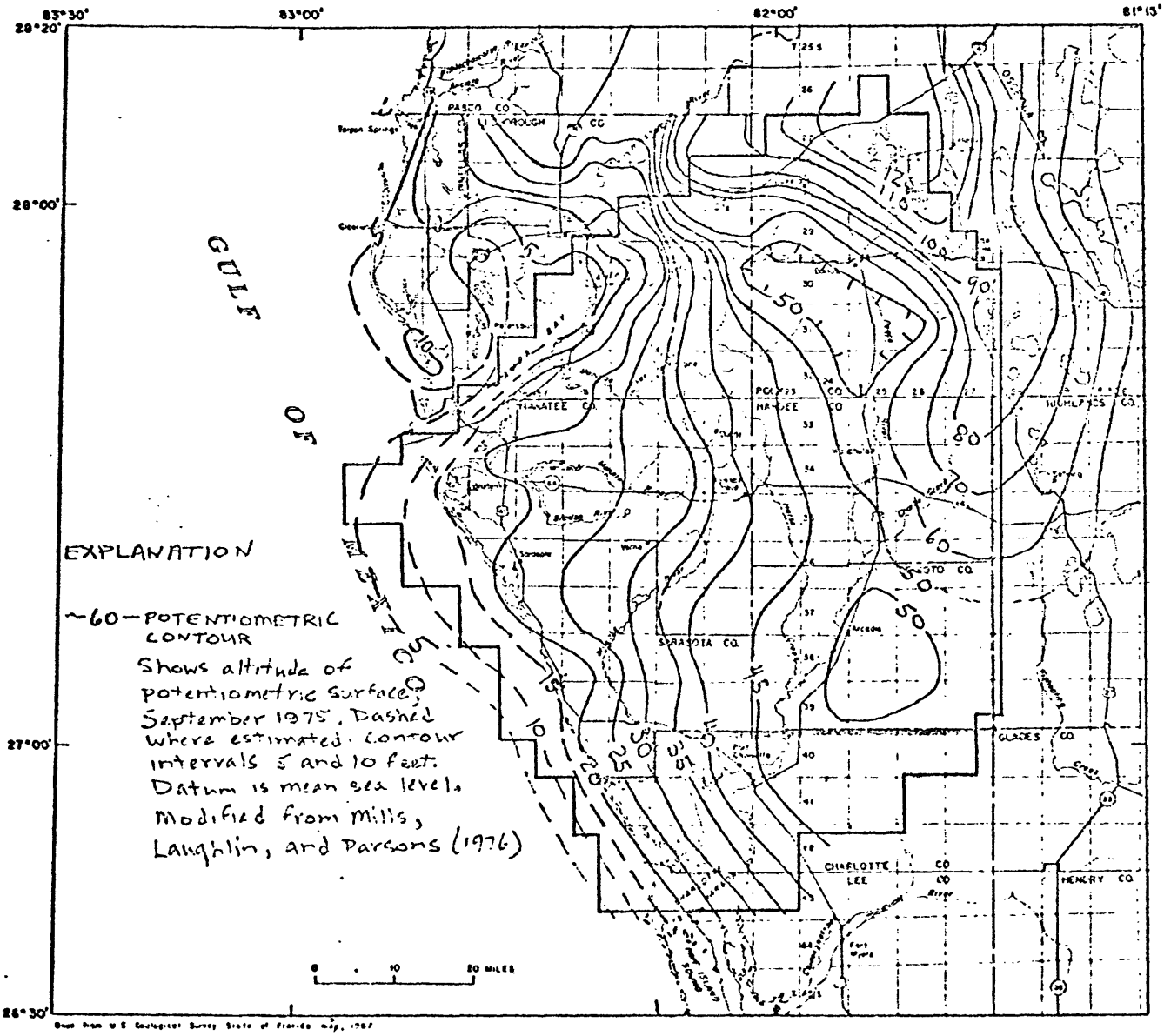


Figure 4. Potentiometric surface of Floridan aquifer, September 1975.

A steady-state condition exists when no changes in aquifer storage occur with time, and such a condition was approximated in September 1975. Hydrographs indicated that at the time of the water-level measurements for the September 1975 potentiometric map, the potentiometric surface was near the end of a summer-long recovery period and was changing little with time. The principal stresses on the aquifer system in September were withdrawals for municipal supplies, phosphate mining, and other industrial supplies. Pumping rates for these uses vary during the course of the year, but these variations are generally too small to have much impact on the regional fluctuations of the potentiometric surface. Withdrawals for irrigation were assumed to be insignificant in September 1975. Field checks indicated that little irrigation occurred during and immediately following the summer rainy season, and hydrographs indicated that in most parts of the study area the potentiometric surface in 1975 did not start declining as a result of the onset of the fall irrigation season until October or early November.

The calibration process was also a means of modifying and improving the modeler's conceptual view of the aquifer system. Simulated potentiometric surfaces obtained early in the process represented an initial conceptual view based on the best available data. The match between the computed and observed potentiometric surfaces was improved and the conceptual view modified by adjusting the input parameters, while staying within a reasonable expected range of error in their values. While the final simulated map does not fit the observed map precisely, the differences can generally be accounted for by the likely range of error in one or more of the input parameters.

Input Parameters

Input parameters to the steady-state model included boundaries, stresses on the aquifer system, and aquifer and confining-bed hydraulic properties.

Boundaries

The Floridan aquifer underlies all of Florida and parts of other southeastern states. However, because of the impracticality of modeling the entire aquifer in the detail desired for the study area, the modeled area was defined by boundaries placed approximately along hydrologic boundaries near the study area (fig. 2). Because the boundaries of the model do not everywhere accurately represent or precisely coincide with hydrologic boundaries, some error is introduced into the model calibration. The errors are probably least in the area of greatest interest, in the central part of the model, where the proposed ground-water developments for phosphate mining are scheduled.

All boundaries of the steady-state model are no-flow. The northern and eastern model boundaries were placed approximately along ground-water divides of the September 1975 potentiometric surface (figs. 3 and 4). As long as those steady-state conditions prevailed, no ground water flowed across those divides, and a no-flow boundary was a reasonable representation of actual hydrologic conditions.

The southeastern model boundary was placed approximately perpendicular to the September 1975 potentiometric contour lines (fig. 4) and thus was approximately parallel to the direction of ground-water flow. Because of the relatively large size of the blocks of the model grid in that area, the boundary could not be placed precisely perpendicular to the contour lines.

The southwestern model boundary was placed a few miles offshore in the Gulf of Mexico (figs. 2 and 3). Ideally, this boundary should be along the sloping saltwater-freshwater interface. Under steady-state conditions this interface acts as a no-flow boundary--all freshwater in the aquifer discharges landward of the interface. The boundary in the two-dimensional model, however, is in effect a vertical boundary and was placed between the shore and the inferred position of the zero potentiometric contour line. The zero potentiometric contour line indicates the approximate position of the trace of the interface and the top of the aquifer, and thus the contour line marks the farthest seaward extent of the interface (fig. 3). Although the position of this contour line is unknown, it may lie 10-15 mi offshore from Manatee and Sarasota Counties, based on an extrapolation of the gradient of the 1975 potentiometric surface (fig. 4). By placing the model boundary nearer shore, the boundary represents an average position of the sloping interface (fig. 3).

The northwestern boundary was placed through Tampa Bay (fig. 2). As suggested by the potentiometric gradients shown on figure 4, Tampa Bay is probably a discharge area, receiving fresh ground water from almost all sides. The no-flow boundary of the model, therefore, is approximately along the axis of a hydrologic trough, across which no ground-water flow occurs.

Ground-Water Withdrawals

Average 1975 ground-water withdrawal rates for phosphate mines and associated chemical plants, municipal supplies, and other self-supplied industries were included in the steady-state model. These rates were assumed to be approximately the same as the stresses on the Floridan aquifer in September 1975. Within the modeled area, average 1975 rates were 174 Mgal/d for phosphate mining, 135 Mgal/d for chemical plants, 53 Mgal/d for municipal supplies, and 25 Mgal/d for other self-supplied industries; the nodal distribution is shown on table 1. In addition, about 13 Mgal/d of artificial recharge from the surficial aquifer to the Floridan aquifer was included at one node (7-19).

Withdrawal amounts and locations for municipal and other industrial supplies were derived from data obtained during the 1975 water-use inventory by the Geological Survey (Leach, 1977). Amounts and locations for the phosphate industry were derived mostly from data supplied by the Florida Phosphate Council. These data included the locations, average pumping rates, and hours pumped during 1975 for individual wells at each phosphate mine and chemical plant. The pumping rates included all Floridan-aquifer withdrawals reported to the Florida Phosphate Council by individual companies. Ground water was pumped for such uses as transport and beneficiation of ore, drying plants, preparation plants, and shops.

Water Table

Average altitudes of the September 1975 water table were estimated for each node from Geological Survey topographic quadrangle maps (scale 1:24,000; contour interval 5 ft) (table 2). The water table was assumed to be a few feet or less below land surface in flat swampy areas, river flood plains, and near lakes; depths of 5 to 20 ft below land surface were assumed for sand-ridge areas.

Table 1. -- Ground-water withdrawals for phosphate industry, other self-supplied industry, and municipal supplies, 1975

Phosphate industry				Other self-supplied industry		Municipal supplies	
Mines		Chemical plants					
Node	Mgal/d	Node	Mgal/d	Node	Mgal/d	Node	Mgal/d
3-23	4.85	5-18	.63	3-29	.37	2-26	.57
3-24	6.47	6-19	25.57	4-15	.10	3-27	.26
6-9	.82	6-22	3.50	4-20	1.20	4-16	.37
6-21	.36	6-23	5.47	4-21	.70	4-17	1.48
6-23	7.59	6-24	9.21	4-26	5.09	4-19	.57
7-19	20.10	7-9	45.00	4-27	5.50	4-21	2.86
7-20	5.97	7-19	3.86	4-28	.65	4-22	3.42
7-21	.23	7-21	2.16	5-11	.03	4-23	1.71
7-23	6.74	7-22	14.32	5-28	1.50	4-26	.78
7-24	15.10	8-23	3.69	6-9	.58	4-27	1.34
7-25	6.99	9-22	1.42	6-26	4.10	4-28	.54
7-26	7.72	9-25	14.36	7-31	1.00	4-29	2.16
8-23	14.94	12-7	5.80	8-28	.20	5-12	3.60
8-26	19.38			8-31	1.45	5-19	1.14
9-20	7.36			14-25	1.78	5-20	.57
9-21	1.09			17-26	.03	5-21	1.71
9-25	16.64			19-6	.65	5-22	2.28
9-26	10.70			26-23	.23	5-23	1.14
9-27	.36			27-30	.10	5-24	1.14
9-28	.14			29-26	.15	5-28	1.63
10-22	2.29					6-12	.96
10-25	12.14					6-25	2.64
11-22	5.74					6-26	.75
						6-31	2.36
						7-11	1.79
						9-10	.83
						10-9	3.04
						10-10	.41
						15-26	.91
						21-11	3.02
						21-12	4.08
						26-25	.76
						30-8	.77
						30-9	.31
						31-8	.07
						31-9	.08
						33-10	.78
						33-11	.23
						33-18	.18
Total (rounded)	174		135		25		53

Table 2. -- Water-table altitude, September 1975

Altitude of water table, in feet above mean sea level

ROW \ COLUMN	1 21	2 22	3 23	4 24	5 25	6 26	7 27	8 28	9 29	10 30	11 31	12 32	13 33	14	15	16	17	18	19	20
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	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	0.0
2	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 130.0	0.0 130.0	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	0.0	0.0	0.0	0.0
3	0.0 145.0	0.0 135.0	0.0 130.0	0.0 132.0	0.0 135.0	0.0 140.0	0.0 132.0	0.0 133.0	0.0 130.0	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	150.0
4	0.0 170.0	0.0 130.0	0.0 122.0	0.0 105.0	0.0 110.0	0.0 120.0	0.0 135.0	0.0 131.0	0.0 128.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0	95.0	100.0	105.0	110.0	127.0	130.0
5	0.0 140.0	0.0 160.0	0.0 120.0	0.0 108.0	0.0 97.0	0.0 100.0	0.0 130.0	0.0 135.0	0.0 131.0	0.0 130.0	35.0 0.0	45.0 0.0	70.0 0.0	75.0	90.0	100.0	115.0	120.0	120.0	120.0
6	0.0 120.0	0.0 140.0	0.0 145.0	0.0 130.0	0.0 130.0	0.0 95.0	0.0 105.0	0.0 104.0	10.0 110.0	20.0 120.0	30.0 120.0	60.0 0.0	60.0 0.0	40.0	45.0	70.0	100.0	60.0	60.0	105.0
7	0.0 135.0	0.0 140.0	0.0 165.0	0.0 145.0	0.0 120.0	0.0 90.0	0.0 115.0	0.0 175.0	5.0 135.0	25.0 130.0	70.0 120.0	70.0 118.0	60.0 0.0	60.0	90.0	100.0	65.0	110.0	140.0	140.0
8	0.0 130.0	0.0 124.0	0.0 124.0	0.0 155.0	0.0 140.0	0.0 130.0	0.0 84.0	0.0 145.0	6.0 140.0	35.0 127.0	80.0 130.0	120.0 100.0	120.0 0.0	115.0	105.0	95.0	90.0	105.0	115.0	116.0
9	0.0 140.0	0.0 139.0	0.0 130.0	0.0 146.0	0.0 120.0	0.0 110.0	0.0 76.0	7.0 120.0	35.0 140.0	45.0 130.0	75.0 140.0	100.0 105.0	105.0 0.0	105.0	100.0	105.0	100.0	85.0	135.0	130.0
10	0.0 124.0	0.0 130.0	0.0 125.0	0.0 124.0	0.0 104.0	0.0 67.0	0.0 120.0	20.0 110.0	35.0 115.0	50.0 135.0	70.0 120.0	75.0 100.0	75.0 0.0	65.0	80.0	95.0	100.0	120.0	135.0	133.0
11	0.0 130.0	0.0 135.0	0.0 120.0	0.0 115.0	0.0 120.0	0.0 62.0	2.0 115.0	22.0 125.0	18.0 127.0	25.0 125.0	45.0 115.0	55.0 105.0	40.0 0.0	60.0	80.0	120.0	130.0	130.0	134.0	130.0
12	0.0 113.0	0.0 114.0	0.0 117.0	0.0 117.0	0.0 84.0	0.0 56.0	5.0 100.0	20.0 105.0	22.0 104.0	30.0 90.0	55.0 86.0	75.0 115.0	50.0 0.0	100.0	105.0	110.0	125.0	125.0	126.0	124.0
13	0.0 114.0	0.0 105.0	0.0 100.0	0.0 85.0	0.0 113.0	0.0 53.0	6.0 85.0	25.0 104.0	20.0 104.0	35.0 75.0	60.0 85.0	100.0 90.0	80.0 0.0	95.0	100.0	110.0	120.0	125.0	122.0	120.0
14	0.0 114.0	0.0 107.0	0.0 97.0	0.0 106.0	0.0 114.0	0.0 40.0	20.0 65.0	30.0 103.0	15.0 110.0	40.0 70.0	65.0 80.0	105.0 83.0	115.0 0.0	110.0	105.0	110.0	115.0	117.0	115.0	116.0
15	0.0 100.0	0.0 100.0	0.0 100.0	0.0 97.0	0.0 110.0	0.0 75.0	15.0 47.0	10.0 101.0	0.0 104.0	55.0 65.0	70.0 75.0	85.0 80.0	110.0 0.0	115.0	90.0	105.0	105.0	110.0	113.0	111.0
16	0.0 87.0	0.0 92.0	0.0 103.0	0.0 90.0	0.0 105.0	1.0 45.0	2.0 76.0	8.0 93.0	15.0 73.0	50.0 55.0	65.0 65.0	70.0 78.0	100.0 0.0	95.0	90.0	85.0	105.0	110.0	105.0	100.0
17	0.0 81.0	0.0 76.0	0.0 85.0	0.0 80.0	0.0 40.0	20.0 44.0	10.0 55.0	15.0 68.0	20.0 73.0	30.0 65.0	40.0 73.0	60.0 81.0	50.0 0.0	70.0	85.0	90.0	65.0	95.0	88.0	85.0
18	0.0 74.0	0.0 73.0	0.0 74.0	0.0 64.0	0.0 35.0	15.0 64.0	20.0 66.0	25.0 65.0	40.0 55.0	60.0 60.0	75.0 66.0	75.0 68.0	80.0 0.0	75.0	80.0	70.0	70.0	80.0	76.0	60.0
19	0.0 70.0	0.0 62.0	0.0 74.0	0.0 50.0	0.0 30.0	10.0 65.0	20.0 67.0	15.0 64.0	30.0 50.0	50.0 75.0	75.0 85.0	65.0 88.0	80.0 0.0	65.0	75.0	55.0	60.0	75.0	75.0	64.0

Table 2. -- Water-table altitude, September 1975 (continued).

