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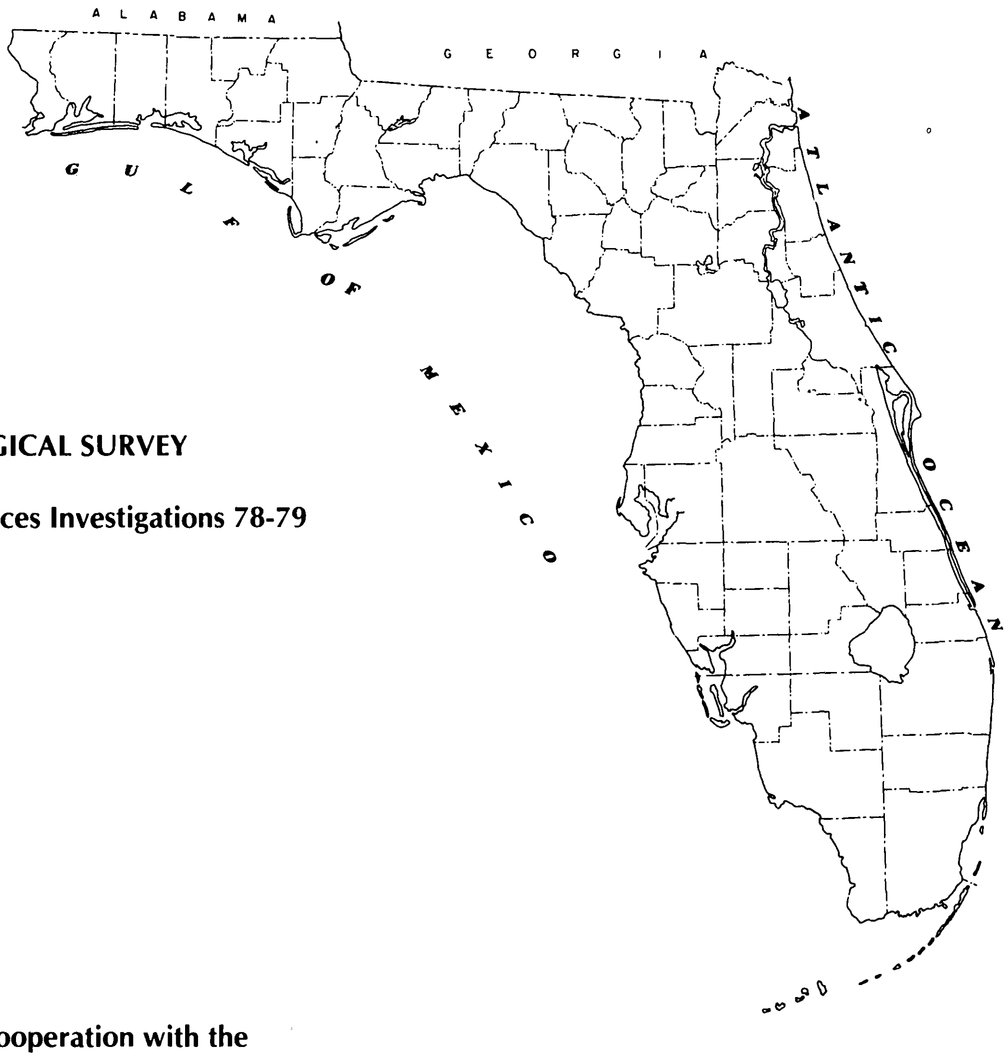
MODEL EVALUATION OF THE HYDROGEOLOGY OF THE CYPRESS CREEK WELL FIELD IN WEST-CENTRAL FLORIDA



U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 78-79

Prepared in cooperation with the
SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT

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16. Abstracts

The Cypress Creek well field is being developed to help supply a rapidly growing population in west-central Florida. The ground-water system in the Cypress Creek well-field area consists of a surficial sand aquifer, a semiconfining clay layer ranging from 2 to 25 feet in thickness, and a sequence of carbonate rocks, approximately 1,000 feet thick, called the Floridan aquifer. All recharge to the Floridan aquifer in the local area is derived from the overlying surficial sand aquifer by downward percolation through the semiconfining clay bed. The major proportion of water supplied to municipal wells open to the Floridan aquifer comes from a dolomitic section of the Avon Park Limestone containing two major cavernous zones. The hydrogeology of the well-field area was evaluated by digital model simulation. Model runs were made to analyze sensitivity of the model to variations in selected hydrologic parameters. The model was tested further by attempting to simulate the potentiometric surface of the Floridan aquifer under actual pumping stresses during the January 1976 dry period.

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October 1978

UNITED STATES DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

The U.S. customary units used in this report can be converted to equivalent metric units as follows:

U.S. customary	Multiply by	Metric
inch (in)	25.4	millimeter (mm)
foot (ft)	.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
foot per second (ft/s)	.3048	meter per second (m/s)
foot per day (ft/d)	.3048	meter per day (m/d)
cubic foot per second (ft^3/s)	.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	6.309×10^{-2}	liter per second (L/s)
million gallons per day (Mgal/d)	.04381	cubic meter per second (m^3/s)
square foot per day (ft^2/d)	.0929	square meter per day (m^2/d)

MODEL EVALUATION OF THE HYDROGEOLOGY OF THE CYPRESS CREEK WELL FIELD IN WEST-CENTRAL FLORIDA

By

Paul D. Ryder

ABSTRACT

The Cypress Creek well field is being developed to help supply a rapidly growing population in west-central Florida. Planned withdrawals from the area could eventually exceed 60 million gallons per day.

The ground-water system in the Cypress Creek well-field area consists of a surficial sand aquifer, a semiconfining clay layer ranging from 2 to 25 feet in thickness, and a sequence of carbonate rocks, approximately 1,000 feet thick, called the Floridan aquifer.

All recharge to the Floridan aquifer in the local area is derived from the overlying surficial sand aquifer by downward percolation through the semiconfining clay bed. Part of this recharge is returned to the surficial deposits within the area as upward leakage, and most of the remainder leaves the area as it flows downgradient within the Floridan aquifer.

The major proportion of water supplied to municipal wells open to the Floridan aquifer comes from a dolomitic section of the Avon Park Limestone containing two major cavernous zones. These zones are at approximately 400 feet and 500 feet below sea level in the well-field area.

The hydrogeology of the well-field area was evaluated by digital model simulation. A two-dimensional finite-difference model was calibrated by simulating natural steady-flow conditions for September 16, 1974. The leakance of the semiconfining layer was the main hydrologic parameter that was varied to achieve a satisfactory calibration. Leakance values (the ratio of hydraulic conductivity to confining-bed thickness) derived from the model were mapped for a 120-square-mile area encompassing the well field. Values ranged from about 10^{-6} to 10^{-2} cubic foot per day per cubic foot. The values encompass the range of estimates obtained from aquifer tests in the area.

Model runs were made to analyze sensitivity of the model to variations in selected hydrologic parameters. Tests were also run to determine the reliability of the parameter estimates used in the calibration. The tests indicated that parameter estimates could be improved in certain areas by (1) locating observation wells away from areas of large irrigation pumping effects, (2) defining the thickness and water-level configuration of the surficial aquifer in the area northeast of the well field, and (3) obtaining data on hydraulic characteristics in the Floridan aquifer in areas where the head difference between the surficial and Floridan aquifers is minimal, by means of aquifer tests.

The model was tested further by attempting to simulate the potentiometric surface of the Floridan aquifer under actual pumping stresses during the January 1976 dry period. The model could not effectively simulate the hydrologic system under these conditions because of the requirement of fixed water levels in the surficial aquifer. Therefore, a quasi-three-dimensional model was used to simulate the system with declining water levels in the surficial aquifer. Those model results indicate the need for better estimates of aquifer characteristics and water-level configuration for the surficial aquifer in the entire modeled area. The use of the three-dimensional model for future predictive analysis for water management will necessitate expansion and redefinition of the boundaries of the model and estimation of new model parameters for the additional area that will be affected by the large-scale withdrawals.

INTRODUCTION

The Cypress Creek well field is located in the center of Pasco County in west-central Florida (fig. 1). The well field is being developed by the City of St. Petersburg, Pinellas County, and Pasco County to help supply the water demands of a rapidly growing part of Florida. The well field (fig. 2) is about 7 mi^2 in areal extent, and withdrawals of 30 Mgal/d are planned. Additional withdrawals from an area bordering the southern boundary may bring the total to over 60 Mgal/d.

Purpose and Scope

The objective of this study was to provide a quantitative description that could be used to guide development and operation of the ground-water flow system in a 120-mi^2 area which includes the Cypress Creek well-field. The approach was to develop and analyze a digital model of the aquifer system. The model was used to:

1. Quantify and improve a conceptual model of the ground-water flow system.
2. Determine hydrologic data deficiencies.
3. Supply guidelines for future data collection.

This report describes the input for the digital model in sufficient detail for the results to be duplicated by others. The report will serve as a basis for further modeling and prediction analysis. More extensive data input would be needed to evaluate the proposals for conjunctive use of ground water and surface water in the well field.

Methods of Investigation

During the investigation, all available hydrologic and geologic records from the Cypress Creek well-field area were examined. These included: rainfall, streamflow, lake and ground-water level data; aquifer-test data and determinations of transmissivity, storage coefficient and leakance values; geologic data including geophysical logs, geologists' logs, and drillers' logs of wells. Many of these data were used in a digital simulation model of ground-water flow in a 120-mi^2 area, including the 7-mi^2 well field.

Previous Investigations

A discussion of the geology and hydrology of the area is presented by Cherry and others (1970), Wetterhall (1964), and in reports by several consulting firms. A regional digital model of the Floridan aquifer in an 875-mi^2 area, including the Cypress Creek well field, was completed by the U.S. Geological Survey in 1975 (Robertson and Mallory, 1977).

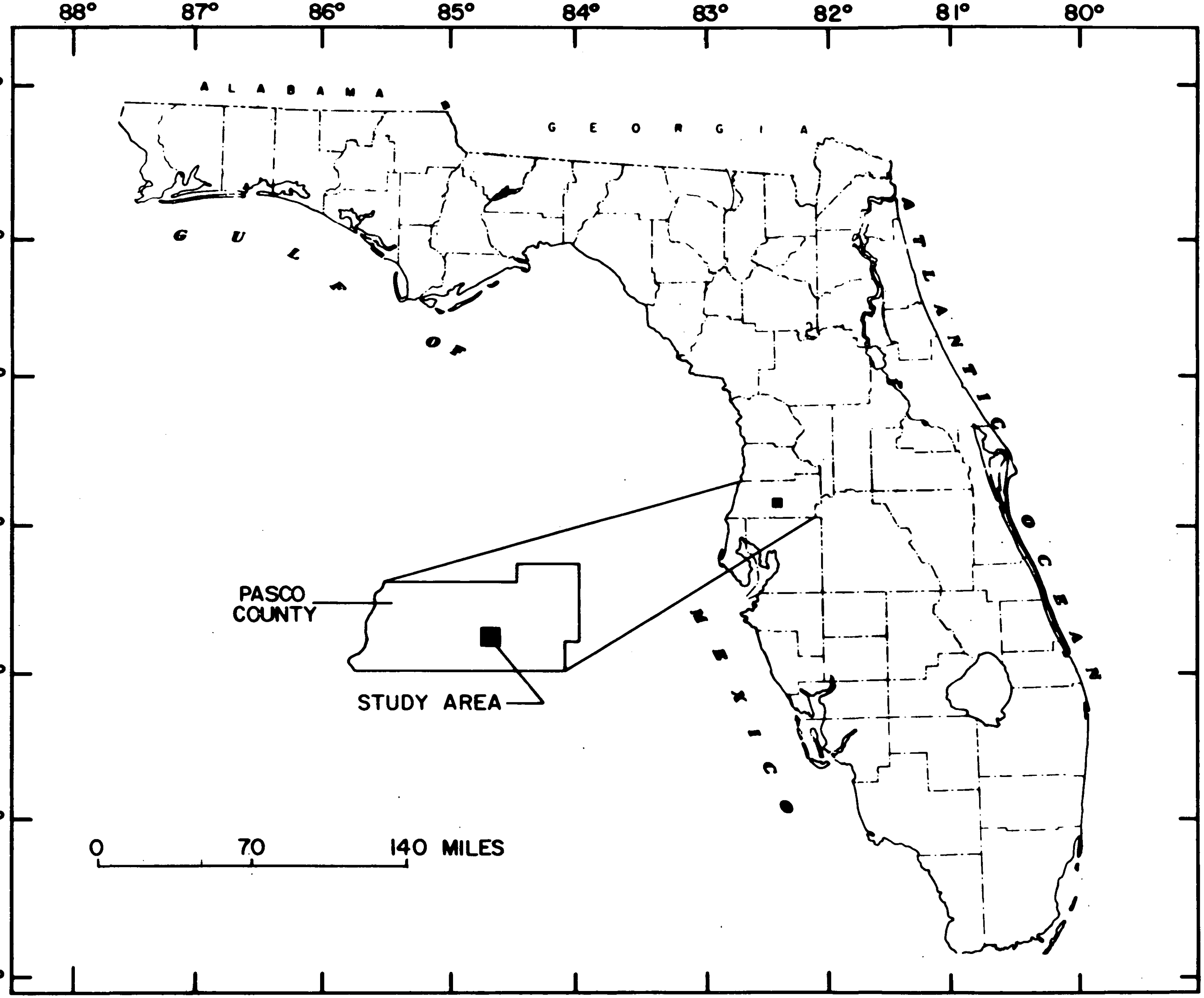


Figure 1.--Location of study area.