Altitude of water table, in feet above mean sea level

Row \ Column	1	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	30	31	32	33							
20	0.0 63.0	0.0 62.0	0.0 67.0	0.0 45.0	0.0 27.0	0.0 47.0	15.0 50.0	25.0 46.0	40.0 70.0	50.0 77.0	65.0 78.0	60.0 88.0	65.0 0.0	55.0	45.0	40.0	60.0	70.0	77.0	75.0
21	0.0 48.0	0.0 70.0	0.0 60.0	0.0 50.0	0.0 26.0	0.0 30.0	8.0 62.0	20.0 70.0	30.0 75.0	40.0 81.0	60.0 84.0	65.0 87.0	65.0 0.0	40.0	35.0	40.0	56.0	76.0	76.0	80.0
22	0.0 65.0	0.0 54.0	0.0 63.0	0.0 62.0	0.0 25.0	0.0 50.0	5.0 77.0	15.0 78.0	25.0 77.0	35.0 81.0	40.0 85.0	35.0 85.0	16.0 0.0	25.0	40.0	60.0	60.0	71.0	71.0	70.0
23	0.0 62.0	0.0 58.0	0.0 60.0	0.0 63.0	0.0 24.0	0.0 55.0	3.0 77.0	20.0 83.0	25.0 82.0	35.0 85.0	35.0 87.0	15.0 88.0	18.0 0.0	40.0	50.0	55.0	65.0	72.0	72.0	67.0
24	0.0 52.0	0.0 55.0	0.0 58.0	0.0 18.0	0.0 23.0	0.0 70.0	0.0 76.0	25.0 72.0	28.0 81.0	30.0 86.0	15.0 88.0	20.0 89.0	25.0 0.0	35.0	45.0	50.0	50.0	60.0	60.0	60.0
25	0.0 35.0	0.0 51.0	0.0 61.0	0.0 17.0	0.0 56.0	0.0 66.0	1.0 69.0	18.0 73.0	20.0 76.0	25.0 80.0	14.0 87.0	20.0 87.0	32.0 0.0	38.0	40.0	40.0	41.0	45.0	50.0	48.0
26	0.0 38.0	0.0 50.0	0.0 46.0	0.0 14.0	0.0 62.0	0.0 60.0	0.0 62.0	16.0 61.0	18.0 70.0	20.0 75.0	21.0 80.0	30.0 81.0	31.0 0.0	34.0	38.0	39.0	37.0	41.0	47.0	32.0
27	0.0 25.0	0.0 45.0	0.0 36.0	0.0 13.0	0.0 52.0	0.0 48.0	0.0 54.0	14.0 60.0	15.0 64.0	13.0 68.0	27.0 77.0	29.0 77.0	29.0 0.0	29.0	33.0	35.0	37.0	38.0	34.0	35.0
28	0.0 21.0	0.0 30.0	0.0 10.0	0.0 12.0	0.0 34.0	0.0 53.0	0.0 57.0	12.0 63.0	14.0 58.0	19.0 65.0	25.0 72.0	27.0 74.0	26.0 0.0	28.0	28.0	31.0	33.0	34.0	35.0	34.0
29	0.0 14.0	0.0 8.0	0.0 30.0	0.0 43.0	0.0 35.0	0.0 46.0	0.0 55.0	4.0 56.0	12.0 57.0	13.0 65.0	22.0 69.0	26.0 73.0	25.0 0.0	25.0	25.0	27.0	31.0	31.0	34.0	33.0
30	0.0 5.0	0.0 34.0	0.0 30.0	0.0 38.0	0.0 34.0	0.0 45.0	0.0 51.0	3.0 53.0	12.0 55.0	8.0 62.0	15.0 66.0	20.0 73.0	23.0 0.0	22.0	24.0	25.0	26.0	27.0	33.0	30.0
31	0.0 19.0	0.0 26.0	1.0 36.0	0.0 34.0	0.0 32.0	0.0 34.0	0.0 42.0	5.0 48.0	11.0 46.0	7.0 55.0	4.0 59.0	12.0 70.0	13.0 0.0	16.0	17.0	19.0	22.0	24.0	28.0	5.0
32	0.0 2.0	4.0 24.0	0.0 29.0	0.0 26.0	0.0 33.0	0.0 37.0	0.0 38.0	1.0 39.0	10.0 41.0	10.0 50.0	5.0 53.0	3.0 0.0	5.0 0.0	7.0	8.0	10.0	14.0	20.0	23.0	4.0
33	0.0 12.0	0.0 17.0	0.0 19.0	0.0 24.0	0.0 26.0	0.0 33.0	0.0 36.0	0.0 38.0	1.0 42.0	7.0 57.0	2.0 58.0	5.0 0.0	2.0 0.0	1.0	2.0	1.0	2.0	3.0	3.0	2.0
34	0.0 17.0	0.0 22.0	0.0 25.0	0.0 26.0	0.0 30.0	0.0 33.0	0.0 35.0	0.0 36.0	0.0 0.0	0.0 0.0	3.0 0.0	4.0 0.0	3.0 0.0	2.0	0.0	0.0	0.0	0.0	5.0	15.0
35	0.0 10.0	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 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0	0.0	0.0	0.0	1.0	6.0	16.0
36	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	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	0.0
37	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	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	0.0

Aquifer Transmissivity

Transmissivity of the Floridan aquifer is shown on figure 5. The map was based in part on the results of aquifer tests conducted at various sites in the study area. Test data included those available from published reports and from tests run by private consultants. All data were analyzed by the Geological Survey to provide consistency and uniformity to the interpretations. The value and distribution of transmissivity (fig. 5) were also based on interpretation of variations in the gradient of the potentiometric surface for September 1975 (fig. 4).

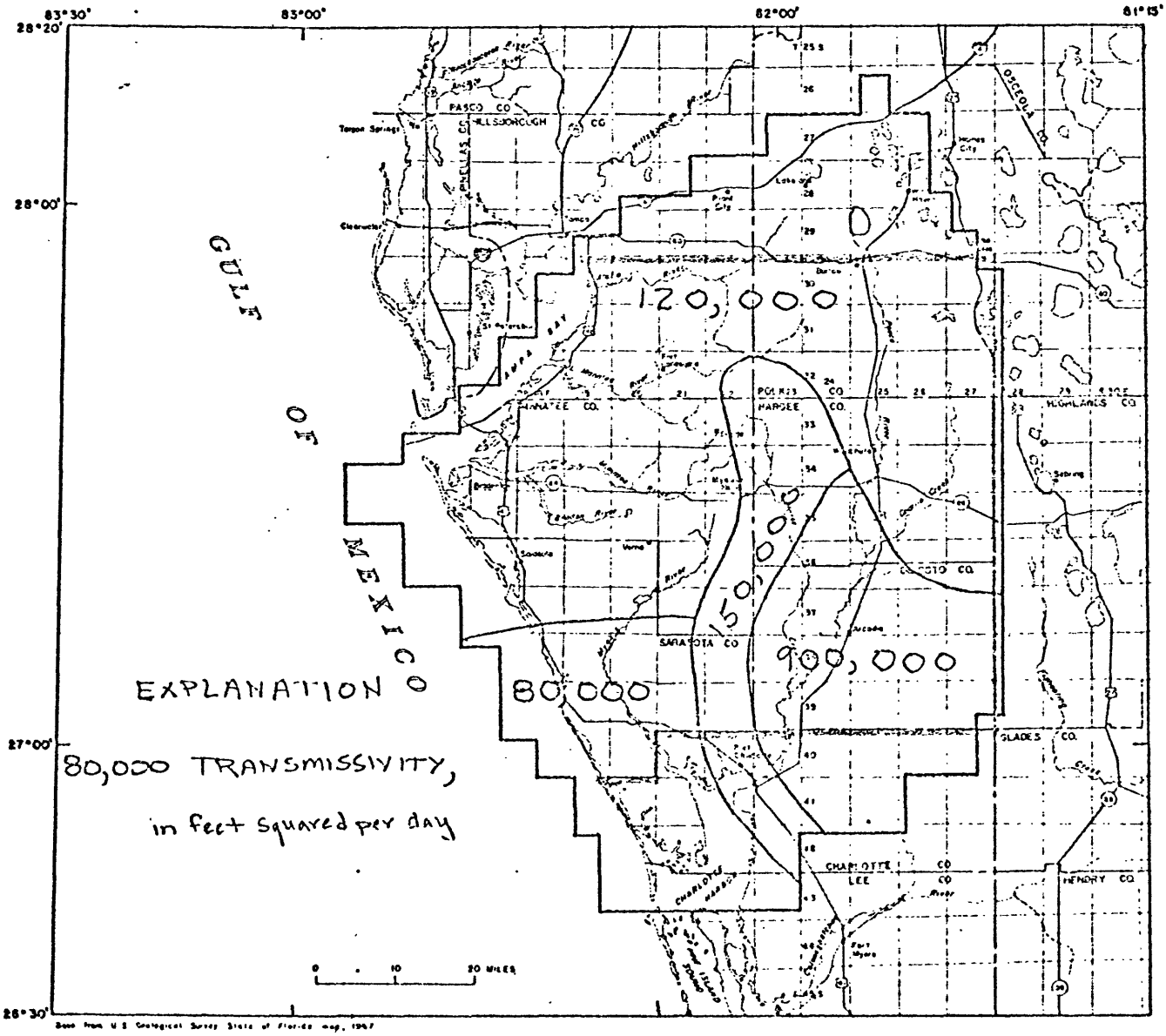
Confining-Bed Thickness

Thickness of the upper confining bed of the Floridan aquifer is shown on figure 6. The map was constructed from maps of the altitude of the top of the confining bed and of the top of the Floridan aquifer. Geologic logs of wells penetrating the full confining-bed thickness were used as additional control.

Vertical Hydraulic Conductivity of Confining Bed

Vertical hydraulic conductivity of the upper confining bed of the Floridan aquifer is shown on figure 7. Control data for mapping vertical hydraulic conductivity (K') were obtained by multiplying leakance coefficients (K'/b') from 7 aquifer tests in the study area by confining-bed thickness (b') at each aquifer test site as determined from figure 6. The initial map based on these control points was modified during the steady-state calibration to achieve an acceptable match between the simulated steady-state potentiometric surface and the September 1975 potentiometric surface. The resulting values of vertical hydraulic conductivity (fig. 7) are probably within the expected range of error of the original aquifer-test estimates.

The leakance coefficient of the upper confining bed of the Floridan aquifer is shown on figure 8. This parameter was determined at each node from the ratio of the confining-bed vertical hydraulic conductivity (fig. 7), and the confining-bed thickness (fig. 6).



Base from U.S. Geological Survey State of Florida map, 1967

Figure 5. Transmissivity of Floridan aquifer.

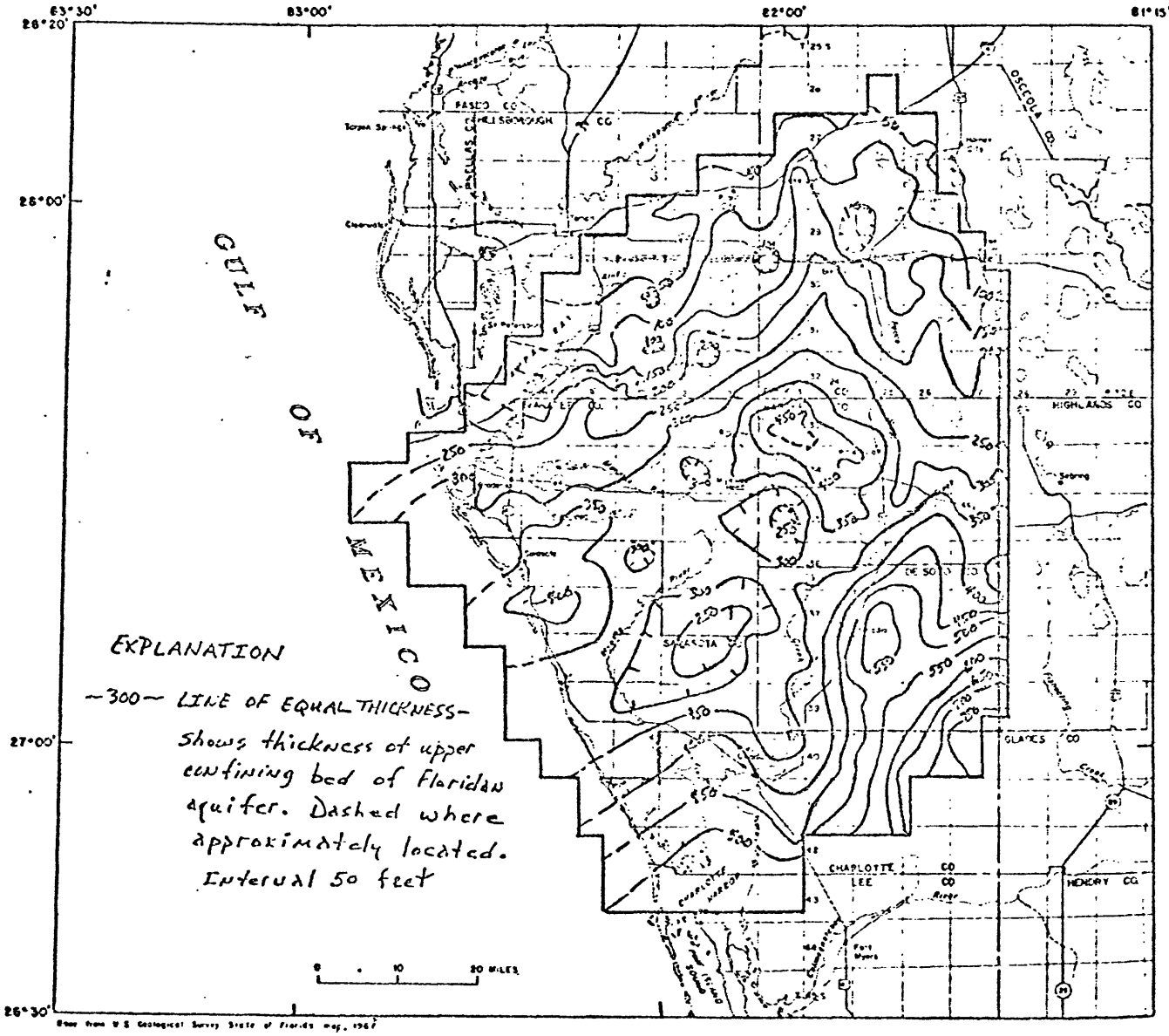


Figure 6.* Thickness of upper confining bed of Floridan aquifer.