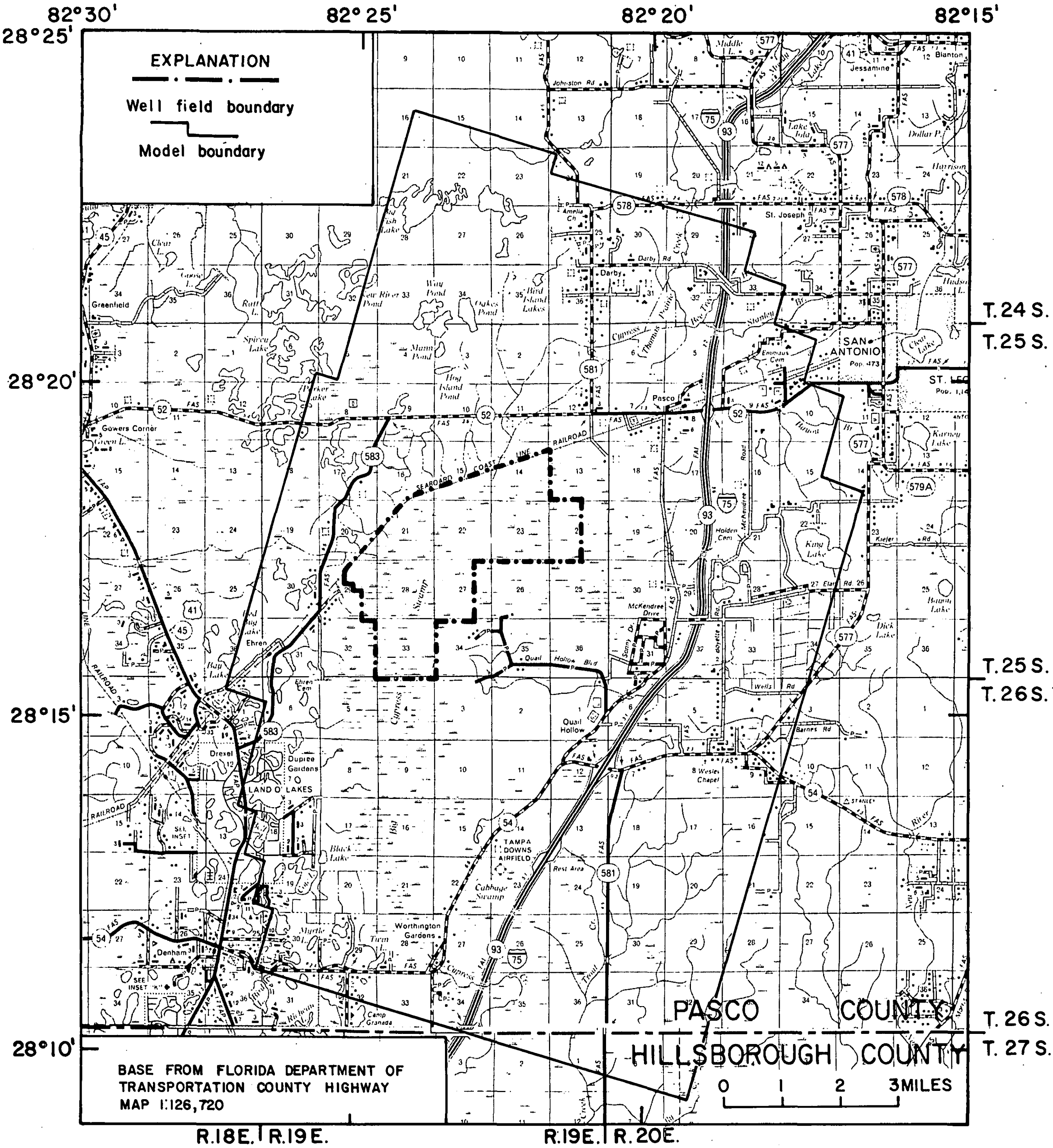


Figure 2.--Location of Cypress Creek well field and study area.

Acknowledgments

This investigation was made in cooperation with the Southwest Florida Water Management District. The consulting firm of Leggette, Brashears and Graham was helpful in providing geologic and hydrologic data from the Cypress Creek well field. The U.S. Army Corps of Engineers' Jacksonville office was helpful in providing geologic data and in constructing a key observation well for use in this study.

DESCRIPTION OF STUDY AREA

Hydrologic Setting

Cypress Creek, which flows southward through about the center of the well field, is tributary to the Hillsborough River. The channel is poorly defined as it meanders through a large, swampy area within the well field. The valley of Cypress Creek slopes very gently, and the drainage divide between adjacent basins is difficult to define in many places.

Cypress Creek drains an area of about 56 mi^2 at State Road 52, north of the well field. The average annual discharge for 12 years of record is 24 ft^3/s; there was no flow for many days in 1967, 1968, and 1973-75.

Cypress Creek drains an area of about 117 mi^2 at State Road 54, south of the well field. The average discharge in the 1975 water year (the first year of continuous record) was 46 ft^3/s; many days of no flow were recorded.

The long-term average annual rainfall for the area is about 56 in, of which about 60 percent occurs during the summer--June through September (Pride and others, 1966, p. 24).

Geologic Formations and Water-Bearing Characteristics

Figure 3 is a generalized geologic column of the Cypress Creek well-field area. The rocks, ranging in age from Eocene to Holocene, are described briefly in the illustration.

The Lake City Limestone of Eocene age is the oldest formation shown. The presence of anhydrite- or gypsum-filled voids in the limestone apparently accounts for a highly mineralized (high sulfate) water and a relatively low formation permeability. However, in other areas the Lake City Limestone has been described as highly permeable in part, and capable of yielding large quantities of water to wells (Wetterhall, 1964, p. 8). The apparent contradiction may lie in where the formation contact between the Lake City Limestone and the Avon Park Limestone is placed.

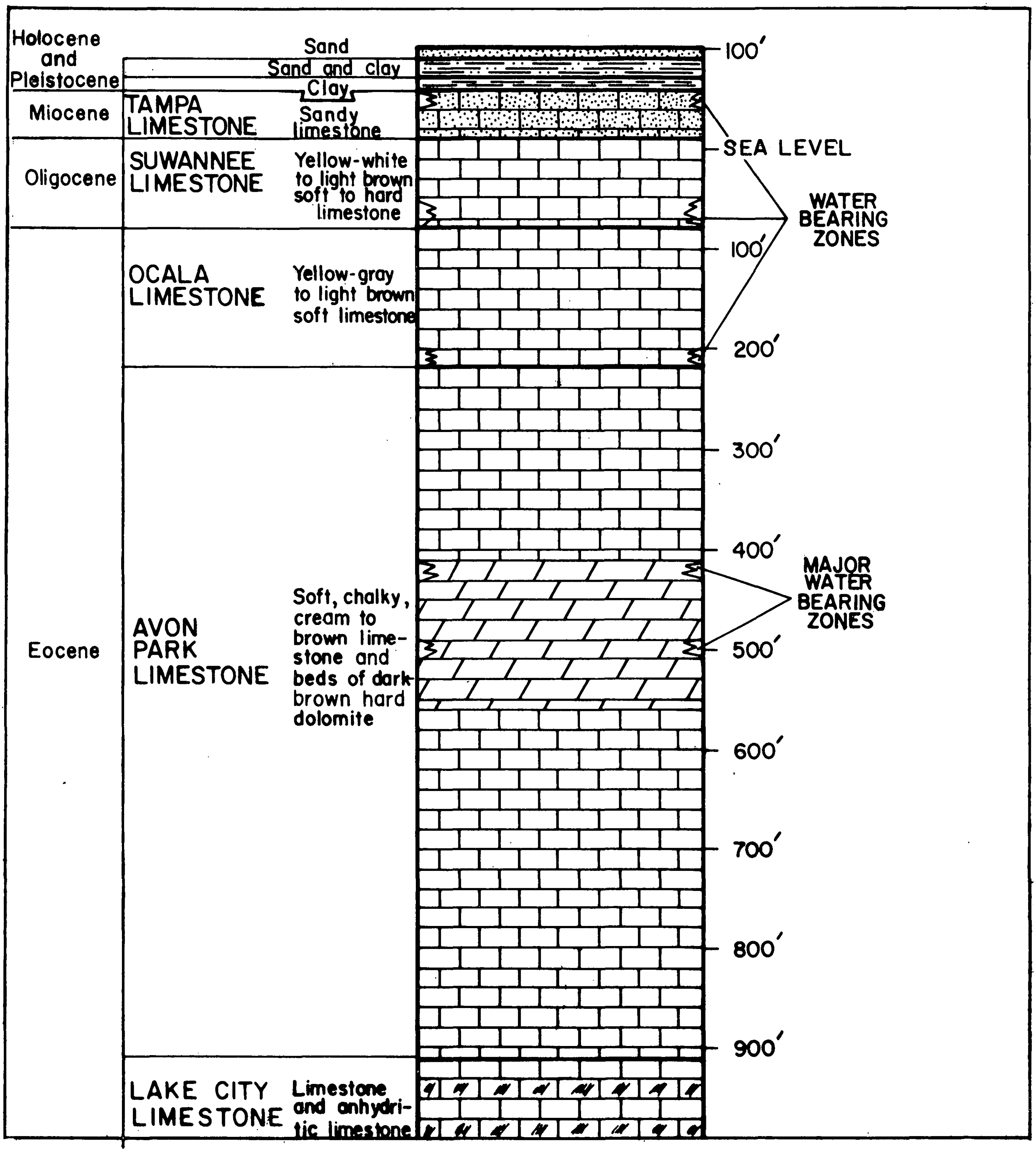


Figure 3.--Generalized geologic column in the Cypress Creek well field.

Overlying the Lake City Limestone is the Avon Park Limestone of Eocene age. A dolomitic section of the formation contains two major cavernous zones that are major water-bearing zones. Field tests indicate that these zones may supply the major part of the inflow to pumping wells open to the entire rock column.

The Ocala Limestone overlying the Avon Park also is of Eocene age. The better water-bearing zone in this formation is located near the zone of contact with the underlying formation.

The Suwannee Limestone of Oligocene age overlies the Ocala Limestone. The formation is relatively permeable, particularly near its base.

The Tampa Limestone of Miocene age overlies the Suwannee Limestone. A water-bearing zone generally occurs near the top of the formation.

Overlying the Tampa Limestone are the unconsolidated deposits of sand, clay, and mixed sand and clay of Pleistocene and Holocene age. The sand can often supply enough water for domestic wells, but objectionable amounts of iron are usually present. The unconsolidated deposits have the important role of receiving and storing rainfall, and transmitting the water to the underlying limestone aquifer.

A geologic fence diagram (figs. 4 and 5) was constructed to show variations in character and thickness of the unconsolidated deposits in and near the well field. A clay layer, ranging in thickness from about 25 ft at well 2 to 2 ft at well 15, is generally present between the bedrock and the sand. The clay functions as a semiconfining layer and retards the vertical movement of water between the overlying sand and the underlying limestone aquifer.

Ground Water

The unconsolidated deposits of sand and clayey sand in the area constitute the surficial aquifer, and the underlying clay beds are referred to as the semiconfining layer. The thick sequence of carbonate rocks is collectively referred to as the Floridan aquifer (Parker and others, 1955, p. 189). Movement of the water in the highly transmissive Floridan aquifer is primarily along solution-enlarged joints and fractures.

A generalized east-west hydrogeologic section through the well field and extending several miles on either side (figs. 6 and 7) shows the altitude of the water table in the surficial aquifer and the potentiometric surface of the Floridan aquifer in May 1975.

Figure 7 shows that in some places the water table is above the potentiometric surface and in other places, below. Where the water table is higher than the potentiometric surface of the Floridan aquifer, water

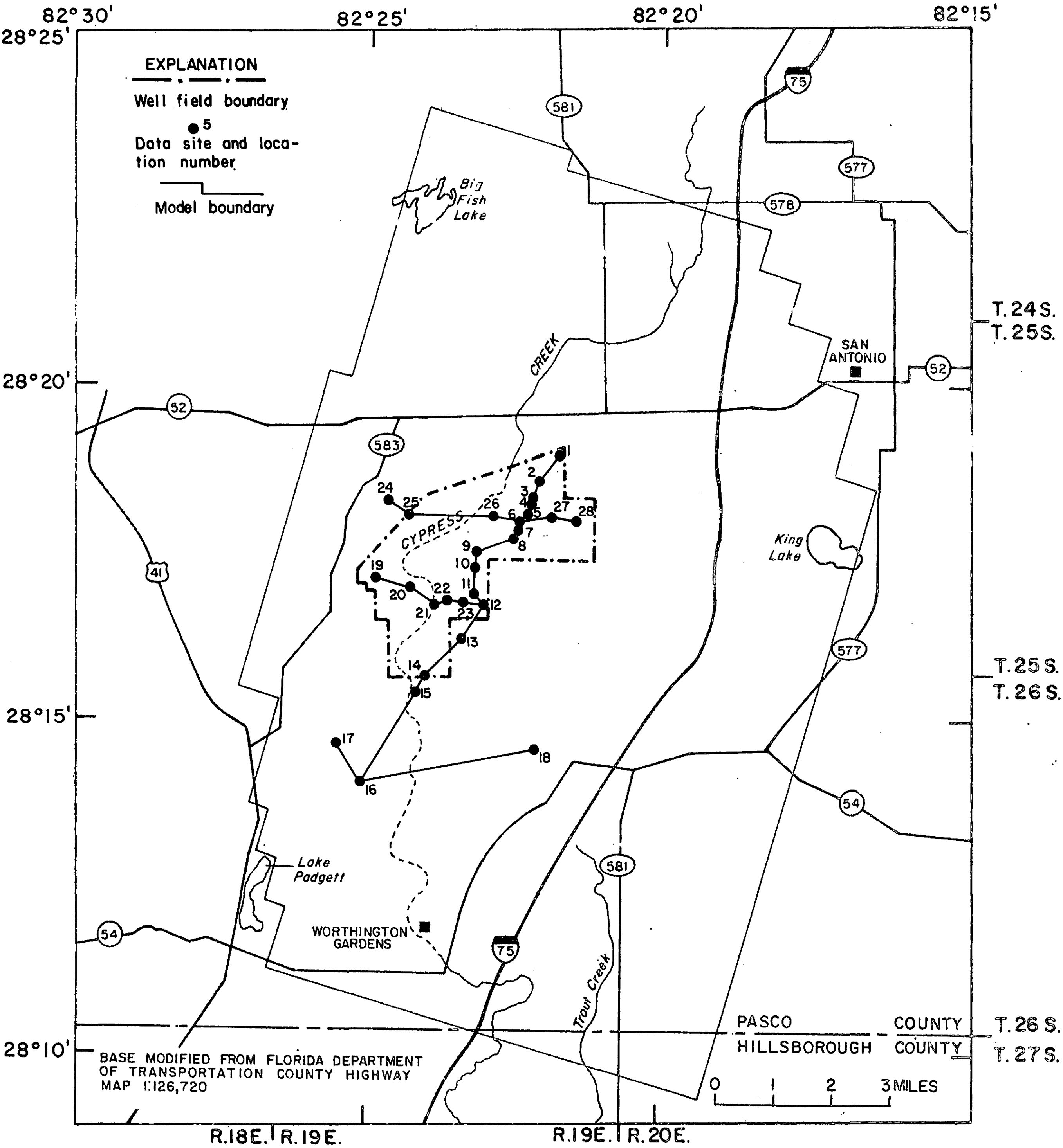


Figure 4.--Location of data sites used in constructing the geologic fence diagram in figure 5.