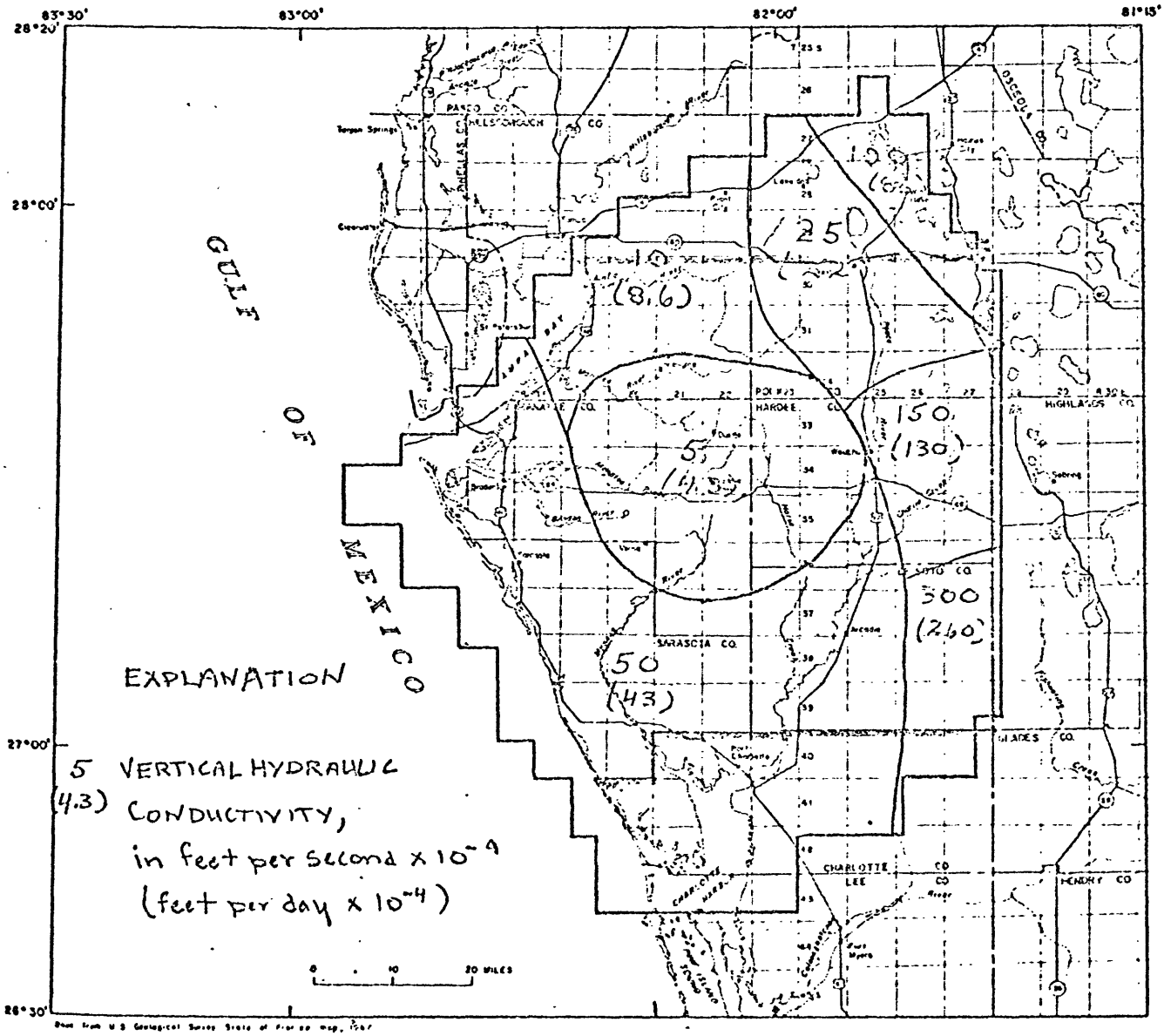


Figure 7. Vertical hydraulic conductivity of upper confining bed of Floridan aquifer.

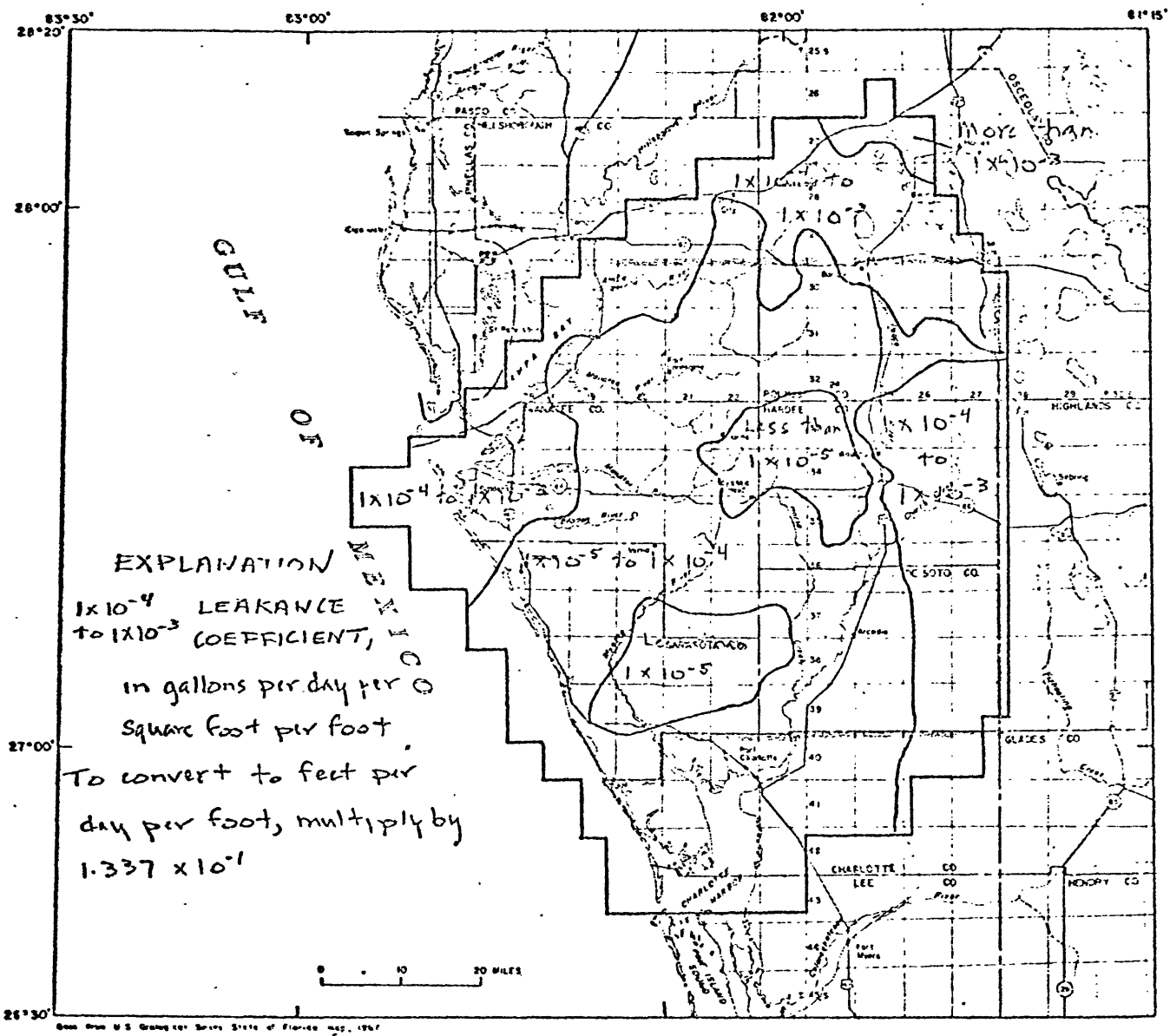


Figure 8. Leakance coefficient of upper confining bed of Floridan aquifer.

Results

The steady-state potentiometric surface simulating September 1975 conditions is shown on figure 9. This surface may be compared with the actual September 1975 potentiometric surface, as mapped on figure 4. Differences between computed and actual heads at nodes of the model grid ranged from 0 to 31.0 ft. The difference was less than 5 ft at 75 percent of the nodes, and more than 20 ft at 1 percent of the nodes. All differences greater than 10 ft occurred in the northern part of the modeled area, mostly in Polk County, and occurred in nodes where withdrawals were occurring, where the potentiometric gradient was relatively steep, and adjacent to boundaries.

A test was made to determine if the differences between the computed and actual heads could be accounted for by a likely range of error in the input parameters. The test thus provided a measure of the reasonableness of the calibration. Each of the three principal input parameters (transmissivity, vertical hydraulic conductivity, and ground-water withdrawal rates for phosphate and other industries) was independently changed by plus or minus a constant factor throughout the model, while all others were held at their calibration values. The range of values used differed for each parameter and reflected a subjective estimate of the likely range of error of each parameter. Withdrawals for municipal supplies were not included because of their probable small range of error.

The test results are shown along two profiles on figure 10. The profiles, taken north-south along column 23 and east-west along row 15 of the model, show the departure from actual September 1975 head for the calibrated model values and for each of the 6 test runs.

Figure 10 indicates that along most parts of these profiles the departure of the steady-state calibrated heads from the September 1975 measured heads could be reduced by varying one or more of the parameters within the ranges shown. The close spacing of the curves in the south, along row 23, indicates computed heads in this area are relatively insensitive to input parameters. However, for purposes of this analysis, departures in this area are in an acceptable range, generally less than 5 ft.

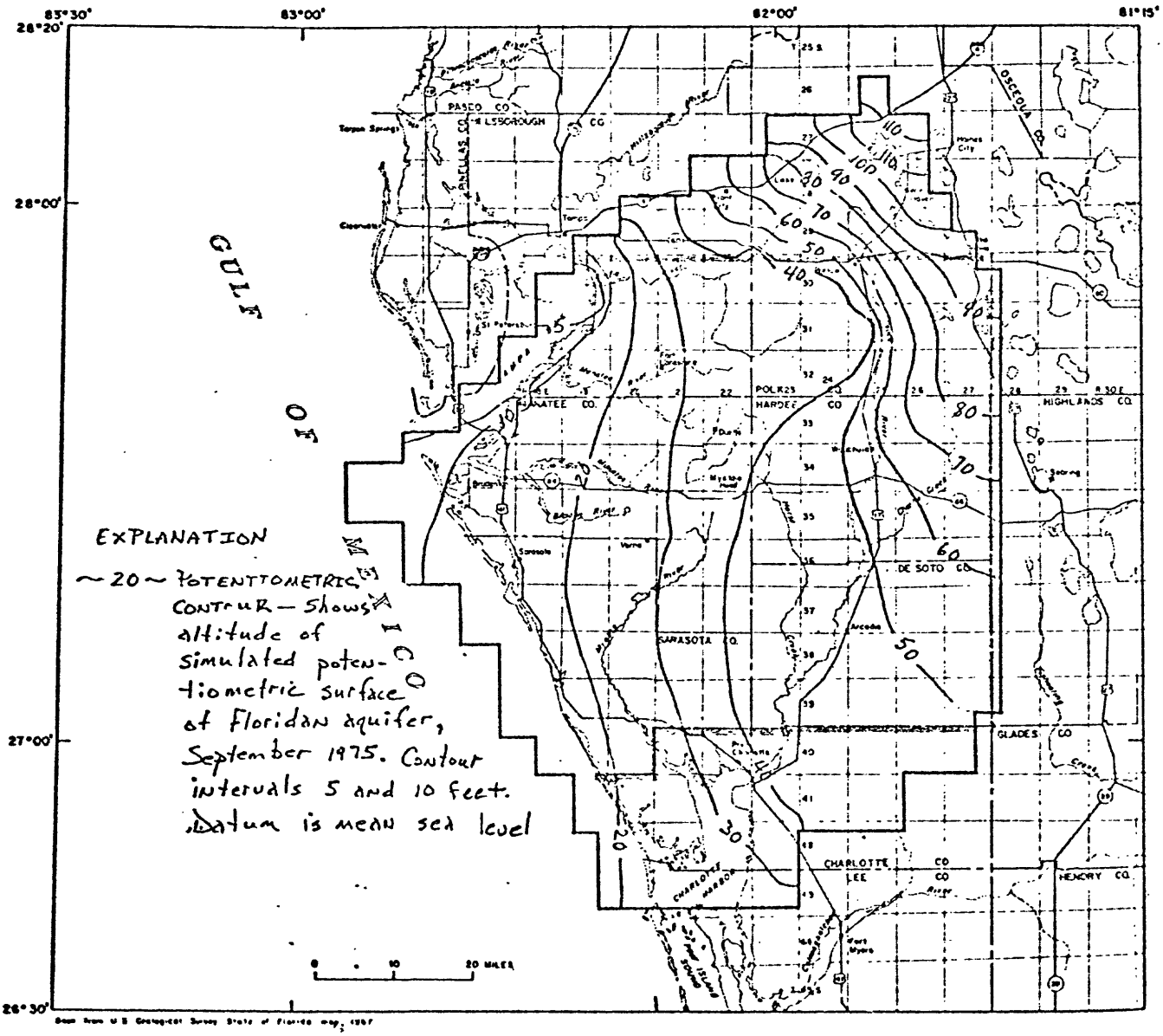


Figure 9. Simulated potentiometric surface of Floridan aquifer. September 1975.

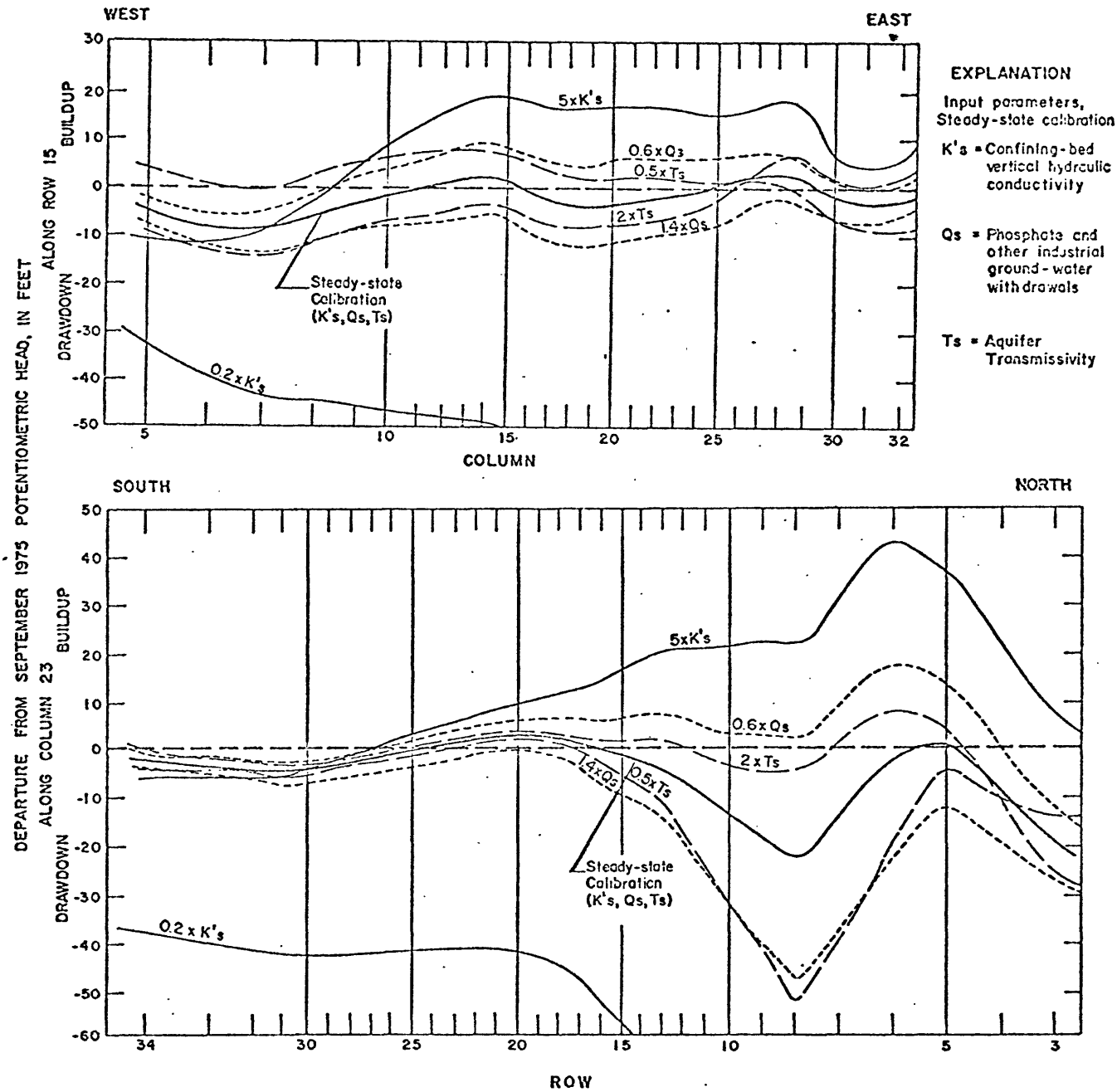


Figure 10. Effect of varying input parameters on steady-state calibration

SIMULATED CHANGES IN GROUND-WATER LEVELS

A transient model analysis was used to simulate changes in the potentiometric surface resulting from proposed ground-water developments by the phosphate industry. The transient analysis was based on transmissivity and leakance values derived from the calibrated steady-state model, with the addition of assumed storage parameters. The model boundary was changed from no-flow to constant-head. A transient calibration is not shown, because that would require an evaluation of ground-water withdrawals for irrigation, and such an evaluation was beyond the scope of this preliminary report. Thus, a critical assumption is that the transient behavior of the aquifer can be adequately simulated by simply adding storage parameters to and modifying boundary conditions of the steady-state model configuration.