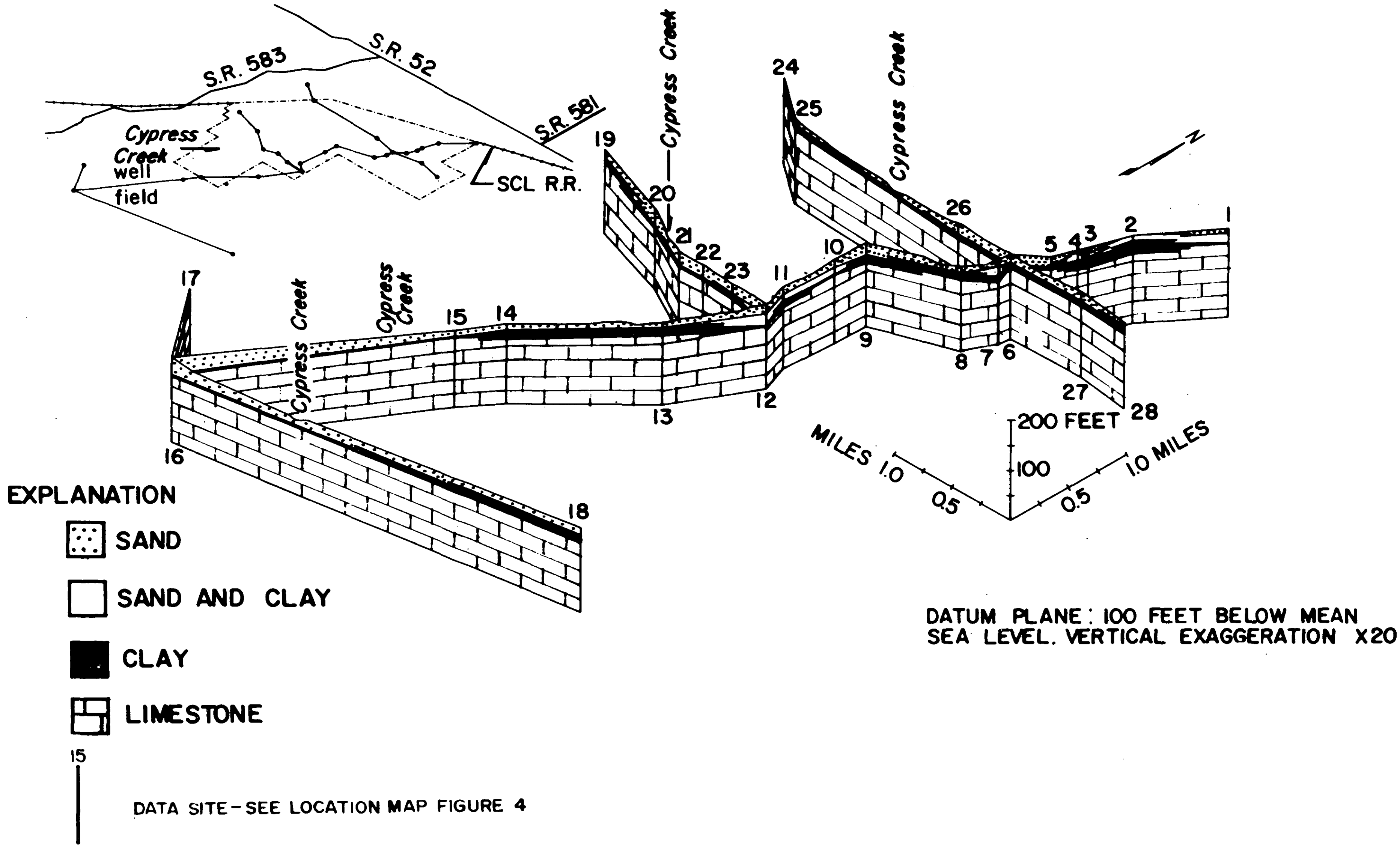


Figure 5.--Geologic fence diagram in Cypress Creek well-field area. (Some data are generalized.)

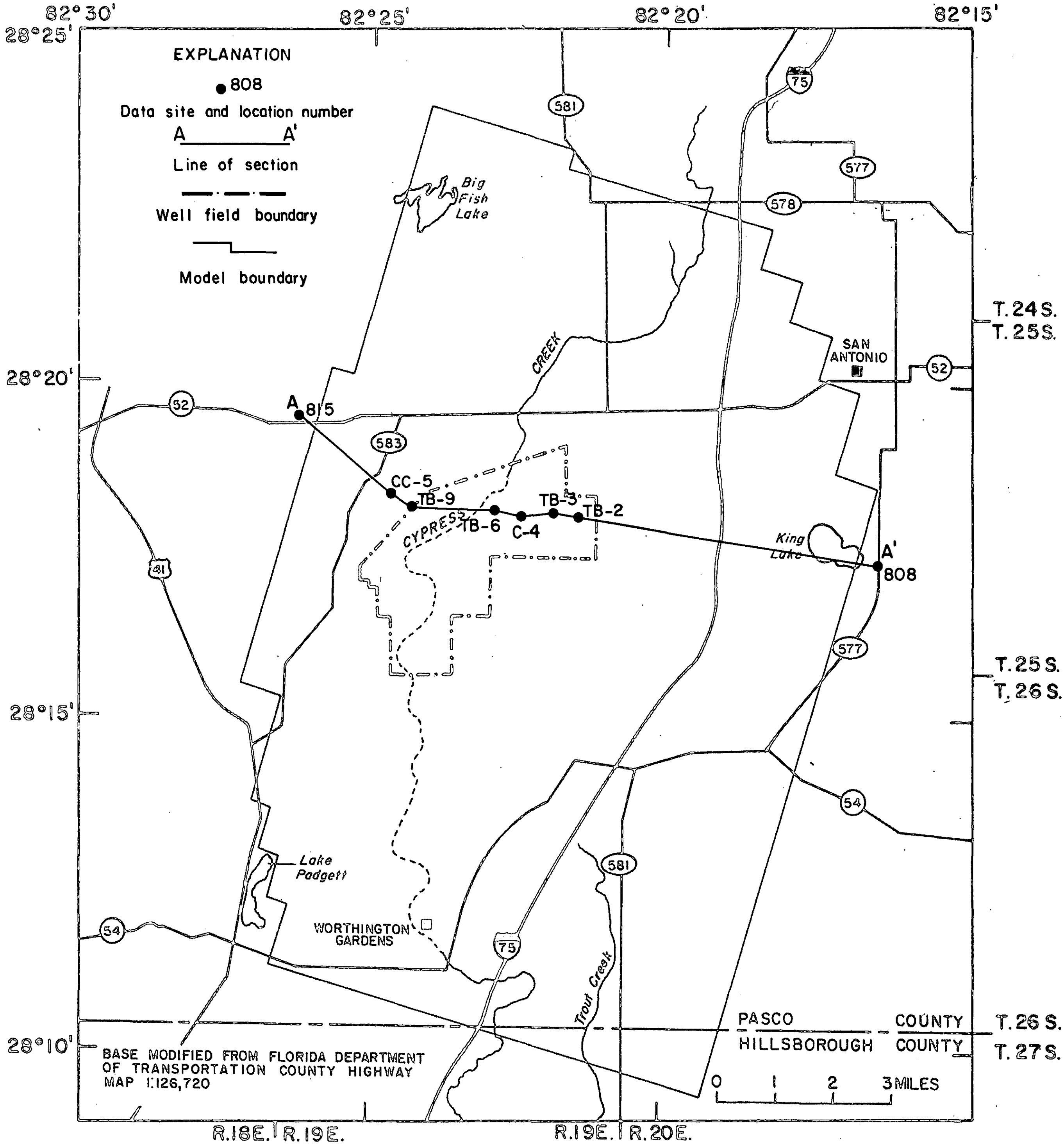


Figure 6.--Location of data sites used in constructing the hydrogeologic section in figure 7.

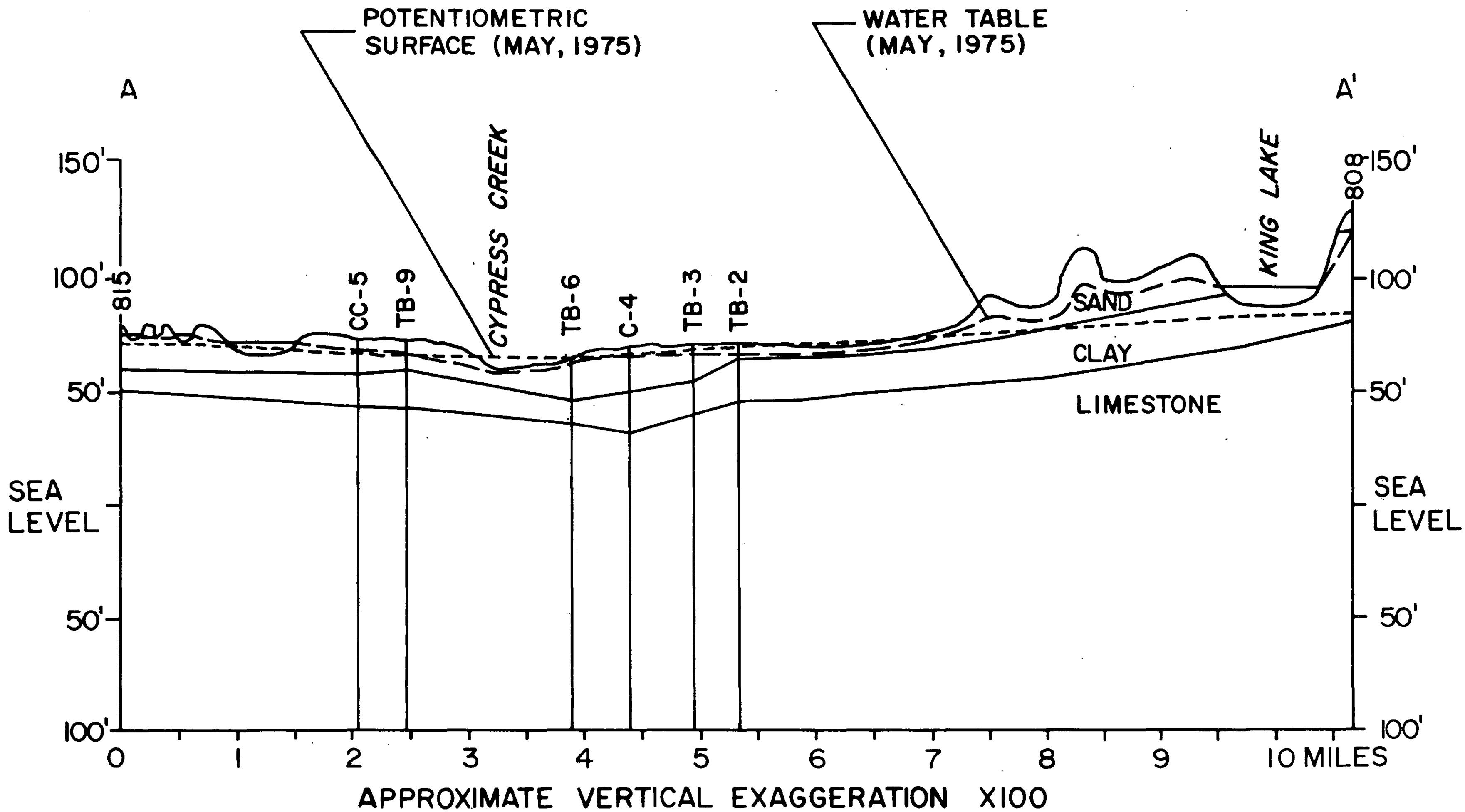


Figure 7.--Hydrogeologic section in the Cypress Creek well-field area showing water level measured in May 1975.

will leak downward from the surficial aquifer through the semiconfining clay layer and into the Floridan aquifer. Where the potentiometric surface is above the water table, leakage from the Floridan aquifer to the surficial aquifer will occur.

The approximate altitude of the water table is shown in figure 8 for September 16, 1974, and in figure 9 for May 12, 1975. These estimates were made by utilizing topographic maps with 2-ft contour intervals (where available), and placing the water table at appropriate depths below land surface; the depths of water levels below land surface in observation wells, and lake and stream stages were used for guidance. The potentiometric-surface contour maps of the Floridan aquifer for September 16, 1974, and May 12, 1975, are shown in figures 10 and 11. These maps are basically taken from unpublished U.S. Geological Survey maps by Mills and Hutchinson; some reinterpretation and refinement was necessary to conform to known hydrologic details.

Each water-table map can be compared with the appropriate potentiometric-surface map to show areas of downward and upward leakage across the semiconfining layer. The comparison shows that although the water table and the potentiometric surface are several feet lower in the dry period (May) than in the wet period (September), the general pattern of flow between and within the aquifers is essentially the same. The maps also show the direction of flow within each aquifer as the water moves downgradient from higher to lower potentials.

All recharge to the Floridan aquifer in the well-field area comes from the overlying sandy surficial aquifer by downward percolation through the semiconfining clay bed. Part of this recharge is returned to the surficial deposits within the area as upward leakage, and most of the remainder leaves the area as it flows downgradient within the Floridan aquifer. Figures 10 and 11 show the direction of flow--the water moves downgradient from higher to lower potentials.