Two plans for development were considered in the transient analysis: (1) an existing-mines plan, which is a continuation and eventual phasing out of existing phosphate mines, and (2) a proposed-mines plan, which is a continuation of existing phosphate mines plus the introduction of all proposed mines. The transient model was used to simulate projected changes in the potentiometric surface resulting from each development plan for both 1985 and 2000. No assessment was made of the accuracy of the simulated changes.

Input Parameters for Transient Analysis

The input parameters in the September 1975 steady-state model were used unchanged in the transient analysis, except that all nodes adjacent to the boundary were changed to constant-head, storage coefficients were added, and ground-water stresses appropriate to each development plan were applied. The initial condition for the transient analysis is the configuration of the simulated potentiometric surface in September 1975; that surface represents an equilibrium condition, when pumping draft is balanced by leakage through the upper confining layer, and where water levels do not change with time. The results of the transient analyses, then, show the singular effects of changes of mine pumpage on changes of water levels from the presumed September 1975 equilibrium.

Boundaries

The position of the model boundary for the transient analysis is the same as for the steady-state calibration. However, in the transient analysis, the entire boundary was designated as constant-head instead of no-flow. The boundary conditions were approximated by holding the potentiometric head constant in the nodes immediately inside the boundary, and thus allowing flow to occur into or out of the modeled area if so dictated by the gradients of the potentiometric surface in adjacent nodes. The constant-head values used were the same as the heads in the boundary nodes of the calibrated steady-state model. As with the steady-state model, simulation of head is less accurate near the constant-head nodes than elsewhere in the model. However, the principal areas of interest, where the greatest amounts of ground-water development and head changes are likely to occur, are away from the boundary nodes.

Nodes along inland segments of the boundary were made constant-head because new stresses on the aquifer system would probably shift the potentiometric contour lines such that the model boundary would no longer approximate ground-water divides. Shifting of the contour lines along the divides is indicated in May potentiometric maps (see, for example, Stewart, Laughlin, and Mills, 1976) which reflect the seasonal stresses of irrigation withdrawals.

Nodes along the coastal segments of the boundary were also designated constant-head instead of no-flow. New stresses to the aquifer system imposed during trainsient conditions would disrupt the steady-state conditions of September 1975, and would probably eventually cause the saltwater-freshwater interface to move eastward. The model cannot simulate the rate of movement and changing position of the interface. Furthermore, any pressure changes associated with changes in potentiometric head due to the newly imposed stresses would be transmitted to all continuous parts of the aquifer, regardless of whether those parts contained saltwater or freshwater. Thus, under transient conditions, the simulation of potentiometric head was assumed to be unaffected by the existence of a saltwater-freshwater interface. Placement of a constant-head boundary along the coastal nodes allowed flow of water across the boundary, thereby approximating the non-steady hydraulic response of the actual flow system.

Storage Coefficients

Storage coefficient of the Floridan aquifer is shown on figure 11. Storage coefficient was determined from the product of an assumed average specific storage of 1.0×10^{-6} ft^{-1} times thickness of the Floridan aquifer, shown on figure 12. Thickness of the Floridan aquifer is highly generalized and was determined from preliminary contour maps of the top and base of the Floridan aquifer.

Storage coefficient of the upper confining bed of the Floridan aquifer is shown on figure 13. Storage coefficient was determined from the product of an assumed average specific storage of 1.0×10^{-5} ft^{-1} times the confining-bed thickness (fig. 6).

Ground-Water Withdrawals

In the transient analyses, projections of the withdrawal rates and durations for existing and proposed mines were used to project changes in the potentiometric surface to be expected during 1975-85 and 1975-2000. Existing mines are those that were in production as of August 1976; proposed mines are those that plan to begin operations after that date. In both the existing-mines and proposed-mines plans, all chemical-plant withdrawal rates were assumed to continue unchanged through 2000, and municipal and other industrial withdrawal rates used in the steady-state calibration were held constant throughout the time spans of the transient analyses.

The rates of ground-water withdrawal and expected life spans of existing mines are shown on figure 14. The initial rates shown are the same as used for the steady-state calibration (table 1), except that an additional 19.87 Mgal/d at 5 nodes was included on figure 14 for "existing" mines that began operations after 1975. As the ore being extracted by the existing mines is depleted, ground-water withdrawals will decrease. In 1985, withdrawals for existing mines are projected to decline to 143 Mgal/d; by 2000, the rates will decline to about 8.2 Mgal/d. Data for the projected life spans of the mines were provided by Texas Instruments, Inc. (William Underwood, written commun., 1977).

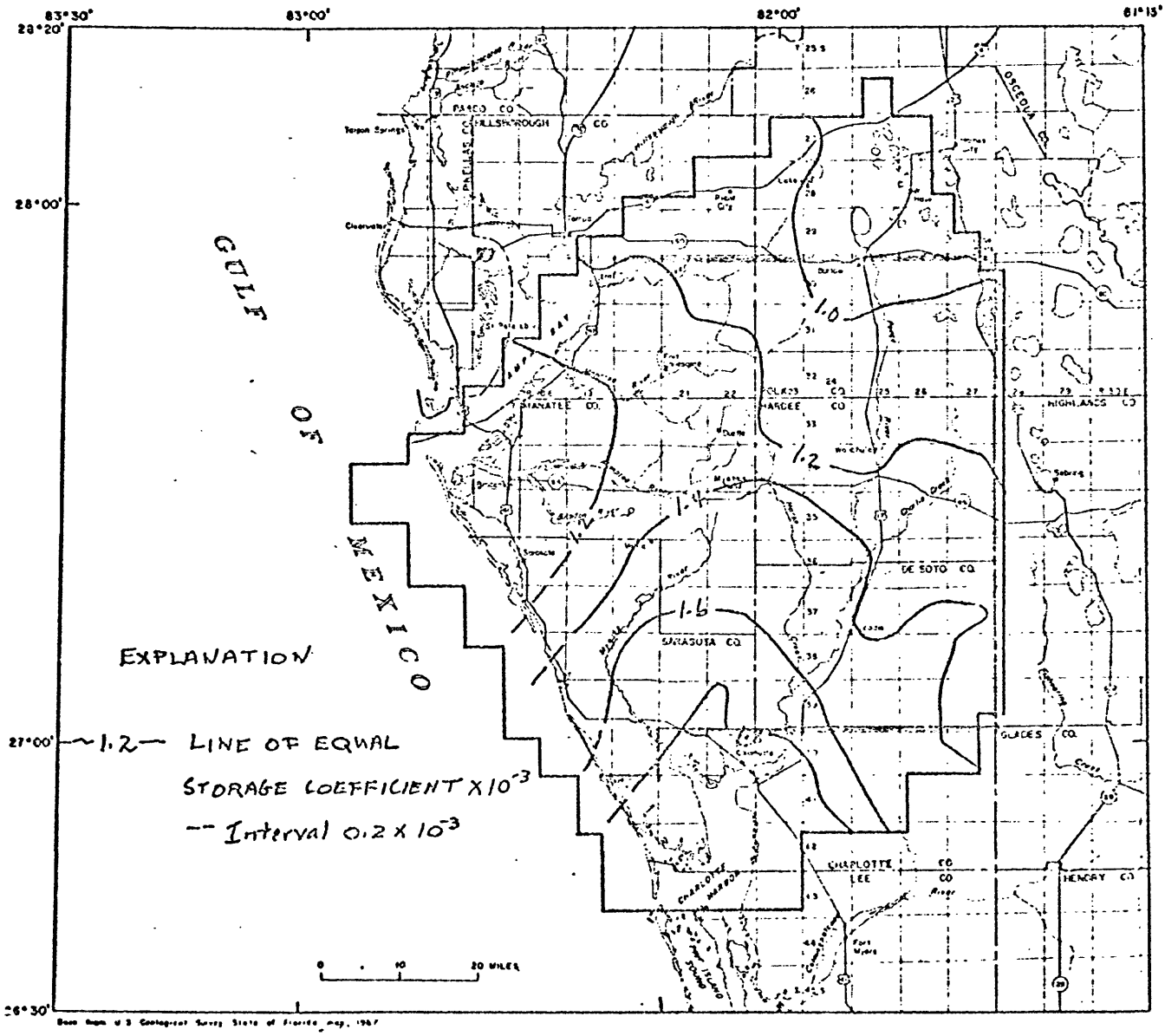


Figure 11. Storage coefficient of Floridan aquifer.

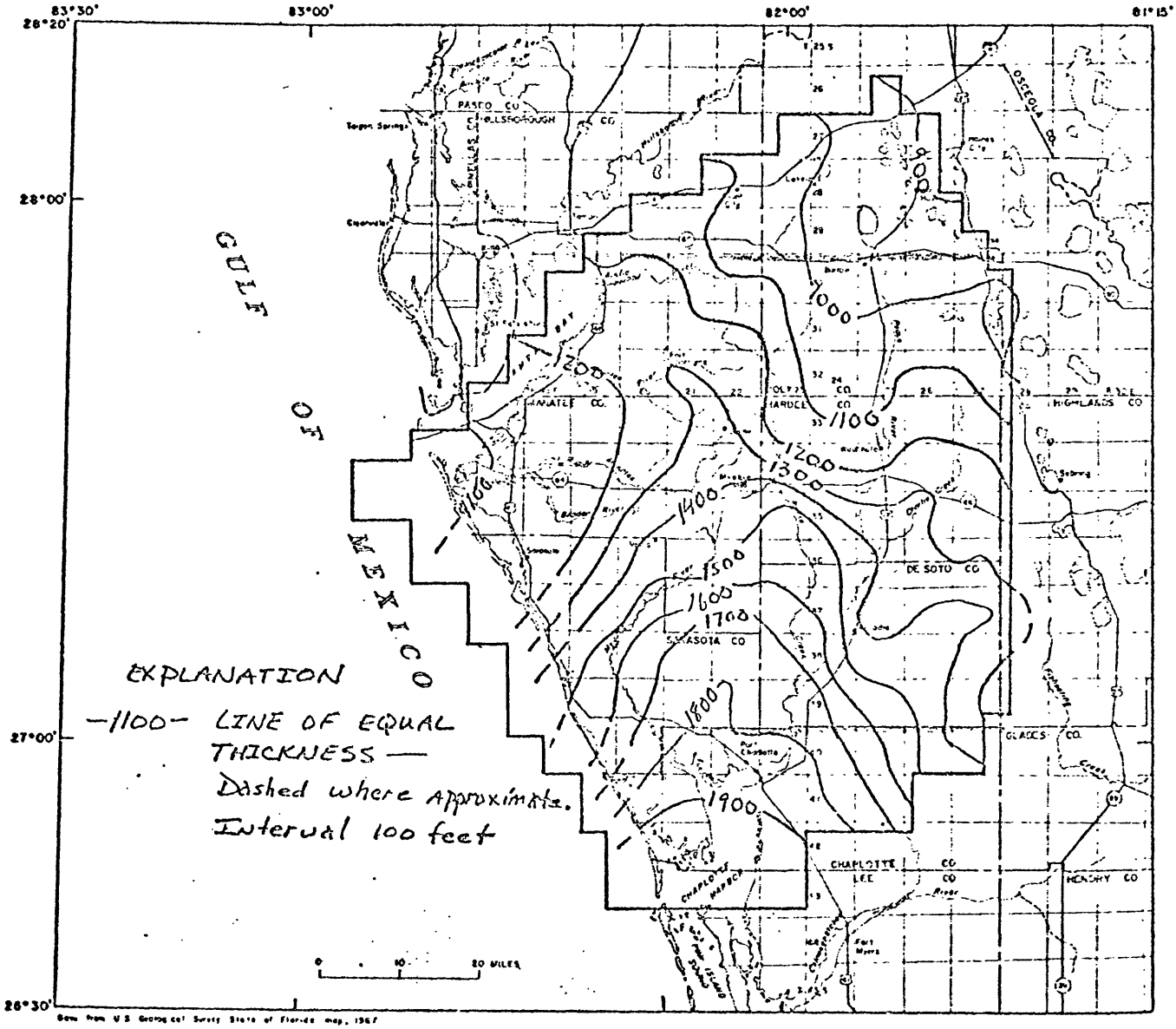


Figure 12. Thickness of Floridan aquifer.

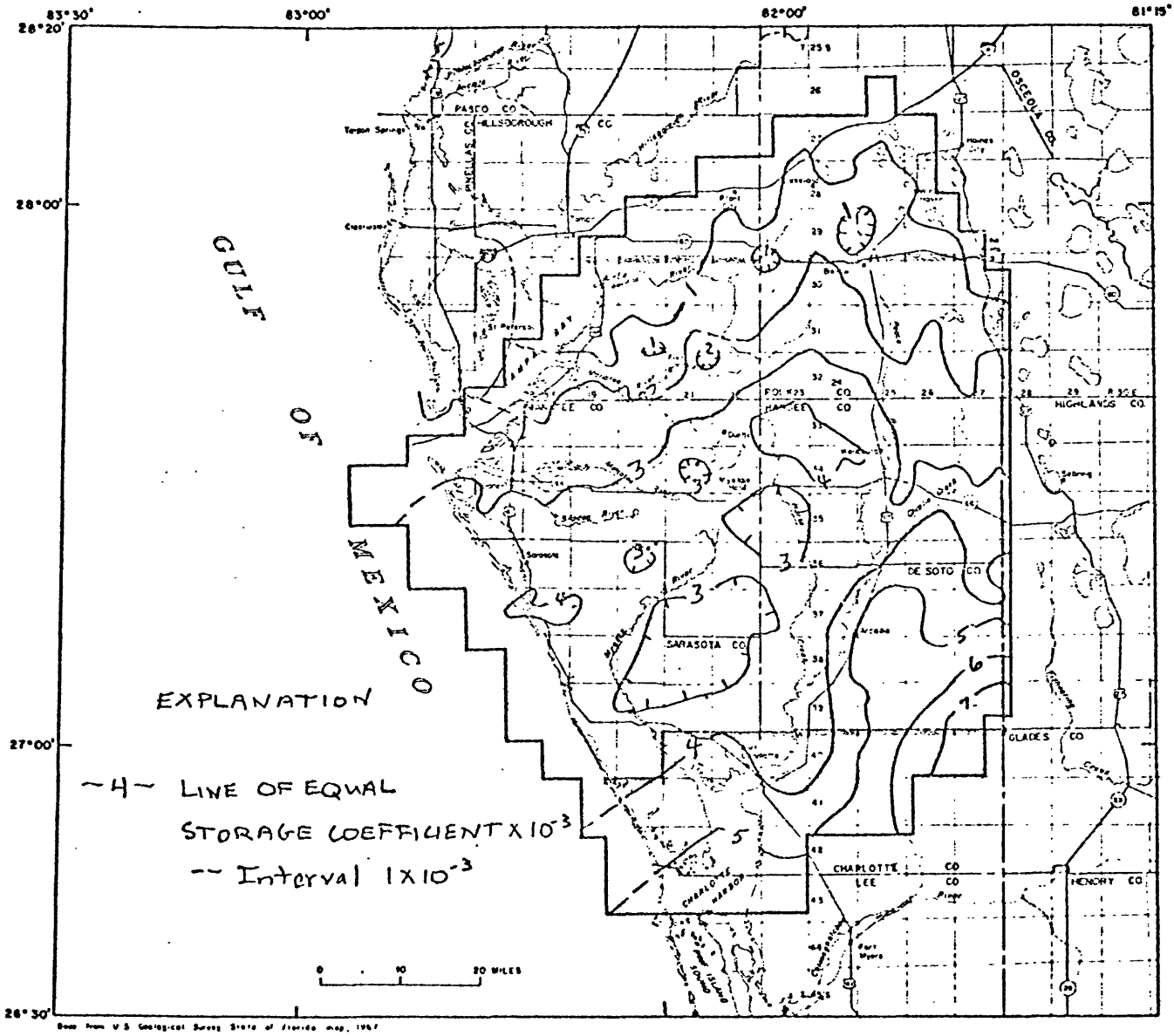


Figure 13. Storage coefficient of upper confining bed of Floridan aquifer.

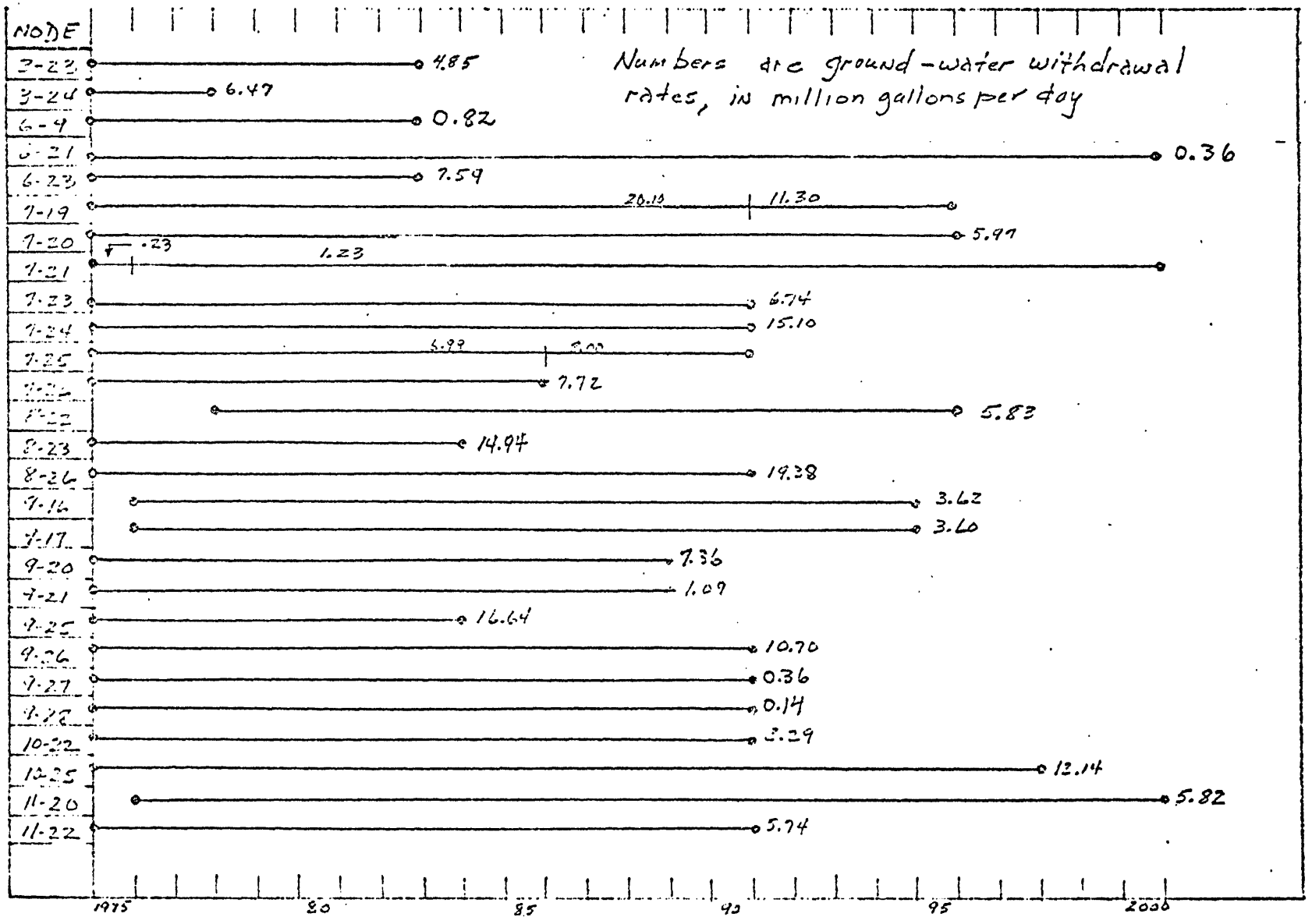


Figure 14. Projected history of ground-water withdrawal rates for existing phosphate mines. Data for life spans of mines from Texas Instruments, Inc. (William Underwood, written commun., 1977).

The rates of ground-water withdrawal and expected life spans of proposed mines are shown on figure 15. In this development plan, these withdrawal rates and durations were superimposed on those of the existing-mines plan. In 1985, the withdrawal rates for proposed mines are expected to be about 82 Mgal/d; by 2000, the rates are expected to increase to 155 Mgal/d. The projected withdrawal rates and life spans of the proposed mines were provided by Texas Instruments, Inc. (William Underwood, written commun., 1977).

The assignment of nodes to proposed-mine withdrawal sites was determined by overlaying the model grid on a map showing areas of proposed mines. Where a mine included more than one node, a single node was arbitrarily selected to represent the site of all the mine's withdrawals. Actual well locations may differ from those selected, but this difference should not significantly affect the regional distribution or amount of head change.

Effects of Phosphate Development

Simulated changes in potentiometric heads resulting from the existing-mines and proposed-mines development plans, projected for 1975-85 and 1975-2000, are given in tables 3-6. Maps showing the changes indicated by the data in these tables are shown on figures 16-19. The positions of the lines of equal change on these maps are based on linear interpolations between data points, plotted at the centers of the blocks. In the computer printouts of tables 3-6, rises in potentiometric head are shown with minus (-) signs; in the maps of figures 16-19, the signs are reversed, and lines of equal decline are shown with minus (-) signs, as a matter of convention.

Tables 3 and 4 and figures 16 and 17 show that in the existing-mines plan the potentiometric surface generally recovers as the withdrawal rates decrease. The maximum amount of predicted recovery for 1985 is 11.9 ft (table 3), and the maximum amount predicted for 2000 is 36.5 ft (table 4), both at node 9-25. In some areas, drawdown rather than recovery is predicted to occur in 1985 as a result of the addition of new withdrawals for existing mines not in operation in 1975. Maximum predicted drawdown is 2.8 ft, in node 9-16 (table 3).

The simulated changes in potentiometric head shown in figures 16 and 17 may be superimposed on the September 1975 potentiometric map (fig. 4) to derive September 1985 and September 2000 potentiometric-level maps.

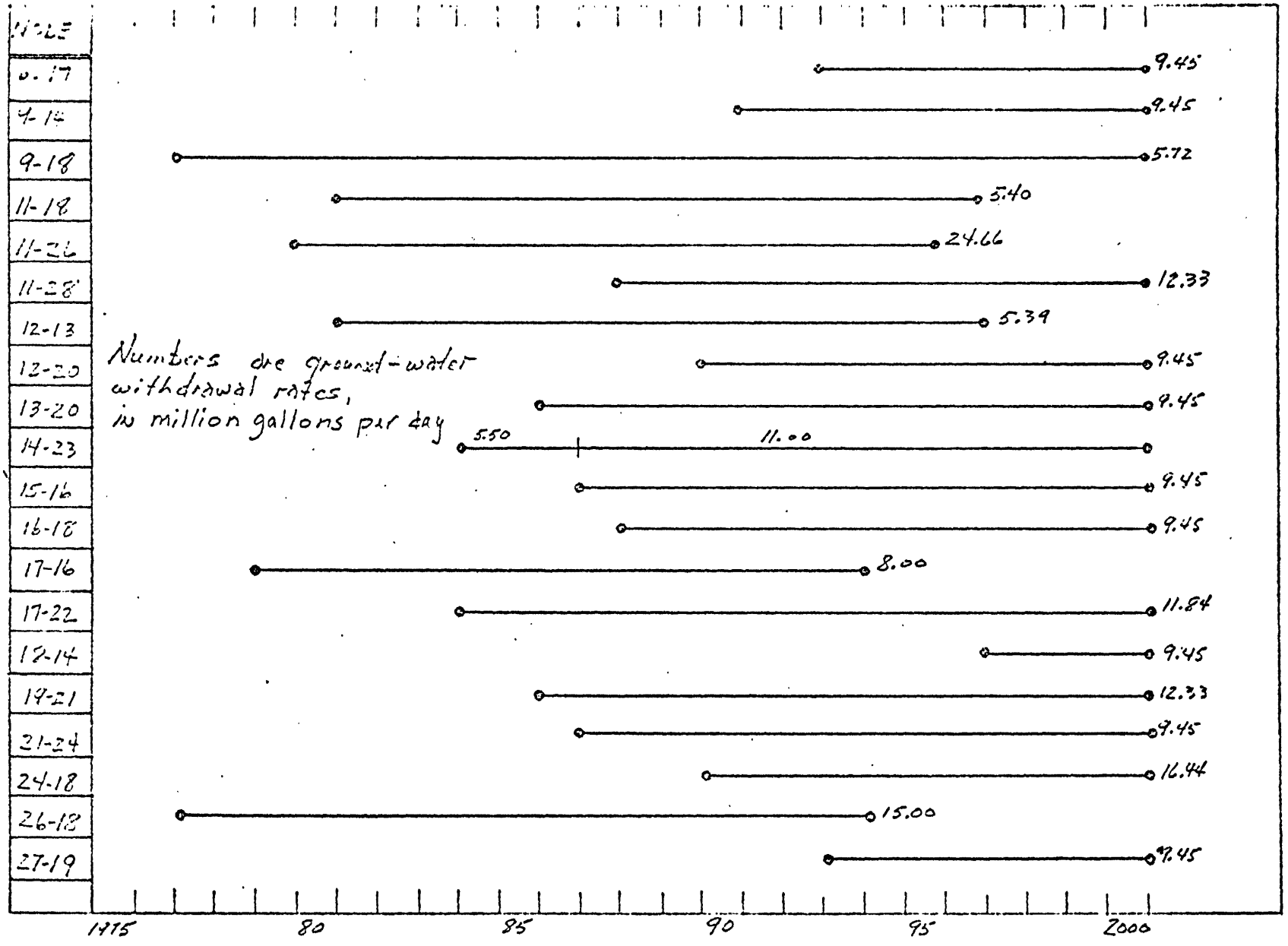


Figure 15. Projected history of ground-water withdrawal rates for proposed phosphate mines. Data for projected withdrawal rates and life spans of mines from Texas Instruments, Inc. (William Undersood, written commun., 1977).

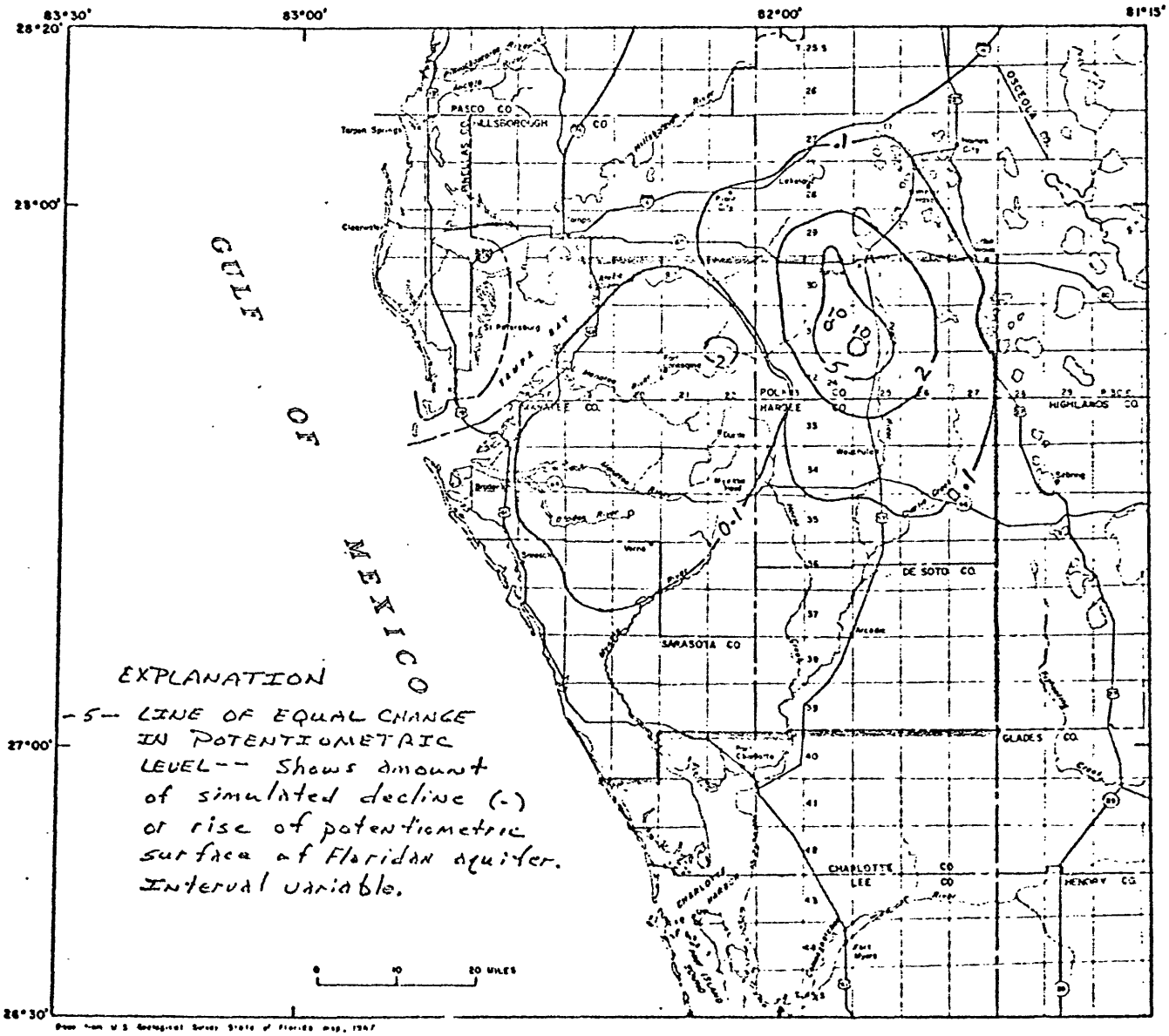


Figure 16. Simulated changes in potentiometric surface, existing-mines development plan, 1975-85.