DIGITAL SIMULATION MODEL

The digital simulation model computes the hydraulic-head changes in time and space in an aquifer system in response to applied hydrologic stresses. Analytical techniques are available that treat aquifers that receive leakage from adjacent semiconfining beds (see Hantush and Jacob, 1955), but the analytical solutions are applicable only to aquifers with relatively simple boundary conditions and uniform characteristics.

The digital simulation model utilizes a finite-difference method in which the differential equations of ground-water flow are solved by numerical approximation. These approximate solutions have the advantage of being applicable to much more complex boundary conditions.

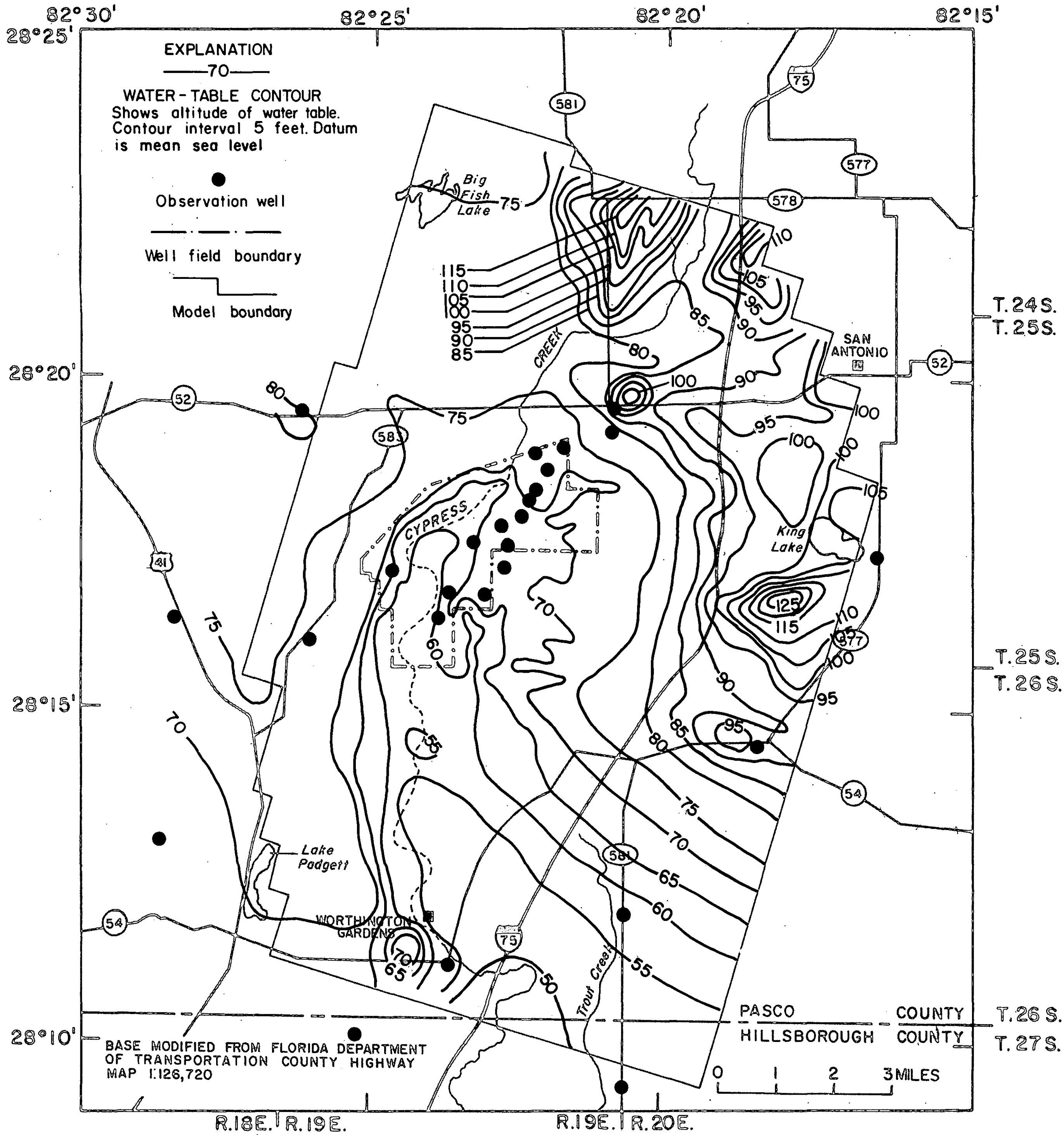


Figure 8.--Estimated water table; control-well data collected on September 16, 1974.

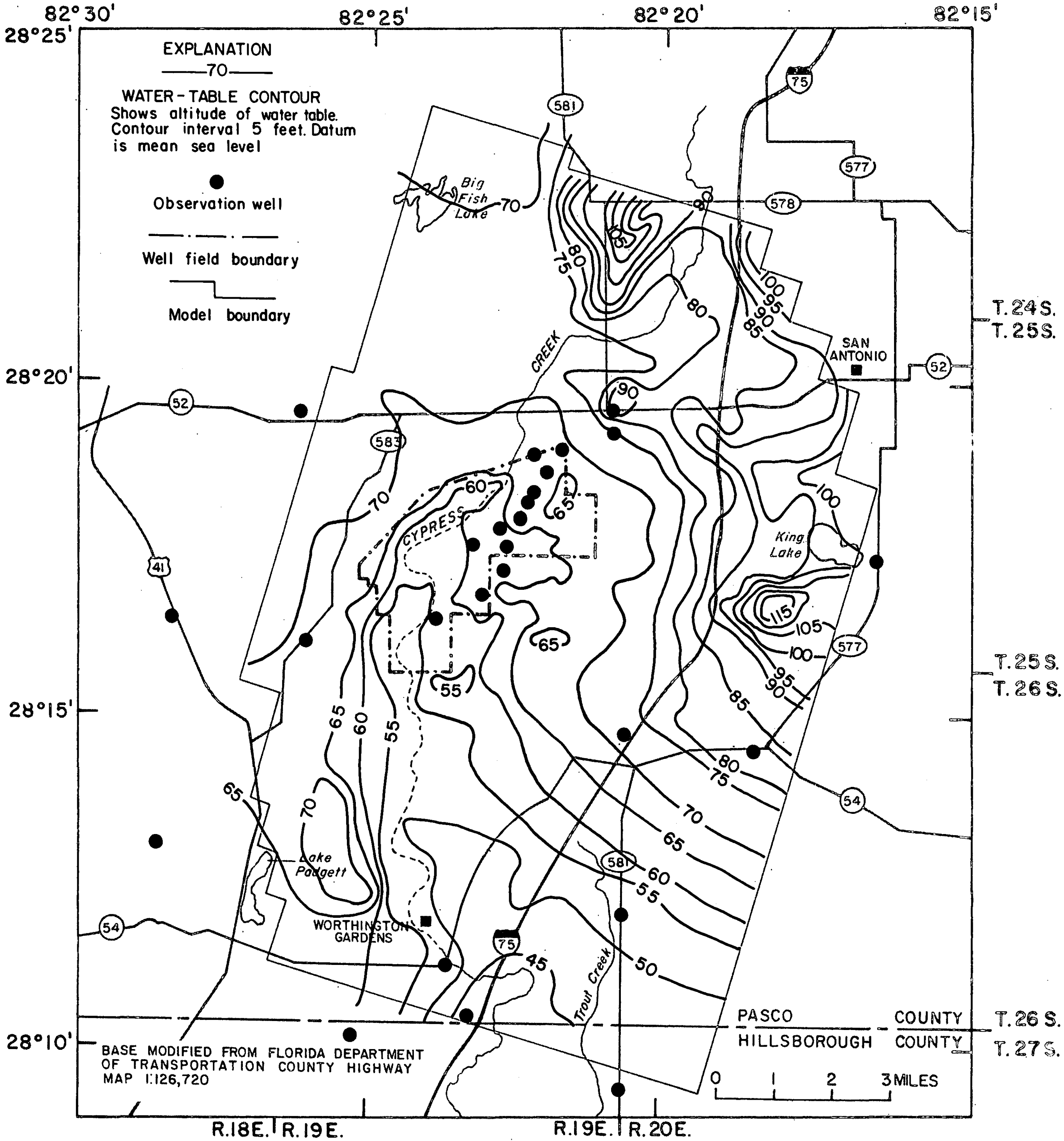


Figure 9.--Estimated water table; control-well data collected on May 12, 1975.

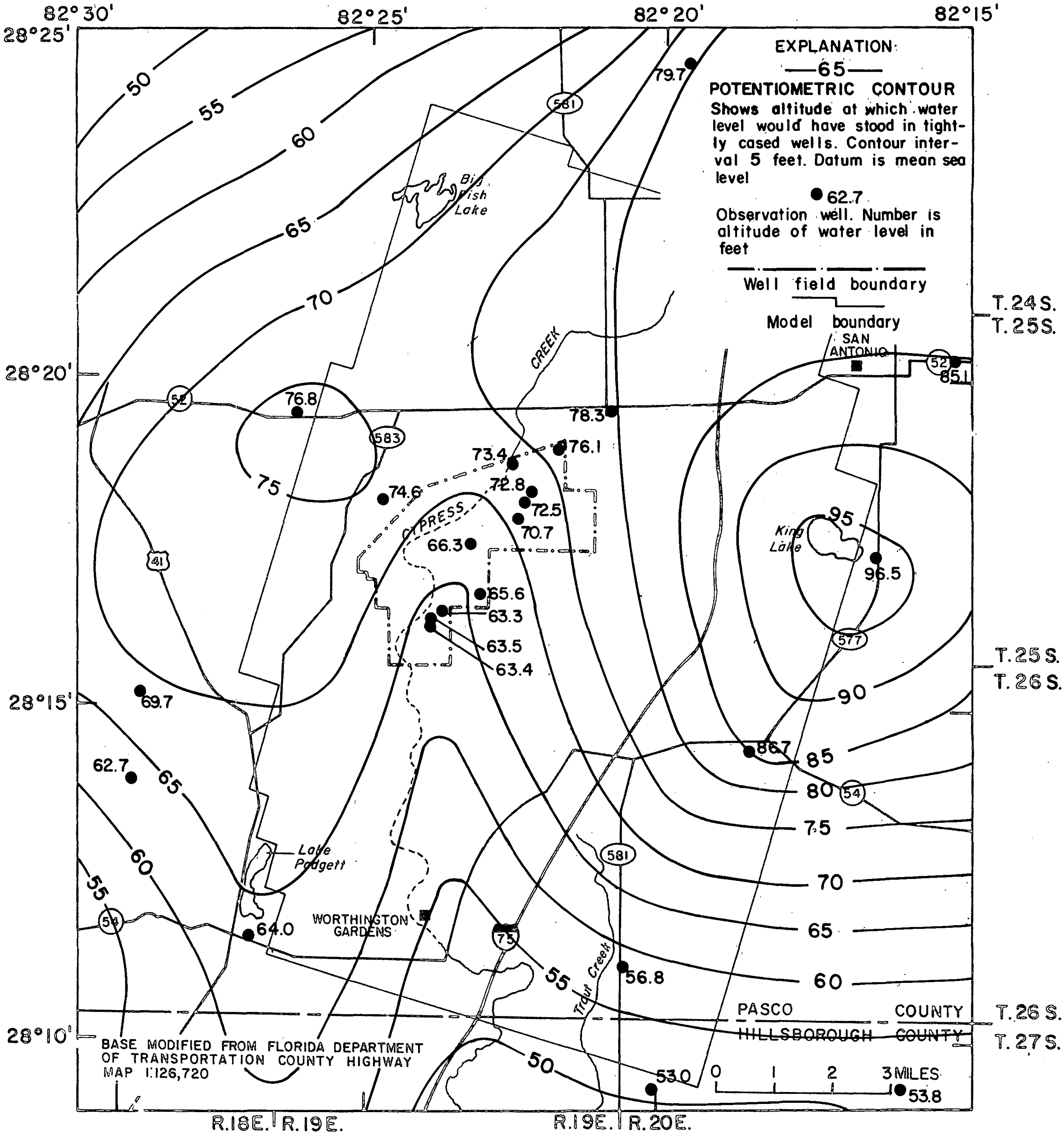


Figure 10.--Potentiometric surface of the Floridan aquifer, September 16, 1974.

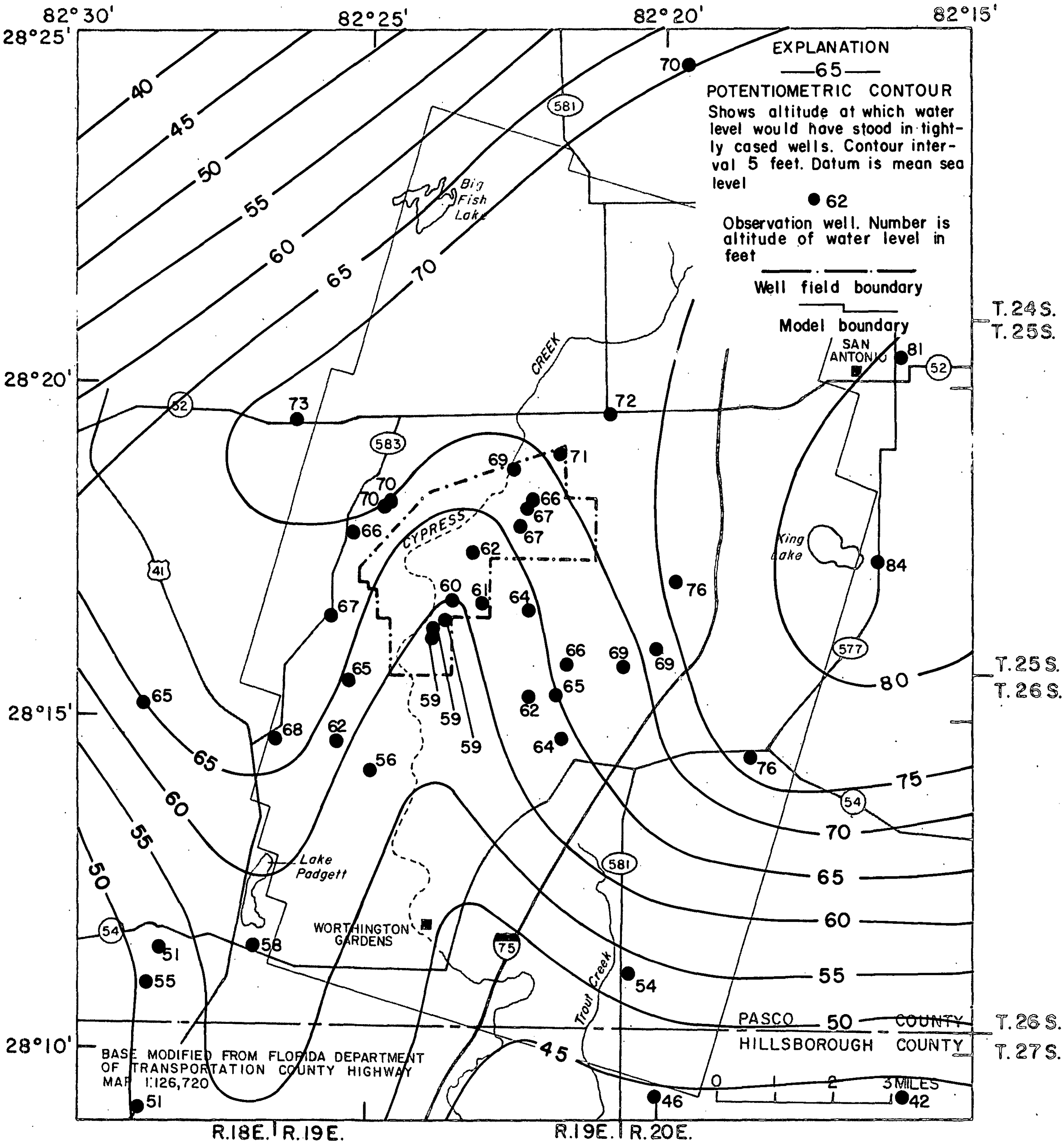


Figure 11.--Potentiometric surface of the Floridan aquifer, May 12, 1975.

Flow Equation

The following partial differential equation of ground-water flow in a confined aquifer in two dimensions, developed and discussed in Pinder and Bredehoeft (1968), is in Trescott, Pinder, and Larson (1976, p. 2):

$$\frac{\partial}{\partial x}\left(T_{xx}\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial x}\left(T_{xy}\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial y}\left(T_{yx}\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(T_{yy}\frac{\partial h}{\partial y}\right) = S\frac{\partial h}{\partial t} + W(x,y,t) \quad (1)$$

where T_{xx}, T_{xy}, T_{yx}, T_{yy} are the components of the transmissivity tensor (L^2/T);

h is the hydraulic head in the aquifer (L);

t is time (T);

S is the storage coefficient (dimensionless);

W(x,y,t) is the volumetric flux per unit surface area (L/T).

If the coordinate axes x and y are co-linear with the principal components of the transmissivity tensor, T_{xx} and T_{yy}, the flow equation has the simplified form:

$$\frac{\partial}{\partial x}\left(T_{xx}\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(T_{yy}\frac{\partial h}{\partial y}\right) = S\frac{\partial h}{\partial t} + W(x,y,t) \quad (2)$$

Equation 2 is solved by finite-difference methods in a digital simulation model by Trescott, Pinder, and Larson (1976). In this model, the source term W(x,y,t) can include well discharge or recharge, transient leakage from a confining bed and steady leakage through a confining bed, recharge from precipitation, and evapotranspiration.

Since recharge wells, precipitation, and evapotranspiration are not used in the two-dimensional flow model of the study area, and transient leakage is not considered to be significant in the area, W(x,y,t) may be expressed as:

$$W(x,y,t) = q_w(x,y,t) - \frac{K'(x,y)}{b'(x,y)}\left(H_o(x,y) - h(x,y,t)\right) \quad (3)$$

where $q_w(x,y,t)$ is the volume rate of withdrawal per unit area (L/T);

K'(x,y) is the vertical hydraulic conductivity in the confining layer (L/T);

h(x,y,t) is the head of the potentiometric surface (L);

$H_o(x,y)$ is the head at the water table (L);

b'(x,y) is the thickness of the confining layer(L).

Trescott, Pinder, and Larson (1976) will be the principal reference for the following sections describing the finite-difference model.

Finite-Difference Method

In order to solve equation 2 for a heterogeneous aquifer with irregular boundaries, the continuous derivatives may be replaced by finite-difference approximations for the derivatives at the node at the center of a block of aquifer whose properties are assumed to be uniform. The following implicit finite-difference equation is written for each node composing the finite-difference grid:

$$\frac{1}{\Delta x_j}\left\{\left[T_{xx(i,j+1/2)}\frac{(h_{i,j+1,k}-h_{i,j,k})}{\Delta x_{j+1/2}}\right]-\left[T_{xx(i,j-1/2)}\frac{(h_{i,j,k}-h_{i,j-1,k})}{\Delta x_{j-1/2}}\right]\right\}$$

$$+\frac{1}{\Delta y_i}\left\{\left[T_{yy(i+1/2,j)}\frac{(h_{i+1,j,k}-h_{i,j,k})}{\Delta y_{i+1/2}}\right]-\left[T_{yy(i-1/2,j)}\frac{(h_{i,j,k}-h_{i-1,j,k})}{\Delta y_{i-1/2}}\right]\right\}$$

$$=\frac{S_{i,j}}{\Delta t}(h_{i,j,k}-h_{i,j,k-1})+\frac{Q_{w(i,j,k)}}{\Delta x_j\,\Delta y_i}-\frac{K'_{i,j}}{b'_{i,j}}(H_{o(i,j)}-h_{i,j,k}) \qquad (4)$$

where i,j,k are indices of the x-, y-, and time-dimensions, respectively;

Δx, Δy, Δt are the increments in the x-, y-, and time-dimensions, respectively;

$Q_{w(i,j,k)}$ is the well discharge (L^3/T).

Writing equation 4 for each node in the region at which the head is unknown results in a system of simultaneous linear equations. The system of equations generated by equation 4 is solved approximately by the strongly implicit procedure of Stone (1968). A discussion of this procedure and its incorporation into a digital simulation model of ground-water flow is found in Trescott, Pinder, and Larson (1976).

The finite-difference solution obtained in the two-dimensional model of the study area is dependent on the following assumptions:

1. Ground water in the Floridan aquifer moves in a horizontal plane in a single-layer, isotropic medium.
2. Water moves vertically into or out of the Floridan aquifer through the semiconfining layer.
3. The Lake City Limestone underlying the Floridan aquifer is impermeable.
4. The head in the surficial aquifer does not change with time or in response to any imposed stress.

Discretization of Input Data

Finite-Difference Grid and Boundary Conditions

The area of interest was subdivided into rectangular blocks composing the finite-difference grid. The grid, shown on figure 12, has 31 rows and 40 columns. The blocks range in size from 1,000 x 1,000 ft in the well field to 4,000 x 4,000 ft near the boundaries.

The limits of the modeled area were chosen on the basis of (1) the configuration of the potentiometric surface of the Floridan aquifer, and (2) the distance from the well field at which the effects of pumping would not likely extend. This distance was estimated using an analytical solution with maximum pumping stress. Figure 13, in which the grid is superimposed on the potentiometric-surface map of September 16, 1974, shows how the limits of the modeled area, of about 120 mi^2, were selected. The model boundary shown in figure 13 by a heavy line represents a no-flow (zero-flux) boundary, and it is drawn across the columns and rows always approximately perpendicular to equipotential lines. Constant-head boundaries, represented by a line with triangles, are located in the upper left corner and across the bottom part of the grid; these allow ground water flowing downgradient to leave the modeled area as underflow.

The stability of these boundaries over the different seasons and over several years of record is evident in unpublished U.S. Geological Survey maps made by C. B. Hutchinson for September and December 1973, and March, May, and July 1974, and by L. R. Mills and C. B. Hutchinson for September 1974, and May and September 1975. Because of heavy pumping from the wells in the well field, it would be expected that in the future, nearby boundaries will change due to the expanding drawdowns.

Potentiometric Surface and Water Table

The average head value of the Floridan aquifer within each block is determined by interpolating between the potentiometric-surface contours of September 16, 1974, shown in figure 13. In like manner, the average head value of the surficial aquifer within each block is determined from figure 14 in which the grid is superimposed on the water-table map for the same date.

Transmissivity, Storage Coefficient, and Leakance

The transmissivity (T) of an aquifer refers to the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. The storage coefficient (S) is the volume of water an aquifer releases from or takes into

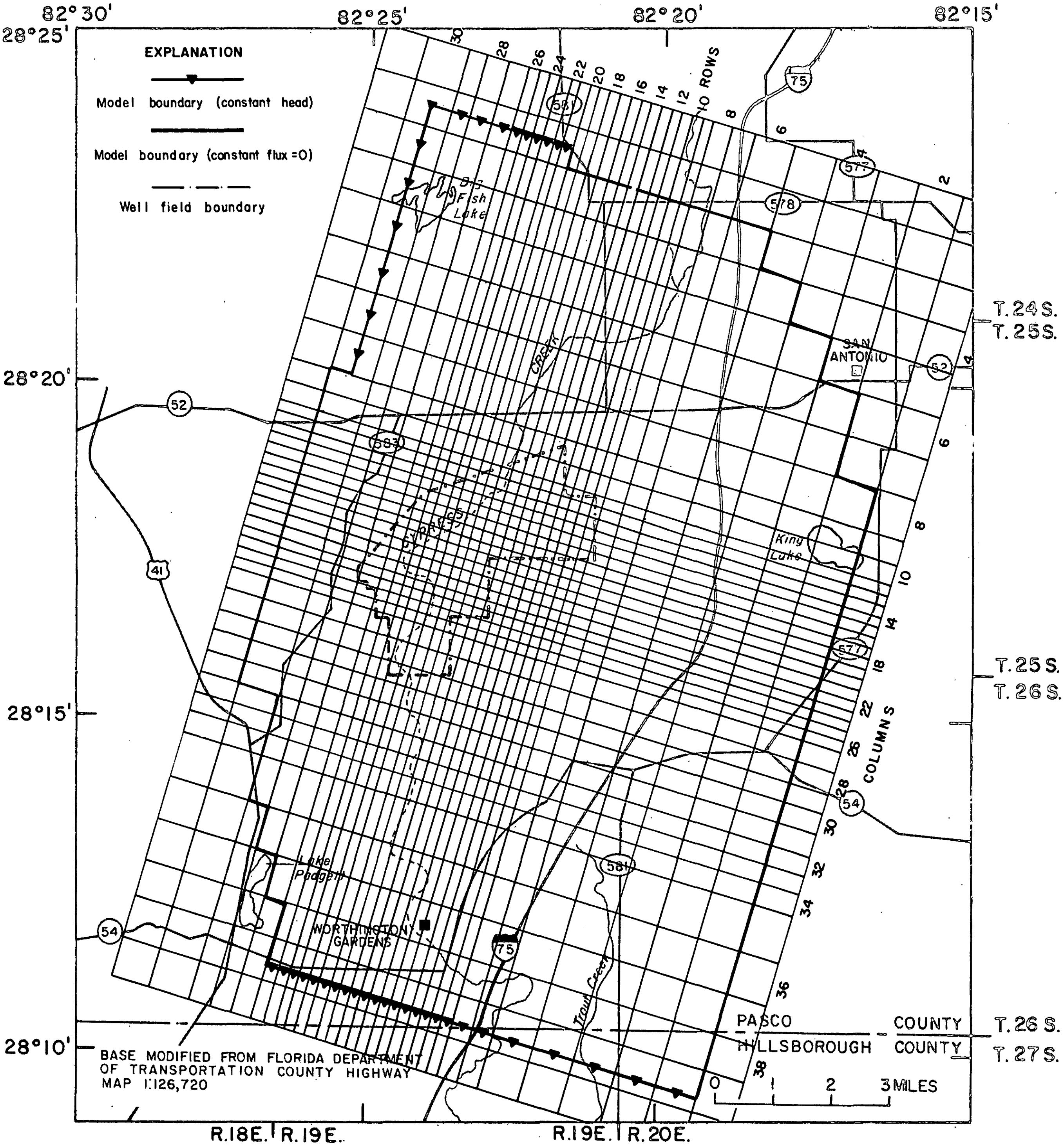


Figure 12.--Finite-difference grid of Cypress Creek well field and surrounding area.