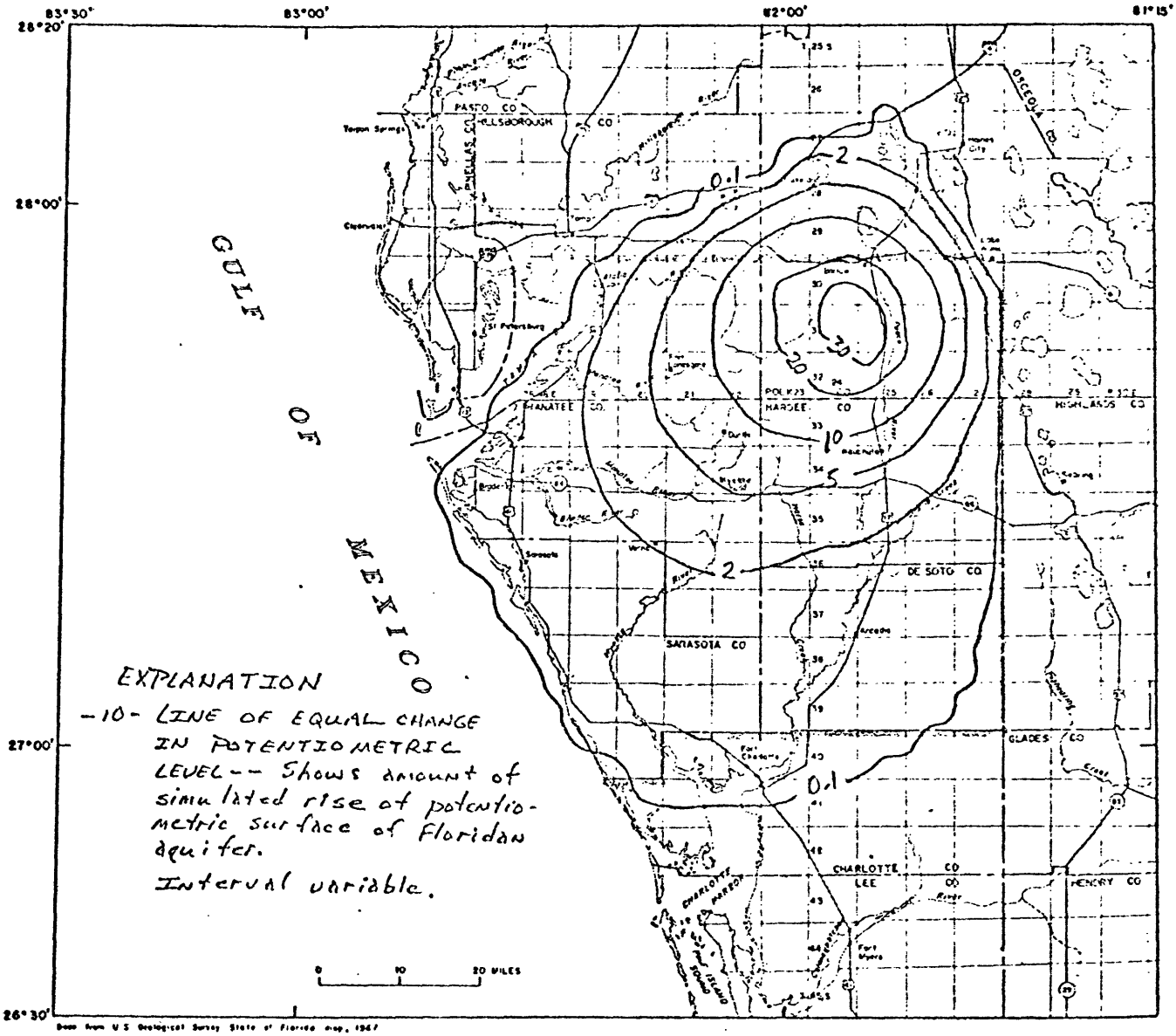


Figure 17. Simulated changes in potentiometric surface, existing-mines development plan, 1975-2000.

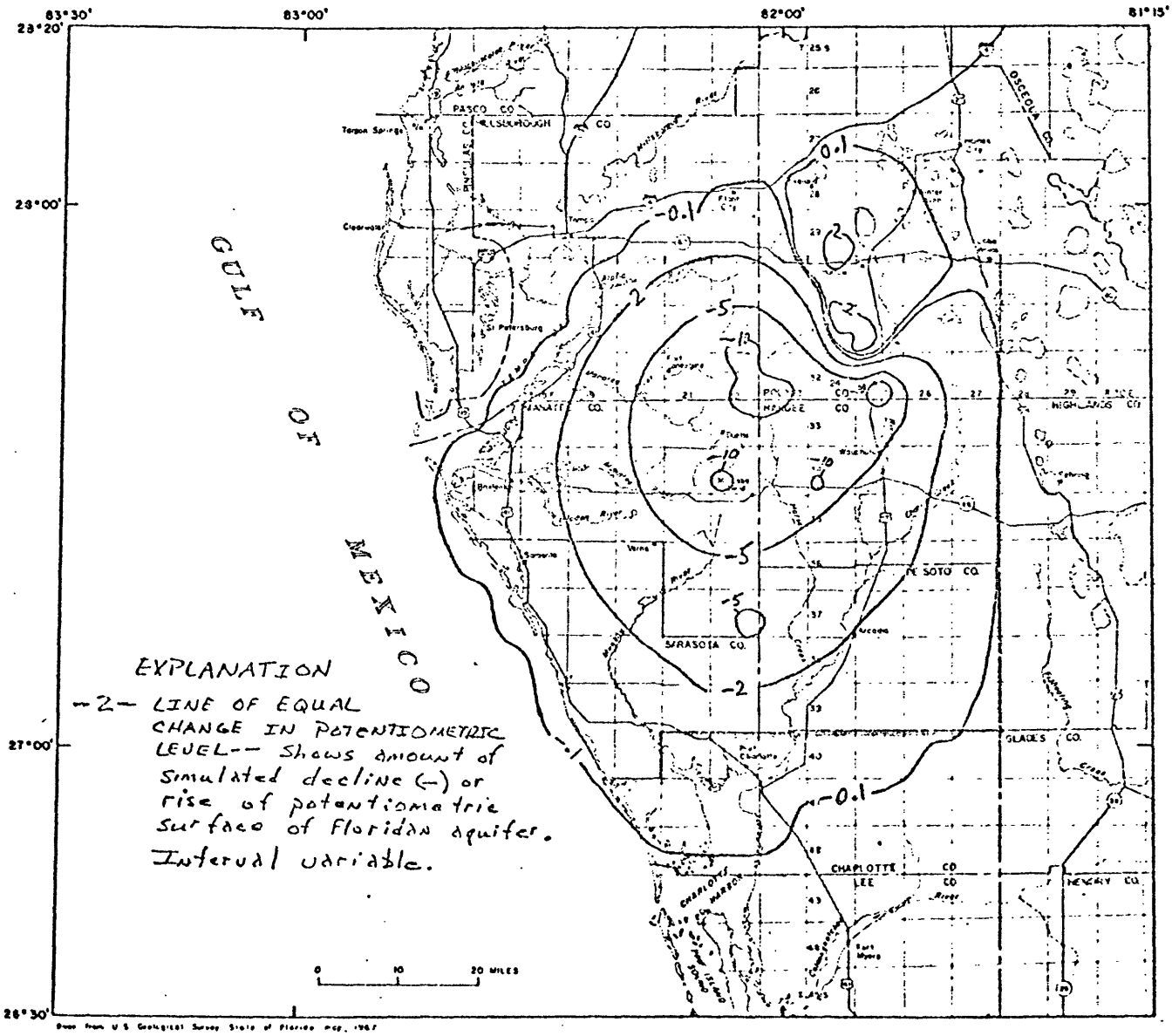


Figure 18. Simulated changes in potentiometric surface, proposed-mines development plan, 1975-85.

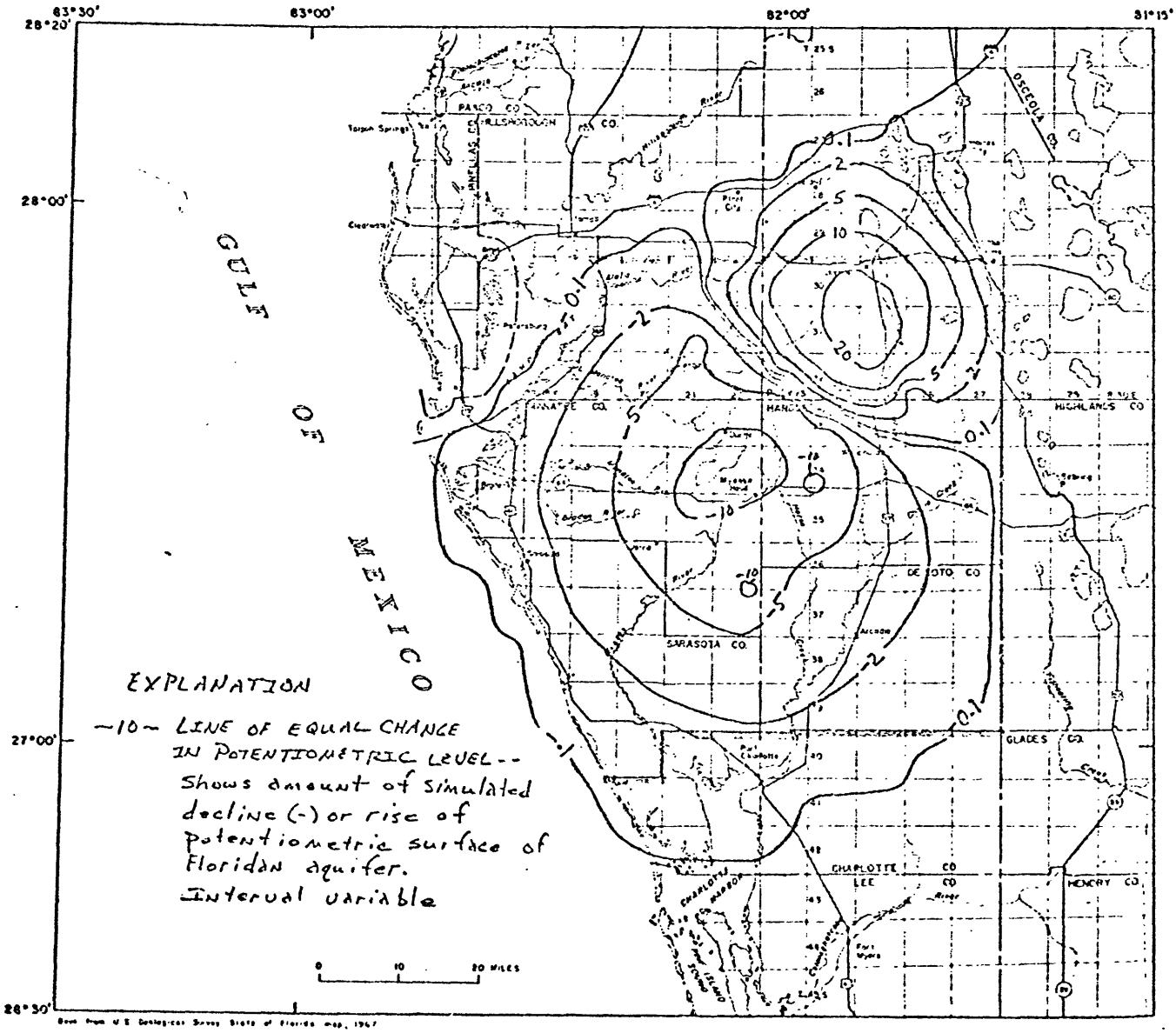


Figure 19. Simulated changes in potentiometric surface, proposed-mines development plan, 1975-2000.

Table 3. -- Simulated changes in potentiometric heads, existing-mines development plan, 1975-85

DRAWDOWN OR RECOVERY (-), IN FEET

ROW \ COLUMN	1	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	30	31	32	33							
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	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	0.0							
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	0.0	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	0.0	0.0							
3	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	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	-0.1	-0.1	0.0	0.0	0.0	0.0	0.0	0.0							
4	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	0.0	0.0	0.0	-0.3
	-0.5	-0.7	-0.8	-0.8	-0.7	-0.6	-0.4	-0.3	0.0	0.0	0.0	0.0	0.0							
5	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	-0.3	-0.4	-0.6	-0.9	-1.2
	-1.6	-1.9	-2.2	-2.1	-1.8	-1.6	-1.2	-0.9	-0.5	0.0	0.0	0.0	0.0							
6	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	-0.4	-0.6	-1.0	-1.5	-2.1
	-3.0	-4.1	-5.6	-4.5	-3.7	-3.0	-2.4	-1.9	-1.2	-0.6	0.0	0.0	0.0							
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.3	0.3	0.2	0.1	-0.2	-0.7	-1.3	-2.0
	-2.8	-4.0	-5.2	-5.3	-5.0	-4.4	-3.6	-2.9	-2.1	-1.2	-0.5	0.0	0.0							
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.5	0.7	0.8	1.0	1.1	0.8	0.1	-0.7	-1.7
	-2.9	-4.3	-10.2	-8.4	-7.8	-6.3	-4.9	-3.7	-2.5	-1.5	-0.7	0.0	0.0							
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.5	0.7	0.9	1.2	1.8	2.8	2.6	1.0	-0.1	-1.1
	-2.4	-4.1	-4.5	-8.5	-11.9	-7.7	-5.3	-3.8	-2.5	-1.5	-0.7	0.0	0.0							
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.5	0.7	0.9	1.1	1.3	1.5	1.4	0.9	0.4	-0.1
	-1.3	-2.4	-4.0	-5.2	-5.8	-5.1	-4.0	-3.1	-2.1	-1.2	-0.6	0.0	0.0							
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.5	0.6	0.8	0.9	1.0	1.1	1.0	0.9	0.9	1.7
	-0.3	-1.1	-2.5	-3.3	-3.6	-3.4	-2.9	-2.3	-1.4	-1.0	-0.5	0.0	0.0							
12	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.9	0.8	0.7	0.7	0.6
	-0.3	-1.1	-1.7	-2.2	-2.5	-2.4	-2.1	-1.8	-1.3	-0.8	-0.4	0.0	0.0							
13	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.3	0.5	0.5	0.6	0.7	0.7	0.7	0.7	0.6	0.4	0.2
	-0.3	-0.6	-1.2	-1.5	-1.7	-1.7	-1.5	-1.3	-1.0	-0.6	-0.3	0.0	0.0							
14	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.3	0.4	0.5	0.6	0.6	0.6	0.6	0.5	0.4	0.3	0.0
	-0.3	-0.6	-0.9	-1.1	-1.2	-1.2	-1.1	-1.0	-0.8	-0.5	-0.2	0.0	0.0							
15	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.3	0.4	0.5	0.5	0.5	0.5	0.5	0.4	0.3	0.2	-0.0
	-0.2	-0.4	-0.6	-0.7	-0.8	-0.8	-0.8	-0.7	-0.6	-0.4	-0.2	0.0	0.0							
16	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.2	0.1	-0.0
	-0.1	-0.3	-0.4	-0.4	-0.4	-0.5	-0.5	-0.5	-0.4	-0.3	-0.1	0.0	0.0							
17	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.4	0.3	0.2	0.2	0.1	0.0
	-0.1	-0.2	-0.2	-0.2	-0.2	-0.3	-0.3	-0.3	-0.3	-0.2	-0.1	0.0	0.0							
18	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.1	0.1	0.0
	-0.0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.2	-0.2	-0.2	-0.1	-0.1	0.0	0.0							
19	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.1	0.1	0.0
	-0.0	-0.0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.0	0.0	0.0							
20	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.0