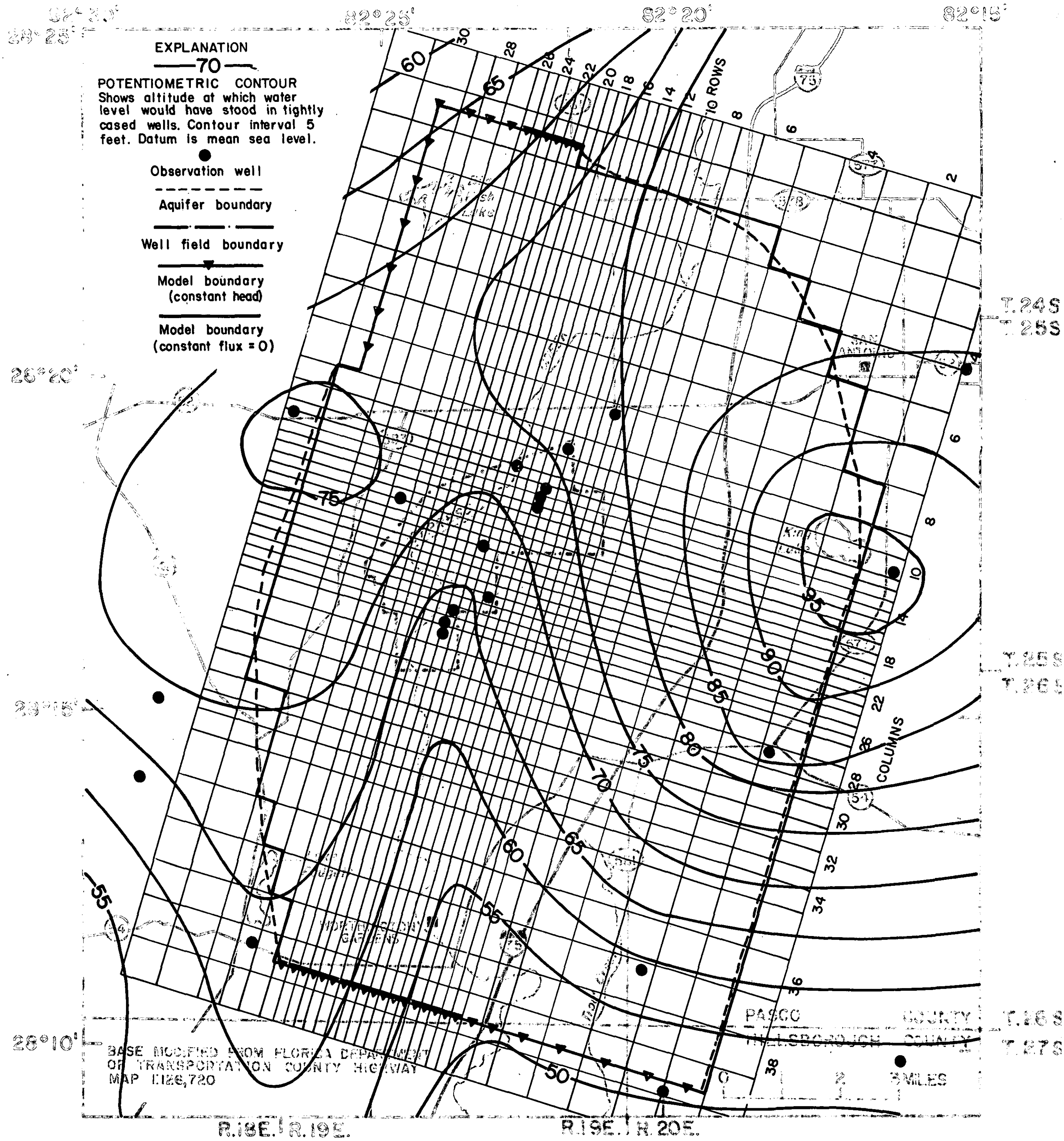


Figure 13.--Finite-difference grid superimposed on the September 16, 1974, potentiometric surface.

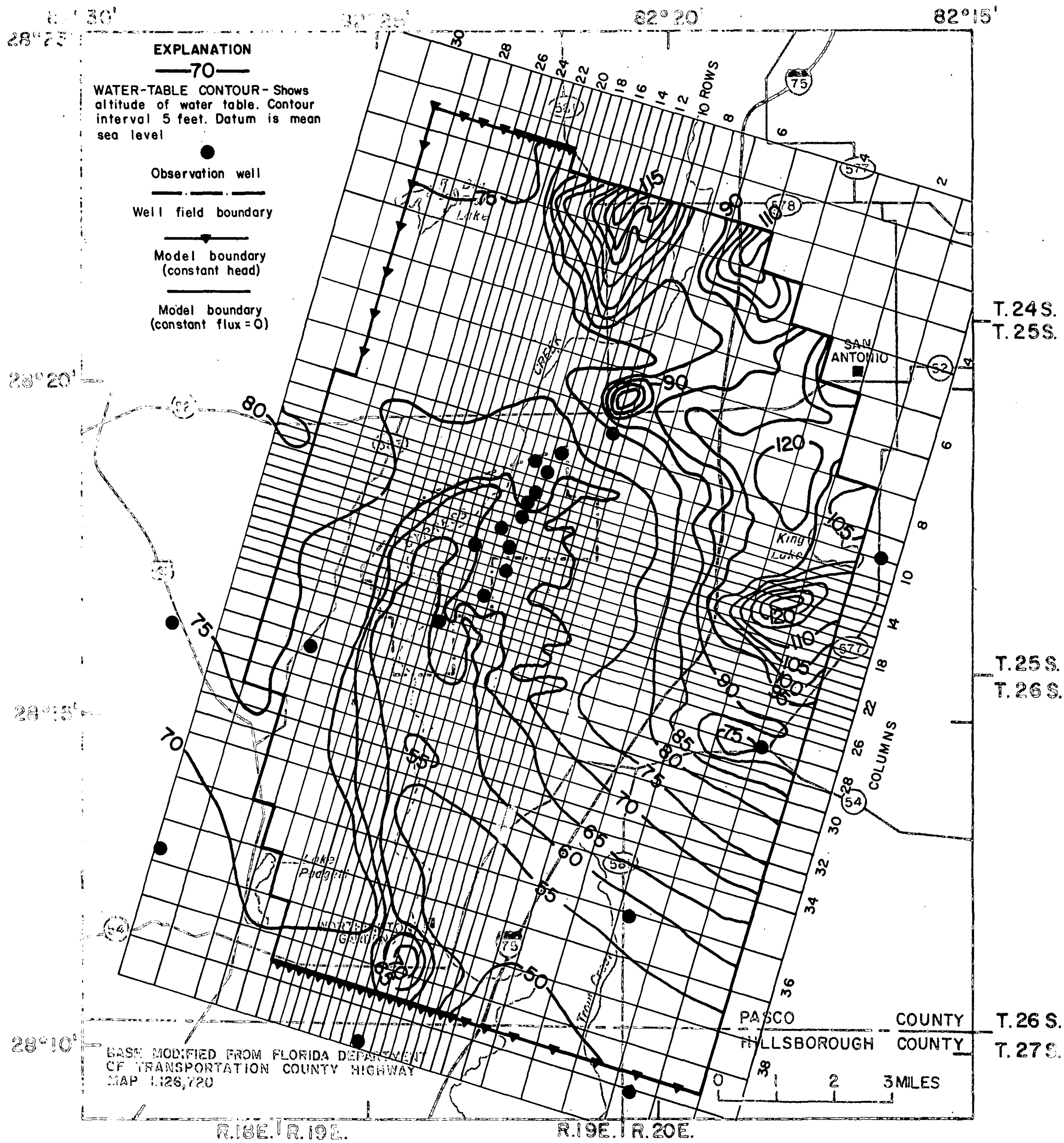


Figure 14.--Finite-difference grid superimposed on the September 16, 1974, water table.

storage per unit surface area of the aquifer per unit change in head. The leakance (K'/b') refers to the ability of the semiconfining layer to transmit water in the direction of the hydraulic gradient, either upward or downward. It is defined by Hantush (1956, p. 702) as the quantity of flow that crosses a unit area of the interface between the main aquifer and the semiconfining layer when the head difference between the main aquifer and the aquifer supplying leakage is unity.

The aquifer properties, T, S, and K'/b', are generally determined by conducting aquifer tests in which water-level changes induced by a pumping well are recorded in nearby observation wells. By knowing the geologic framework, the correct mathematical model can be selected with which to analyze the aquifer-test data, and a solution is obtained.

Five aquifer-test sites in and near the Cypress Creek well field are shown in figure 15. The aquifer-test data were analyzed according to infinite leaky-aquifer models of Hantush and Jacob (1955) and Hantush (1956). The analyses support the premise that the quantity of water stored in the semiconfining layer is negligible. Analyses of water-level changes in the Lake City Limestone indicate that the only significant leakage to and from the Floridan aquifer occurs from the surficial aquifer. Estimated values of T, S, and K'/b' are shown for each test except at site C-10 where K'/b' was not determined because of the short duration of the test (fig. 15).

The least accurate of the aquifer properties determined by these aquifer tests may be K'/b' since there is an order of magnitude variation in b', thickness of semiconfining layer, within the radius sampled by each test. This ratio also exhibits much greater variation from one test site to another than does either T or S (see figure 15). Thus, K'/b' was chosen as the main variable parameter with which the digital simulation model was calibrated.

Model Calibration

Purpose and Procedure

In the calibration of the model development, it is imperative that a steady-flow (equilibrium) condition exists across the semiconfining layer. This condition is attained after sufficient time has elapsed following a stress on the system, such as a significiant rainfall, or large-scale withdrawal or recharge activities by man. The steady-flow condition will exist until it is disrupted by another stress. Flow across the semiconfining layer can be approximately steady even when the system as a whole is declining slightly due to loss of water from storage.

When this steady-flow condition can be shown to approximate a steady-state condition, the storage term in the flow equation can be eliminated during model calibration. Referring to equations 2 and 3 in the Flow

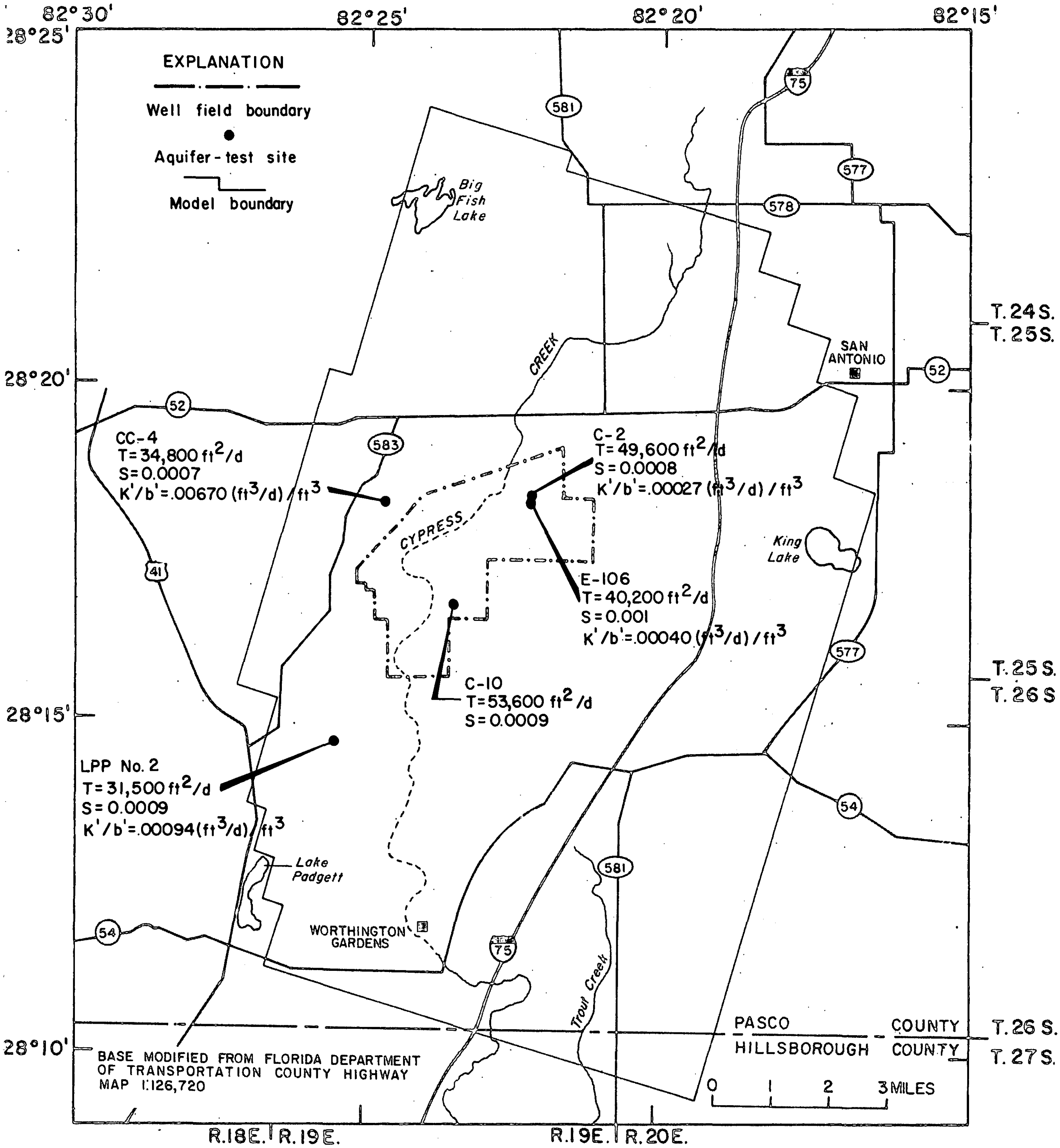


Figure 15.--Locations of aquifer-test sites, and estimated values of transmissivity (T), storage coefficient (S), and leakance (K'/b').

Equation section of the report, the model simulates steady-state conditions when $\frac{dh}{dt} = 0$. Thus when a true steady-state condition prevails, the rate of storage change term, $S\frac{dh}{dt}$, is zero and $h(x,y,t) = h(x,y)$ is constant in the leakage term. Since $H_o(x,y)$ is assumed constant in time, the head separation between aquifers, and consequently the leakage term, are constant under the assumption of steady state.

The steady-flow approximation to steady state is clarified by looking at the terms on the right-hand side of the differential equation,

$$S\frac{dh}{dt} + q_w(x,y,t) + \frac{K'(x,y)}{b'(x,y)} (H_o(x,y) - h(x,y,t)),$$

under steady-flow conditions. The pumpage term is usually known (or may be non-existent). The storage and leakage terms may be estimated from analyses of hydrographs and aquifer tests. An example of "steady flow" approximating a steady-state condition is provided by analyzing the hydrographs of deep and shallow wells at site E-107. During the period October 8-14, 1974 (a period of no rainfall and no local pumpage), the head in the Floridan aquifer declined from 70.85 ft to 70.45 ft while the water-table head declined from 69.50 ft to 69.15 ft. Thus $\frac{dh}{dt}$ was approximately 0.067 ft/d and H_o-h was approximately constant ("steady flow") at -1.3 ft. Average estimates for storage coefficient and leakance, obtained from aquifer-test data shown in figure 15, were 0.0009 and 0.002 d^{-1}, respectively. The storage term was (0.0009)(0.067) = 0.00006 ft/d, the pumpage term was zero, and the leakage term was (0.002)(-1.3) = -0.0026 ft/d. Thus, leakage was about 43 times greater than the storage term. Therefore, change in storage was relatively negligible, and the model could be calibrated as steady state. At any other time during a condition of steady flow, the aquifer characteristics are the same and a new calibration should be identical to the first.

During calibration, an aquifer parameter (or parameters) is adjusted until the computer-generated output compares favorably (within acceptable limits) with a set of field observations from the aquifer. Other input data, such as boundary conditions and hydraulic stresses, may be adjusted as necessary to achieve calibration. The process of adjusting parameters is a subjective one, and a given combination of parameters that produces an acceptable calibration is usually not a unique one. Thus the model parameters must always be kept within the plausibility limits established by field tests and observations.

The process of calibrating the model accomplishes the following: (1) provides an improved conceptualization of the aquifer system; (2) designates those areas requiring additional data collection and field testing; and (3) determines the kinds of field data and tests that are needed in order to make the model a more correct approximation of the prototype.

September 16, 1974, Steady-Flow Calibration

A condition of steady flow across the semiconfining layer in the Cypress Creek well field and the surrounding area existed on September 16, 1974. Rainfall data, and analyses of hydrographs from recorder wells in the surficial and Floridan aquifers, indicate that rainfall effects on the aquifer system in the well-field area were negligible for 8 days before September 16, 1974, when the water levels were measured. Although some rain fell near the southern boundary of the modeled area for several days preceding September 16, the effects on the aquifer system appeared to be local and did not affect the well-field area. No manmade stresses that would significantly affect the regional flow pattern were known to exist in the area during this period. The start-up input (model parameters and initial and boundary conditions) for the model included the potentiometric surface and water table shown in figures 13 and 14, respectively, and uniform values for the leakance (K'/b') of the semiconfining bed and transmissivity (T) of the aquifer.

The K'/b' and T values were adjusted during a number of steady-state computer runs, until the computed potentiometric surface closely approximated the observed September 16, 1974, potentiometric surface. The criterion used in this analysis is that a condition of steady state is closely approximated when the head change in all nodes between time steps in transient simulations is less than 0.01 ft. The result is shown in figure 16. The mean of the differences between the observed and computed heads in the 14 blocks containing control wells was 0.43 ft, with a standard deviation of $\pm$0.66 ft. The mean of the differences between the observed and computed heads at all nodes was 0.16 ft, with a standard deviation of $\pm$0.64 ft.

Estimates of leakance and transmissivity derived from the model calibration are shown in figures 17 and 18, respectively. Leakance ranges from 4×10^{-6} to 1.6×10^{-2} $(ft^3/d)/ft^3$. The distribution of leakage rates per unit area for September 16, 1974, (fig. 19) is obtained after multiplying the leakance value (K'/b') at each node by the difference in head between the water table and potentiometric surface (H_o-h) at that node. Areas of maximum downward leakage correlate approximately with highs in the potentiometric surfaces of the surficial and confined aquifers along the western side and in the east-central part of the modeled area. A trough-shaped area of maximum upward leakage extends from the well field to the southern boundary of the modeled area. This area also approximately coincides with an area of relatively high transmissivity (fig. 18). Transmissivity values range from 40,000 to 48,000 ft^2/d over the modeled area.

Tests of Calibration Accuracy

The accuracy of the model calibration was tested in three ways:

1. Comparison of the potentiometric surface observed in May 1975 with the potentiometric surface obtained by steady-flow model simulation using the May 12, 1975, water table.

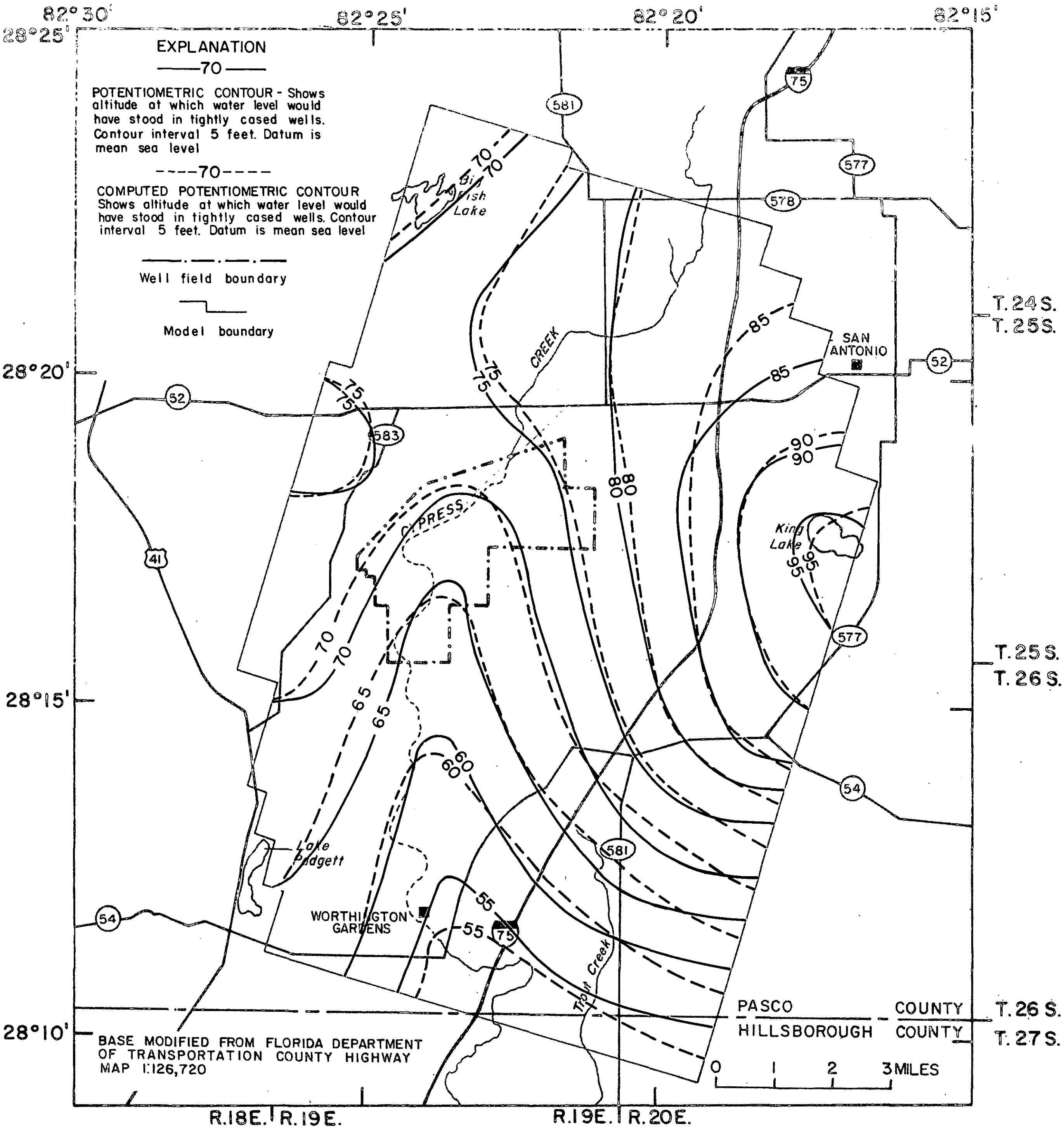


Figure 16.--Comparison of observed and computed potentiometric surface, September 16, 1974.

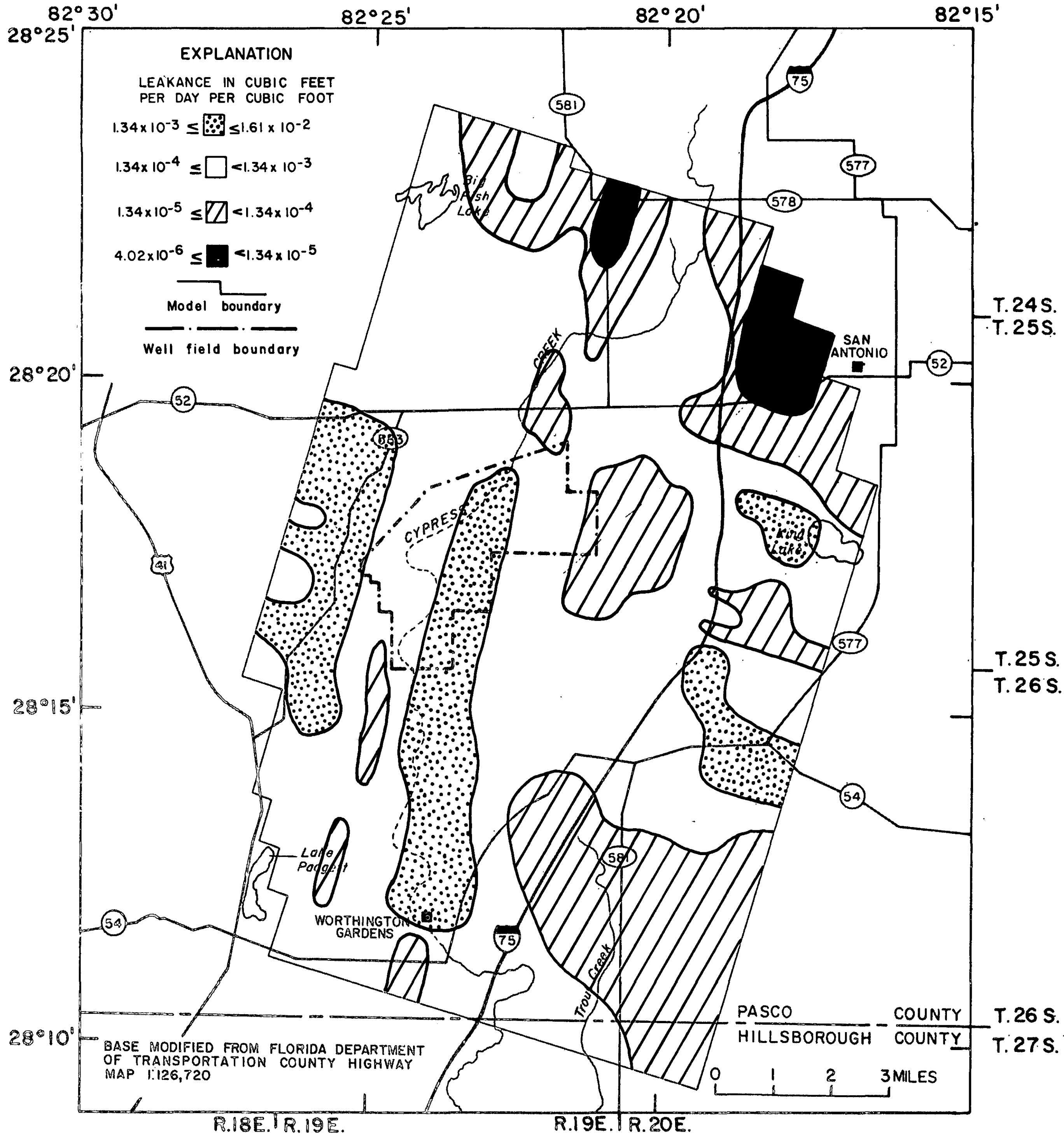


Figure 17.--Leakance (K'/b') distribution derived from steady-flow calibration of model.

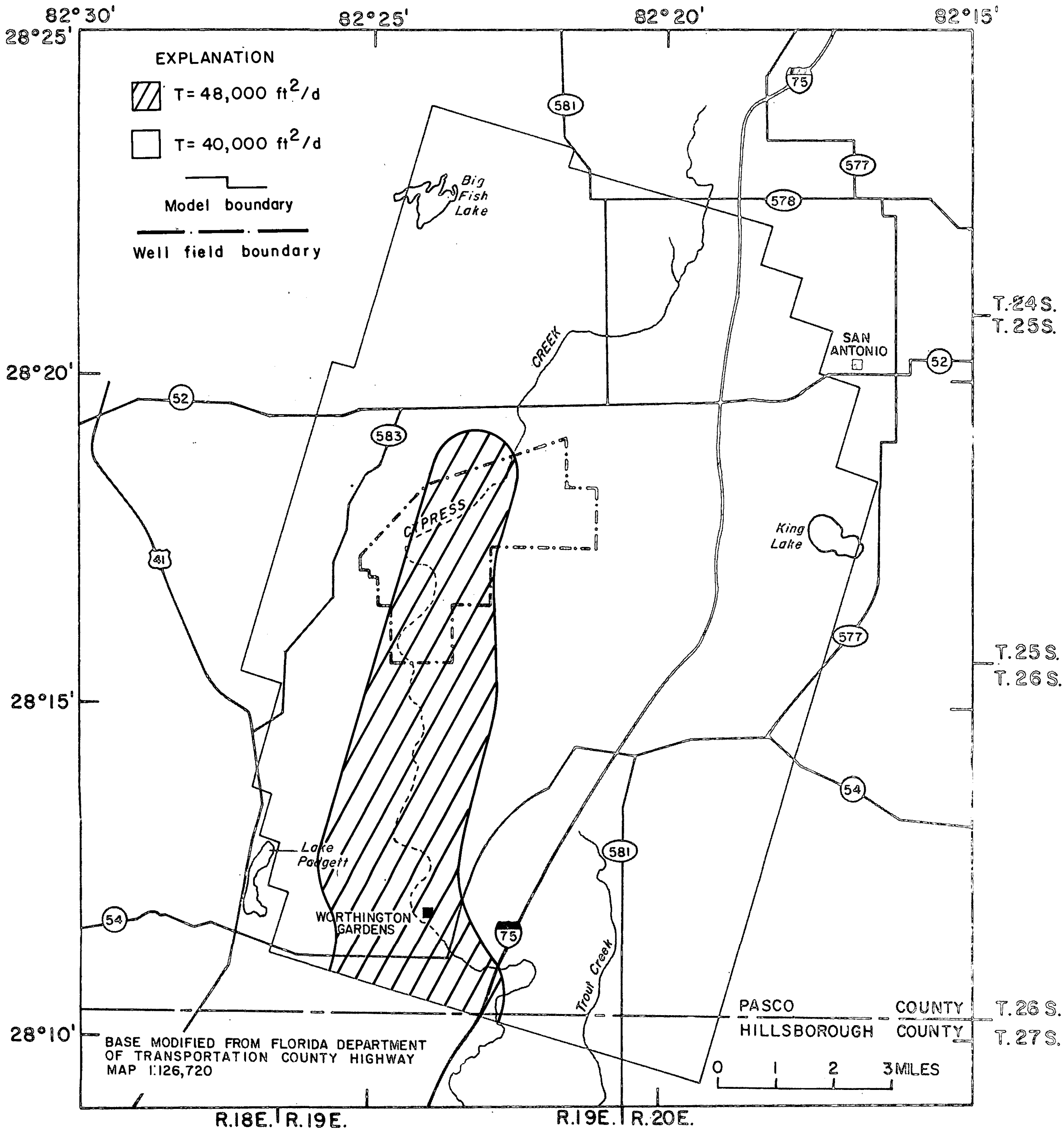


Figure 18.--Transmissivity (T) distribution derived from steady-flow calibration of model.