Table 3. -- Simulated changes in potentiometric heads, existing-mines development plan, 1975-85 (continued)

DRAWDOWN OR RECOVERY (-), IN FEET

ROW \ COLUMN	1	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	30	31	32	33							
	0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.1	-0.1	-0.1	-0.0	0.0	0.0							
21	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	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							
22	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	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							
23	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	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							
24	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0							
25	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0
	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0							
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0							
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0							
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0							
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0							
30	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	0.1	0.1	0.1	0.1	0.1	0.1
	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0							
31	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	0.1	0.1	0.1	0.1	0.1
	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
32	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	0.1	0.1	0.1	0.1
	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
33	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	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	0.0							
34	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	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	0.0							
35	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	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	010	0.0	0.0	0.0	0.0	0.0							
36	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	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	0.0							
37	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	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	0.0							

Table 4. -- Simulated changes in potentiometric heads, existing-mines development plan, 1975-2000

DRAWDOWN OR RECOVERY (-), IN FEET

ROW \ COLUMN	1	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	30	31	32	33							
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	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	0.0							
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	0.0	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	0.0	0.0							
3	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	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	-0.3	-0.3	0.0	0.0	0.0	0.0	0.0	0.0							
4	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	0.0	0.0	0.0	-1.4
	-2.6	-3.2	-3.5	-3.4	-3.1	-2.7	-2.1	-1.3	0.0	0.0	0.0	0.0	0.0							
5	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	-1.6	-2.8	-3.9	-4.9	-5.9	-7.0
	-8.0	-8.8	-9.2	-9.1	-8.4	-7.4	-6.0	-4.5	-2.5	0.0	0.0	0.0	0.0							
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.2	-2.1	-2.9	-3.9	-5.2	-6.7	-8.3	-10.1	-11.8	-13.7
	-15.5	-17.4	-19.7	-18.7	-17.3	-15.3	-12.8	-10.1	-6.7	-3.2	0.0	0.0	0.0							
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.9	-1.7	-2.8	-3.9	-5.1	-6.4	-8.1	-10.0	-12.4	-15.4	-19.4	-21.-
	-23.3	-26.3	-30.5	-32.9	-31.0	-27.8	-22.0	-17.0	-11.7	-6.8	-2.8	0.0	0.0							
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.4	-2.4	-3.6	-4.8	-6.0	-7.3	-9.0	-10.8	-13.1	-15.7	-18.6	-21.7
	-24.6	-28.6	-34.7	-33.8	-34.5	-35.7	-26.5	-19.8	-13.4	-7.9	-3.6	0.0	0.0							
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.6	-1.8	-2.8	-4.0	-5.2	-6.3	-7.6	-9.1	-10.8	-12.4	-15.2	-18.1	-22.3
	-23.7	-26.1	-29.0	-31.8	-36.5	-33.3	-25.2	-19.0	-12.9	-7.6	-3.5	0.0	0.0							
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	-2.1	-3.0	-4.1	-5.3	-6.3	-7.5	-8.8	-10.2	-11.9	-13.6	-15.4	-17.5
	-19.8	-22.6	-24.2	-26.2	-29.0	-24.5	-19.8	-15.5	-10.7	-6.4	-3.0	0.0	0.0							
11	0.0	0.0	0.0	0.0	0.0	0.0	-0.3	-1.2	-2.2	-3.1	-4.1	-5.2	-6.1	-7.1	-8.2	-9.5	-10.7	-12.0	-13.0	-13.5
	-16.7	-19.8	-19.8	-20.2	-20.2	-17.9	-15.0	-12.1	-8.6	-5.3	-2.5	0.0	0.0							
12	0.0	0.0	0.0	0.0	0.0	0.0	-0.5	-1.3	-2.2	-3.1	-4.1	-5.0	-5.8	-6.7	-7.7	-8.8	-9.9	-10.8	-11.8	-12.7
	-14.4	-15.8	-16.1	-16.1	-15.4	-13.9	-11.9	-9.8	-7.2	-4.5	-2.1	0.0	0.0							
13	0.0	0.0	0.0	0.0	0.0	0.0	-0.6	-1.3	-2.2	-3.0	-3.9	-4.7	-5.5	-6.3	-7.1	-8.1	-9.0	-9.8	-10.5	-11.3
	-12.2	-12.9	-13.1	-12.8	-12.1	-10.9	-9.4	-7.8	-5.9	-3.7	-1.8	0.0	0.0							
14	0.0	0.0	0.0	0.0	0.0	-0.1	-0.6	-1.4	-2.2	-2.9	-3.7	-4.5	-5.1	-5.8	-6.5	-7.3	-8.1	-8.7	-9.3	-9.8
	-10.3	-10.6	-10.6	-10.2	-9.6	-8.6	-7.4	-6.3	-4.8	-3.1	-1.5	0.0	0.0							
15	0.0	0.0	0.0	0.0	0.0	-0.2	-0.7	-1.4	-2.1	-2.8	-3.5	-4.1	-4.7	-5.3	-5.9	-6.5	-7.1	-7.6	-8.0	-8.4
	-8.6	-8.7	-8.5	-8.0	-7.4	-6.6	-5.8	-5.0	-3.9	-2.5	-1.2	0.0	0.0							
16	0.0	0.0	0.0	0.0	-0.0	-0.3	-0.7	-1.3	-2.0	-2.6	-3.2	-3.8	-4.3	-4.8	-5.3	-5.8	-6.2	-6.6	-6.9	-7.0
	-7.1	-6.9	-6.6	-6.0	-5.2	-5.0	-4.5	-3.9	-3.1	-2.1	-1.0	0.0	0.0							
17	0.0	0.0	0.0	0.0	-0.1	-0.3	-0.7	-1.3	-1.9	-2.4	-3.0	-3.4	-3.8	-4.3	-4.7	-5.1	-5.4	-5.7	-5.8	-5.9
	-5.7	-5.4	-4.9	-4.1	-3.6	-3.7	-3.5	-3.1	-2.5	-1.7	-0.8	0.0	0.0							
18	0.0	0.0	0.0	0.0	-0.1	-0.3	-0.7	-1.2	-1.7	-2.2	-2.7	-3.1	-3.4	-3.8	-4.1	-4.4	-4.7	-4.8	-4.9	-4.8
	-4.6	-4.2	-3.5	-3.1	-3.1	-2.9	-2.8	-2.5	-2.0	-1.4	-0.7	0.0	0.0							
19	0.0	0.0	0.0	0.0	-0.0	-0.3	-0.6	-1.1	-1.6	-2.0	-2.4	-2.8	-3.0	-3.3	-3.6	-3.8	-4.0	-4.1	-4.0	-3.9
	-3.4	-3.2	-2.7	-2.7	-2.6	-2.4	-2.3	-2.0	-1.6	-1.1	-0.6	0.0	0.0							
20	0.0	0.0	0.0	0.0	0.0	-0.3	-0.6	-1.0	-1.4	-1.8	-2.1	-2.4	-2.7	-2.9	-3.1	-3.3	-3.4	-3.4	-3.3	-3.2

Table 4. -- Simulated changes in potentiometric heads, existing-mines development plan, 1975-2000 (continued)

DRAWDOWN OR RECOVERY(-), IN FEET

ROW \ COLUMN	1	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	30	31	32	33							
	-2.9	-2.5	-2.4	-2.3	-2.3	-2.2	-1.9	-1.7	-1.4	-0.9	-0.5	0.0	0.0							
21	0.0	0.0	0.0	0.0	0.0	-0.2	-0.5	-0.9	-1.3	-1.6	-1.9	-2.2	-2.4	-2.5	-2.7	-2.8	-2.8	-2.8	-2.7	-2.6
	-2.3	-2.0	-2.0	-2.0	-1.9	-1.8	-1.7	-1.5	-1.1	-0.8	-0.4	0.0	0.0							
22	0.0	0.0	0.0	0.0	0.0	-0.2	-0.5	-0.8	-1.1	-1.4	-1.7	-1.9	-2.0	-2.2	-2.3	-2.4	-2.4	-2.3	-2.2	-2.1
	-1.8	-1.8	-1.8	-1.7	-1.7	-1.6	-1.5	-1.2	-0.9	-0.6	-0.3	0.0	0.0							
23	0.0	0.0	0.0	0.0	0.0	-0.1	-0.4	-0.7	-1.0	-1.2	-1.5	-1.6	-1.8	-1.9	-2.0	-2.0	-2.0	-1.9	-1.8	-1.6
	-1.5	-1.5	-1.5	-1.5	-1.4	-1.3	-1.2	-1.0	-0.8	-0.5	-0.3	0.0	0.0							
24	0.0	0.0	0.0	0.0	0.0	0.0	-0.3	-0.6	-0.9	-1.1	-1.3	-1.4	-1.5	-1.6	-1.7	-1.7	-1.6	-1.5	-1.5	-1.3
	-1.3	-1.2	-1.3	-1.3	-1.2	-1.1	-1.0	-0.9	-0.6	-0.4	-0.2	0.0	0.0							
25	0.0	0.0	0.0	0.0	0.0	0.0	-0.3	-0.5	-0.8	-0.9	-1.1	-1.2	-1.3	-1.4	-1.4	-1.4	-1.4	-1.3	-1.2	-1.2
	-1.2	-1.2	-1.2	-1.1	-1.0	-1.0	-0.9	-0.7	-0.6	-0.4	-0.2	0.0	0.0							
26	0.0	0.0	0.0	0.0	0.0	0.0	-0.2	-0.5	-0.7	-0.8	-1.0	-1.1	-1.1	-1.2	-1.2	-1.2	-1.2	-1.1	-1.0	-1.0
	-1.0	-1.0	-1.0	-1.0	-0.9	-0.8	-0.7	-0.6	-0.5	-0.3	-0.2	0.0	0.0							
27	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.4	-0.6	-0.7	-0.8	-0.9	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-0.9	-0.9
	-0.9	-0.9	-0.9	-0.8	-0.8	-0.7	-0.6	-0.5	-0.4	-0.3	-0.1	0.0	0.0							
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.3	-0.5	-0.6	-0.7	-0.8	-0.8	-0.9	-0.9	-0.9	-0.9	-0.9	-0.8	-0.8
	-0.8	-0.8	-0.8	-0.7	-0.7	-0.6	-0.5	-0.5	-0.4	-0.2	-0.1	0.0	0.0							
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.2	-0.4	-0.5	-0.6	-0.7	-0.7	-0.7	-0.7	-0.8	-0.7	-0.7	-0.7	-0.7
	-0.7	-0.7	-0.6	-0.6	-0.6	-0.5	-0.4	-0.4	-0.3	-0.2	-0.1	0.0	0.0							
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.2	-0.3	-0.4	-0.5	-0.6	-0.6	-0.6	-0.7	-0.7	-0.6	-0.6	-0.6	-0.6
	-0.6	-0.6	-0.6	-0.5	-0.5	-0.4	-0.4	-0.3	-0.2	-0.2	-0.1	0.0	0.0							
31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.3	-0.3	-0.4	-0.4	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
	-0.5	-0.5	-0.4	-0.4	-0.4	-0.3	-0.3	-0.2	-0.2	-0.1	-0.0	0.0	0.0							
32	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.2	-0.2	-0.3	-0.3	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
	-0.4	-0.4	-0.3	-0.3	-0.3	-0.2	-0.2	-0.2	-0.1	-0.1	0.0	0.0	0.0							
33	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.1	-0.2	-0.2	-0.2	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3
	-0.3	-0.2	-0.2	-0.2	-0.2	-0.1	-0.1	-0.1	0.0	0.0	0.0	0.0	0.0							
34	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
	-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							
35	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	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	0.0							
36	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	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	0.0							
37	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	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	0.0							

Table 5. -- Simulated changes in potentiometric heads, proposed-mines development plan, 1975-85

DRAWDOWN OR RECOVERY (-), IN FEET

ROW \ COLUMN	-1	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	30	31	32	33							
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	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	0.0							
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	0.0	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	0.0	0.0							
3	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	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	0.0							
4	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	0.0	0.0	0.0	-0.1
	-0.1	-0.2	-0.3	-0.3	-0.3	-0.2	-0.2	-0.1	0.0	0.0	0.0	0.0	0.0							
5	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	0.3	0.5	0.5	0.4	0.3	0.0
	-0.3	-0.6	-0.8	-0.8	-0.7	-0.6	-0.4	-0.3	-0.1	0.0	0.0	0.0	0.0							
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.0	1.2	1.4	1.6	1.7	1.6	1.4	1.0	0.4
	-0.4	-1.5	-3.1	-2.1	-1.5	-1.0	-0.7	-0.5	-0.2	-0.1	0.0	0.0	0.0							
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.3	1.9	2.5	2.9	3.3	3.6	3.8	3.8	3.6	3.1	2.4
	1.6	0.3	-1.0	-1.3	-1.2	-0.9	-0.6	-0.3	-0.1	0.1	0.1	0.0	0.0							
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	2.2	3.1	3.9	4.5	5.2	6.0	6.7	7.0	6.7	5.8	4.7
	3.3	1.8	-4.2	-2.6	-2.2	-1.1	-0.2	0.2	0.5	0.4	0.2	0.0	0.0							
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.0	2.8	3.9	4.9	5.7	6.7	7.9	9.8	10.6	10.7	8.4	6.8
	5.2	3.3	0.9	-1.0	-4.5	-0.5	0.9	1.3	1.2	0.8	0.4	0.0	0.0							
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	2.4	3.5	4.7	5.9	6.8	7.6	8.5	9.4	10.1	10.3	9.6	8.7
	7.4	6.1	4.8	4.2	4.2	5.5	4.5	3.4	2.2	1.2	0.6	0.0	0.0							
11	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.5	2.8	3.9	5.3	6.7	7.9	8.3	8.9	9.6	10.4	11.7	10.7	11.0
	8.9	7.8	7.2	7.2	8.9	15.1	7.9	4.9	2.9	1.5	0.7	0.0	0.0							
12	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.7	3.0	4.1	5.6	7.3	9.5	8.8	9.0	9.5	10.0	10.4	10.2	10.0
	9.1	8.5	8.1	8.0	8.4	9.3	6.9	4.8	3.0	1.6	0.7	0.0	0.0							
13	0.0	0.0	0.0	0.0	0.0	0.0	0.8	1.9	3.1	4.2	5.6	7.0	8.1	8.5	8.9	9.3	9.6	9.8	9.7	9.5
	9.2	8.9	8.8	8.2	7.6	7.1	5.8	4.4	2.9	1.7	0.8	0.0	0.0							
14	0.0	0.0	0.0	0.0	0.0	0.2	0.9	2.0	3.2	4.3	5.5	6.7	7.5	8.2	8.7	9.1	9.4	9.4	9.4	9.3
	9.2	9.2	9.9	8.2	7.1	6.1	5.0	3.9	2.7	1.6	0.7	0.0	0.0							
15	0.0	0.0	0.0	0.0	0.0	0.4	1.0	2.1	3.2	4.2	5.4	6.4	7.2	8.0	8.6	9.1	9.2	9.1	9.1	9.0
	9.0	9.0	8.6	7.5	6.4	5.4	4.4	3.5	2.5	1.5	0.7	0.0	0.0							
16	0.0	0.0	0.0	0.0	0.1	0.5	1.1	2.1	3.2	4.1	5.2	6.1	6.9	7.8	8.7	9.6	9.2	8.9	8.7	8.7
	8.9	9.2	8.0	6.6	5.5	4.7	3.9	3.2	2.3	1.4	0.7	0.0	0.0							
17	0.0	0.0	0.0	0.0	0.1	0.5	1.1	2.1	3.1	4.0	5.0	5.9	6.6	7.6	8.8	11.3	9.3	8.5	8.3	8.3
	8.8	10.8	7.4	5.5	4.7	4.3	3.6	2.9	2.2	1.4	0.7	0.0	0.0							
18	0.0	0.0	0.0	0.0	0.1	0.5	1.1	2.0	3.0	3.8	4.7	5.5	6.2	7.0	7.8	8.6	8.2	7.7	7.5	7.4
	7.4	7.2	5.5	4.5	4.3	3.9	3.3	2.7	2.0	1.3	0.6	0.0	0.0							
19	0.0	0.0	0.0	0.0	0.1	0.5	1.1	1.9	2.8	3.6	4.4	5.1	5.7	6.3	6.8	7.2	7.1	6.9	6.6	6.3
	6.0	5.3	4.3	4.1	3.9	3.6	3.2	2.6	1.9	1.2	0.6	0.0	0.0							
20	0.0	0.0	0.0	0.0	0.0	0.5	1.1	1.9	2.7	3.4	4.1	4.7	5.2	5.6	6.0	6.2	6.2	6.0	5.8	5.4

Table 5. -- Simulated changes in potentiometric heads, proposed-mines development plan, 1975-85 (continued)

DRAWDOWN OR RECOVERY (-), IN FEET																				
COLUMN / ROW	1	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	30	31	32	33							
0	4.0	4.2	3.9	3.7	3.6	3.4	3.0	2.4	1.8	1.1	0.6	0.0	0.0							
21	0.0	0.0	0.0	0.0	0.0	0.4	1.0	1.7	2.5	3.1	3.8	4.3	4.7	5.0	5.3	5.5	5.5	5.3	5.1	4.7
0	4.1	4.0	3.5	3.4	3.2	3.0	2.8	2.4	1.7	1.1	0.5	0.0	0.0							
22	0.0	0.0	0.0	0.0	0.0	0.3	0.9	1.6	2.3	2.8	3.4	3.9	4.3	4.6	4.8	4.9	4.9	4.9	4.5	4.1
0	3.4	3.3	3.2	3.1	2.9	2.8	2.6	2.2	1.6	1.0	0.5	0.0	0.0							
23	0.0	0.0	0.0	0.0	0.0	0.2	0.8	1.5	2.1	2.6	3.1	3.5	3.9	4.2	4.4	4.6	4.6	4.5	4.0	3.5
0	3.2	3.1	3.0	2.8	2.7	2.5	2.3	2.0	1.5	0.9	0.5	0.0	0.0							
24	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.3	1.9	2.4	2.8	3.2	3.5	3.8	4.1	4.3	4.5	4.4	3.7	3.2
0	3.1	2.9	2.8	2.6	2.4	2.2	2.0	1.7	1.3	0.9	0.5	0.0	0.0							
25	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.2	1.7	2.1	2.6	2.9	3.2	3.5	3.8	4.2	4.6	4.9	3.7	3.1
0	2.9	2.7	2.6	2.4	2.2	2.0	1.8	1.5	1.2	0.8	0.4	0.0	0.0							
26	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.1	1.6	1.9	2.3	2.6	2.9	3.2	3.5	4.0	4.9	7.1	3.6	3.1
0	2.8	2.6	2.4	2.2	2.0	1.8	1.6	1.4	1.1	0.7	0.4	0.0	0.0							
27	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.9	1.4	1.7	2.1	2.4	2.6	2.9	3.2	3.5	3.9	4.1	3.1	2.8
0	2.6	2.4	2.2	2.0	1.8	1.6	1.4	1.2	1.0	0.6	0.3	0.0	0.0							
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.2	1.5	1.8	2.0	2.3	2.5	2.8	2.9	3.1	3.0	2.7	2.5
0	2.3	2.1	2.0	1.8	1.6	1.5	1.3	1.1	0.9	0.6	0.3	0.0	0.0							
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.0	1.2	1.5	1.8	2.0	2.2	2.4	2.5	2.5	2.4	2.3	2.2
0	2.1	1.9	1.8	1.6	1.5	1.3	1.1	1.0	0.7	0.5	0.2	0.0	0.0							
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.8	1.1	1.3	1.5	1.7	1.9	2.1	2.1	2.1	2.1	2.0	1.9
0	1.8	1.7	1.6	1.4	1.3	1.1	1.0	0.8	0.6	0.4	0.2	0.0	0.0							
31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.6	0.8	1.1	1.2	1.4	1.5	1.7	1.7	1.7	1.7	1.7	1.6
0	1.5	1.4	1.3	1.2	1.1	0.9	0.8	0.7	0.5	0.3	0.1	0.0	0.0							
32	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4	0.6	0.8	1.0	1.1	1.2	1.3	1.4	1.4	1.4	1.4	1.3
0	1.2	1.1	1.0	0.9	0.8	0.7	0.6	0.5	0.3	0.2	0.0	0.0	0.0							
33	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4	0.5	0.7	0.8	0.8	0.9	1.0	1.0	1.0	1.0	0.9
0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.0	0.0	0.0	0.0	0.0							
34	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3
0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
35	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	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	0.0	0.0							
36	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	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	0.0	0.0							
37	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	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	0.0	0.0							

Table 6. -- Simulated changes in potentiometric heads, proposed-mines development plan, 1975-2000

DRAWDOWN OR RECOVERY(-), IN FEET

ROW \ COLUMN	1	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	30	31	32	33							
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	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	0.0							
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	0.0	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	0.0	0.0							
3	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	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	-0.2	-0.2	0.0	0.0	0.0	0.0	0.0	0.0							
4	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	0.0	0.0	0.0	-1.1
	-1.8	-2.3	-2.6	-2.6	-2.4	-2.1	-1.6	-1.0	0.0	0.0	0.0	0.0	0.0							
5	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	-0.3	-0.6	-1.1	-2.0	-3.1	-4.3
	-5.4	-6.4	-7.0	-7.0	-6.6	-5.8	-4.8	-3.6	-2.0	0.0	0.0	0.0	0.0							
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.2	-0.1	-0.1	-0.2	0.1	-3.0	-5.8	-8.2
	-10.6	-13.0	-15.6	-15.0	-14.0	-12.4	-10.4	-8.2	-5.4	-2.5	0.0	0.0	0.0							
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.7	1.0	1.0	0.8	0.4	-0.4	-1.8	-3.7	-6.8	-11.1	-14.0
	-15.9	-19.4	-24.2	-27.2	-25.9	-23.4	-18.1	-13.7	-9.2	-5.2	-2.1	0.0	0.0							
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.6	2.1	2.5	2.8	2.8	1.7	0.2	-1.8	-4.1	-7.4	-11.1
	-14.7	-19.4	-26.3	-26.2	-27.6	-29.6	-21.2	-15.3	-9.9	-5.6	-2.5	0.0	0.0							
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.5	2.2	3.0	3.9	4.9	6.9	4.3	2.5	1.2	0.1	-4.2	-9.3
	-11.6	-14.9	-18.8	-22.6	-26.2	-25.8	-18.6	-13.3	-8.5	-4.9	-2.2	0.0	0.0							
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	2.1	2.9	3.7	4.5	5.1	5.4	4.9	4.1	3.2	2.0	0.1	-2.3
	-5.4	-9.3	-12.1	-15.4	-19.3	-15.7	-11.6	-7.9	-5.3	-3.2	-1.5	0.0	0.0							
11	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.5	2.5	3.4	4.3	5.1	5.6	6.0	6.0	5.7	5.3	4.8	4.3	4.3
	-0.2	-4.6	-6.0	-4.1	-9.5	-8.2	-5.4	-0.4	-2.4	-1.9	-1.0	0.0	0.0							
12	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.7	2.9	3.8	4.8	5.6	6.2	6.7	7.1	7.2	7.1	7.0	7.3	8.6
	4.0	0.6	-1.2	-3.1	-4.3	-4.2	-3.0	-1.4	-1.5	-1.2	-0.6	0.0	0.0							
13	0.0	0.0	0.0	0.0	0.0	0.0	0.9	2.0	3.2	4.2	5.3	6.2	7.0	7.7	8.4	8.8	8.7	8.8	9.2	10.7
	6.8	4.4	3.0	1.0	-0.7	-1.3	-1.2	-0.8	-0.8	-0.6	-0.4	0.0	0.0							
14	0.0	0.0	0.0	0.0	0.0	0.3	1.1	2.2	3.4	4.5	5.7	6.8	7.8	8.8	9.9	10.9	10.5	10.3	10.0	9.6
	8.1	7.0	7.7	4.1	2.0	0.7	0.2	0.0	-0.1	-0.2	-0.1	0.0	0.0							
15	0.0	0.0	0.0	0.0	0.0	0.5	1.2	2.4	3.7	4.8	6.1	7.4	8.5	9.8	11.4	14.4	12.4	11.9	10.8	9.9
	8.8	8.0	7.0	5.1	3.4	2.2	1.3	0.8	0.4	0.2	0.0	0.0	0.0							
16	0.0	0.0	0.0	0.0	0.1	0.6	1.3	2.5	3.8	5.0	6.4	7.9	9.1	10.4	11.5	12.6	12.7	14.1	11.5	10.2
	9.5	9.0	7.3	5.6	4.4	3.1	2.2	1.5	0.9	0.5	0.2	0.0	0.0							
17	0.0	0.0	0.0	0.0	0.1	0.7	1.4	2.6	3.9	5.1	6.6	8.2	9.7	11.3	11.5	11.7	11.7	11.7	10.8	10.0
	9.9	11.2	7.6	5.6	4.8	3.9	2.8	2.0	1.3	0.7	0.3	0.0	0.0							
18	0.0	0.0	0.0	0.0	0.1	0.7	1.5	2.6	3.9	5.1	6.6	8.3	10.2	13.5	11.6	11.0	10.7	10.4	9.8	9.2
	8.7	8.2	6.3	5.2	4.9	4.3	3.3	2.4	1.6	0.9	0.4	0.0	0.0							
19	0.0	0.0	0.0	0.0	0.1	0.7	1.5	2.6	3.8	5.0	6.4	7.9	9.2	10.5	10.4	10.1	9.8	9.5	8.9	8.3
	7.5	6.5	5.4	5.1	4.8	4.5	3.7	2.8	1.9	1.1	0.5	0.0	0.0							
20	0.0	0.0	0.0	0.0	0.0	0.6	1.4	2.5	3.7	4.8	6.1	7.2	8.2	9.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 6. -- Simulated changes in potentiometric heads, proposed-mines development plan, 1975-2000 (continued).

DRAWDOWN OR RECOVERY (-), IN FEET

COLUMN / ROW	1	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	30	31	32	33							
	6.6	5.7	5.2	5.0	4.7	4.4	3.8	2.9	2.0	1.2	0.6	0.0	0.0							
21	0.0	0.0	0.0	0.0	0.0	0.6	1.3	2.4	3.5	4.5	5.6	6.6	7.3	8.0	8.3	8.5	8.5	8.2	7.6	6.4
	5.8	5.1	5.0	5.1	4.5	4.1	3.7	3.1	2.1	1.3	0.4	0.0	0.0							
22	0.0	0.0	0.0	0.0	0.0	0.5	1.2	2.2	3.3	4.2	5.2	6.0	6.6	7.2	7.7	8.0	8.2	8.1	7.2	6.2
	5.2	4.8	4.7	4.5	4.2	3.8	3.5	2.9	2.1	1.3	0.6	0.0	0.0							
23	0.0	0.0	0.0	0.0	0.0	0.3	1.1	2.1	3.0	3.8	4.7	5.4	6.0	6.6	7.1	7.7	8.3	8.8	7.1	5.5
	4.7	4.5	4.3	4.1	3.8	3.5	3.1	2.7	2.0	1.3	0.6	0.0	0.0							
24	0.0	0.0	0.0	0.0	0.0	0.0	0.9	1.9	2.8	3.5	4.2	4.9	5.4	5.9	6.5	7.3	8.5	11.5	6.9	5.3
	4.5	4.3	4.0	3.8	3.5	3.2	2.8	2.4	1.9	1.3	0.6	0.0	0.0							
25	0.0	0.0	0.0	0.0	0.0	0.0	0.8	1.7	2.5	3.2	3.8	4.4	4.8	5.3	5.8	6.3	6.9	7.4	5.6	4.5
	4.3	4.0	3.7	3.5	3.2	2.9	2.5	2.2	1.7	1.1	0.5	0.0	0.0							
26	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.5	2.3	2.9	3.4	3.9	4.3	4.7	5.0	5.4	5.6	5.5	4.8	4.4
	4.0	3.7	3.5	3.2	2.9	2.6	2.3	2.0	1.5	1.0	0.5	0.0	0.0							
27	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.3	2.0	2.5	3.0	3.4	3.8	4.1	4.3	4.6	4.7	4.7	4.7	4.1
	3.7	3.4	3.2	2.9	2.6	2.3	2.1	1.7	1.4	0.9	0.4	0.0	0.0							
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.7	2.1	2.6	2.9	3.2	3.5	3.8	3.9	4.0	4.0	3.9	3.5
	3.4	3.1	2.9	2.6	2.4	2.1	1.8	1.4	1.2	0.8	0.4	0.0	0.0							
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	1.4	1.8	2.2	2.5	2.8	3.0	3.3	3.4	3.4	3.4	3.3	3.2
	3.0	2.8	2.5	2.3	2.1	1.9	1.6	1.4	1.1	0.7	0.3	0.0	0.0							
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.2	1.5	1.9	2.2	2.4	2.6	2.9	2.9	2.9	2.9	2.9	2.8
	2.6	2.4	2.2	2.0	1.8	1.6	1.4	1.2	0.9	0.6	0.3	0.0	0.0							
31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.9	1.2	1.5	1.8	2.0	2.1	2.3	2.4	2.4	2.4	2.4	2.3
	2.2	2.0	1.9	1.7	1.5	1.3	1.1	0.9	0.7	0.4	0.2	0.0	0.0							
32	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.6	0.9	1.2	1.4	1.5	1.7	1.8	1.9	1.9	2.0	2.0	1.9
	1.8	1.6	1.5	1.3	1.2	1.0	0.8	0.7	0.4	0.2	0.0	0.0	0.0							
33	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.6	0.8	0.9	1.1	1.2	1.3	1.4	1.4	1.4	1.4	1.3
	1.2	1.1	0.9	0.8	0.7	0.6	0.4	0.3	0.0	0.0	0.0	0.0	0.0							
34	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.4	0.5	0.6	0.6	0.6	0.6	0.6	0.5	0.4
	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
35	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	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	0.0							
36	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	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	0.0							
37	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	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	0.0							

Tables 5 and 6 and figures 18 and 19 show that in the proposed-mines plan the potentiometric surface generally recovers in the northeastern part of the study area, and it generally declines in the remainder of the area. For 1985 (table 5), the maximum predicted recovery is 4.5 ft (node 9-25), and the maximum predicted drawdown is 15.1 ft (node 11-26). For 2000 (table 6), the maximum predicted recovery is 29.6 ft (node 8-26) and the maximum predicted drawdown is 14.4 ft (node 15-16).

As with the existing-mines development plan, the simulated changes in potentiometric head resulting from the proposed-mines development plan may be superimposed on the September 1975 potentiometric map to obtain predicted water levels for 1985 and 2000.

APPRAISAL OF RESULTS

The model and simulation results described in this report represent a preliminary step in a continuing effort to understand the response of the hydrogeologic system in west-central Florida to changes in pumping stress. A number of problem areas remain. These include the inadequacy of this model to simulate accurately complex field conditions, especially in the representation of boundary conditions; a sketchy knowledge of aquifer and confining-bed characteristics; and the lack of reliable quantitative information on the amounts and locations of major ground-water withdrawals. In addition, calibration of the transient model is incomplete.

All of these factors contribute to uncertainties in the reliability of the model calibration and simulated potentiometric-head changes for 1985 and 2000. Thus, the findings should be viewed as preliminary, although they are probably reasonable approximations of water-level changes that would result from the specified alternative plans of phosphate development. The results are presented primarily to provide timely support to efforts aimed at evaluating the hydrologic effects of phosphate mining.

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