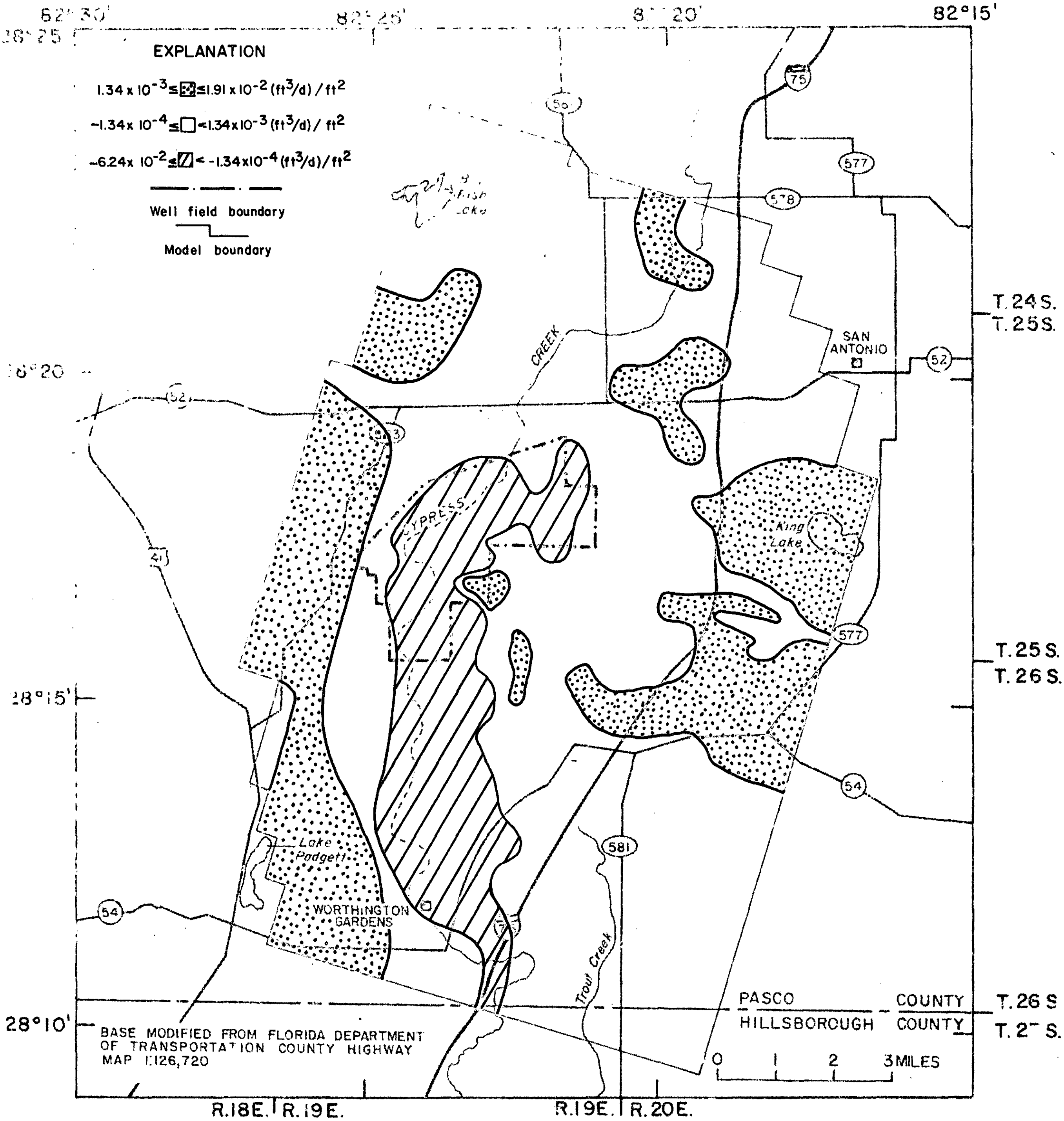


Figure 19.--Leakage rate per unit area obtained by multiplying leakance (K'/b') by head difference between water table and potentiometric surface (H_c-h) at each node; September 16, 1974.

2. Comparison of observed drawdowns with drawdowns obtained by model simulation of actual pumpage from the northeastern part of the well field, July 15 to September 15, 1976.

3. Comparison of observed drawdowns with drawdowns obtained by model simulation of actual pumpage from the southern part of the well field, January 20-28, 1976.

Simulation of Potentiometric Surface Using May 1975 Water Table

The model was calibrated using September 1974 conditions. In September of any normal year, water levels in the surficial aquifer and Floridan aquifer are at or near their maximums and there is little or no pumpage for citrus irrigation. A normal May presents a contrasting condition: water levels are at or near their minimums for the year, and maximum amounts of water are being pumped for irrigation.

About one-half inch of rainfall occurred in the well-field area 2 days prior to the May 12, 1975, water-level measurements. Analyses of hydrographs indicate that the effect of the recharge had dissipated by May 12, and that a condition of steady flow existed across the semiconfining layer. Therefore, it was decided to test the model calibration by replacing the September 1974 water table with the estimated May 12, 1975, water table (fig. 9). Values for the constant-head boundary nodes were replaced with May 12, 1975, values, and pumping rates for citrus irrigation were estimated and averaged for each node as follows:

NODE		PUMPAGE (gal/min)	NODE		PUMPAGE (gal/min)	NODE		PUMPAGE (gal/min)
Row	Column		Row	Column		Row	Column	
3	28	45	6	28	121	25	35	90
4	16	108	10	38	144	26	36	180
4	27	144	13	38	76	27	16	139
5	20	76	17	38	45	27	37	180
5	28	422	24	36	90	TOTAL PUMPAGE = 2.7 Mgal/d		

The model was run to steady state and the observed May 12, 1975, potentiometric surface was compared with the simulated surface (fig. 20). Of the 28 grid blocks containing control wells, the mean of the differences between the observed and computed heads was 0.58 ft, with a standard deviation of ±1.23 ft.

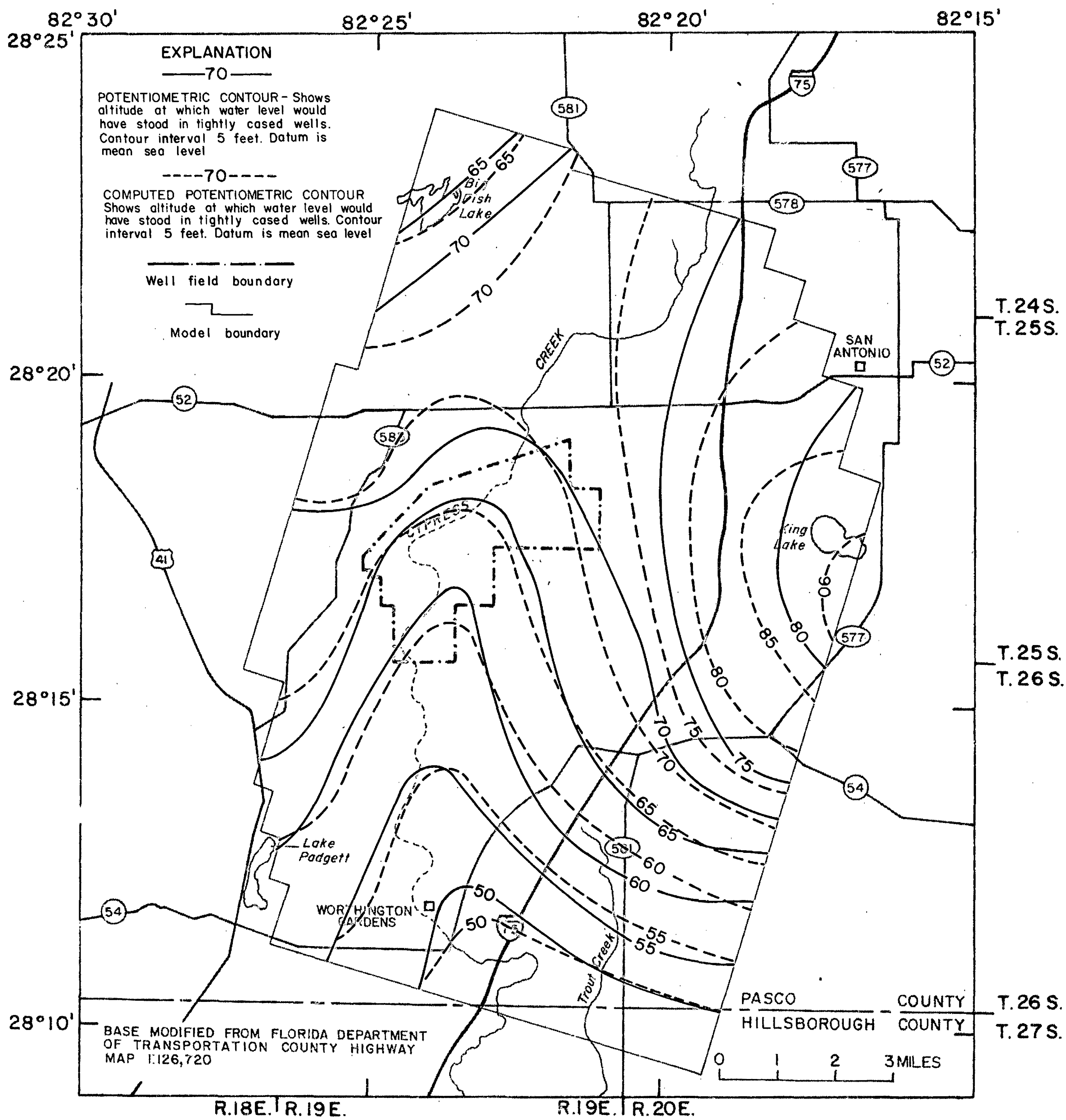


Figure 20.--Comparison of observed and computed potentiometric surface, May 12, 1975.

When considering the entire modeled area, the maximum difference between computed and observed heads occurs at the potentiometric high near King Lake south of San Antonio. In this area, the computed head is as much as 8 ft higher than the observed head. Assuming that the conceptual model of the aquifer system is essentially correct, and that the measured water levels accurately represent the head in the Floridan aquifer, one or more of the following (not necessarily listed in order of importance) may account for the large difference between observed and computed heads:

1. Since some rain fell in the area a few days before the May 12 water-level measurements were taken, transient effects may have existed and the system may not have readjusted to a steady-flow condition.

2. Since all the observation wells in this area are within or near large citrus groves, the observed water levels may be influenced by local depressions due to irrigation pumpage, and thus are not representative of the regional potentiometric surface. (Two key wells are located outside the model boundary (fig. 11, wells with values of 84 and 81 ft); therefore, it was impossible to include pumpage from these groves in the simulation model.) This could affect the assumption of the location of the no-flow boundary.

3. Water may be flowing in the aquifer across the no-flow boundary of the model. This would necessitate changing the boundary condition or relocating the no-flow boundary westward.

4. An excessively high estimate of the May 1975 water table in the area could account for the excessively high potentiometric surface computed by the model. Figure 9 shows the relatively few control wells for guiding the estimate of the water table in this area. In addition, figure 7 shows a very thin surficial aquifer in well 808 near King Lake. It is possible that parts of the surficial aquifer in this area may be thin enough to be dewatered during the dry season.

5. An excessively low estimate of the September 1974 water table in this area of downward leakage would cause the calibrated value of K'/b' to be too high, or the calibrated value of T to be too low. A steady-state simulation with a correct estimate of the May 1975 water table, and having these erroneous values of K'/b' or T, would produce the excessively high potentiometric surface recorded in figure 20.

The test of the model calibration by simulating the May 1975 potentiometric surface is effective for those areas of the model having large differences in head between the water table and potentiometric surface. The test has shown a significant error in the calibration for that part of the modeled area located south of San Antonio. The collection of additional water-level data in this area in both the surficial aquifer and Floridan aquifer would permit a better estimate of the water table and better definition of the model boundary. This would contribute to an improved calibration of the model.

Large areas of the model exhibit a year-round condition of no difference in head between the water table and potentiometric surface, or differences of only 1 or 2 ft. The test described above does little to determine the accuracy of the model calibration in these areas. The calibration in these areas can be tested by introducing additional real pumpages in the vicinity and comparing simulated drawdowns to observed data.

Simulation of Pumpage, July 15 to September 15, 1976

Figure 21 shows the location of production wells C-1, C-2, and C-3 in the northeast part of the well field. Also shown are the locations of seven continuously recording observation wells and two intermittently measured wells open to the Floridan aquifer. The deep wells, with the exception of well CC-3, were paired with shallow wells so that the water table could be measured periodically. The production wells were pumped intermittently from July 15 to September 15, 1976, at an aggregate rate of as much as 10 Mgal/d.

A water table was estimated for July 15, 1976, based upon measurements from 14 observation wells. Rainfall data and analyses of well hydrographs indicated that a condition of steady flow across the semiconfining layer existed on July 15. (Well C-1 was pumping at 1,300 gal/min on July 13 and 14, but the drawdown was nearly stabilized by July 15.) Constant-head node values in the model were estimated on the basis of the July 15 data.

The model was run to steady state with the new water table and with well C-1 pumping at 1,300 gal/min. The resulting computed potentiometric surface was compared to head data observed on July 15 (table 1). The mean of the differences between computed and observed heads for the nodes corresponding to the 9 well sites in table 1 was 0.29 ft, with a standard deviation of ± 1.1 ft. The computed potentiometric surface was entered into the model as the July 15 starting head for the pumping simulation. A uniform storage coefficient of 7.0×10^{-4}, from aquifer-test data, was chosen for the transient simulation. Pumpage from the three production wells was generalized and represented in the model by seven periods as shown in table 2.

A summertime period of pumping was chosen with the assumption that the intensity and frequency of rainfall would suffice to keep the water table from declining significantly. Rainfall for the period July 15 to September 2, 1976, was recorded at a gage near production well C-3 as follows:

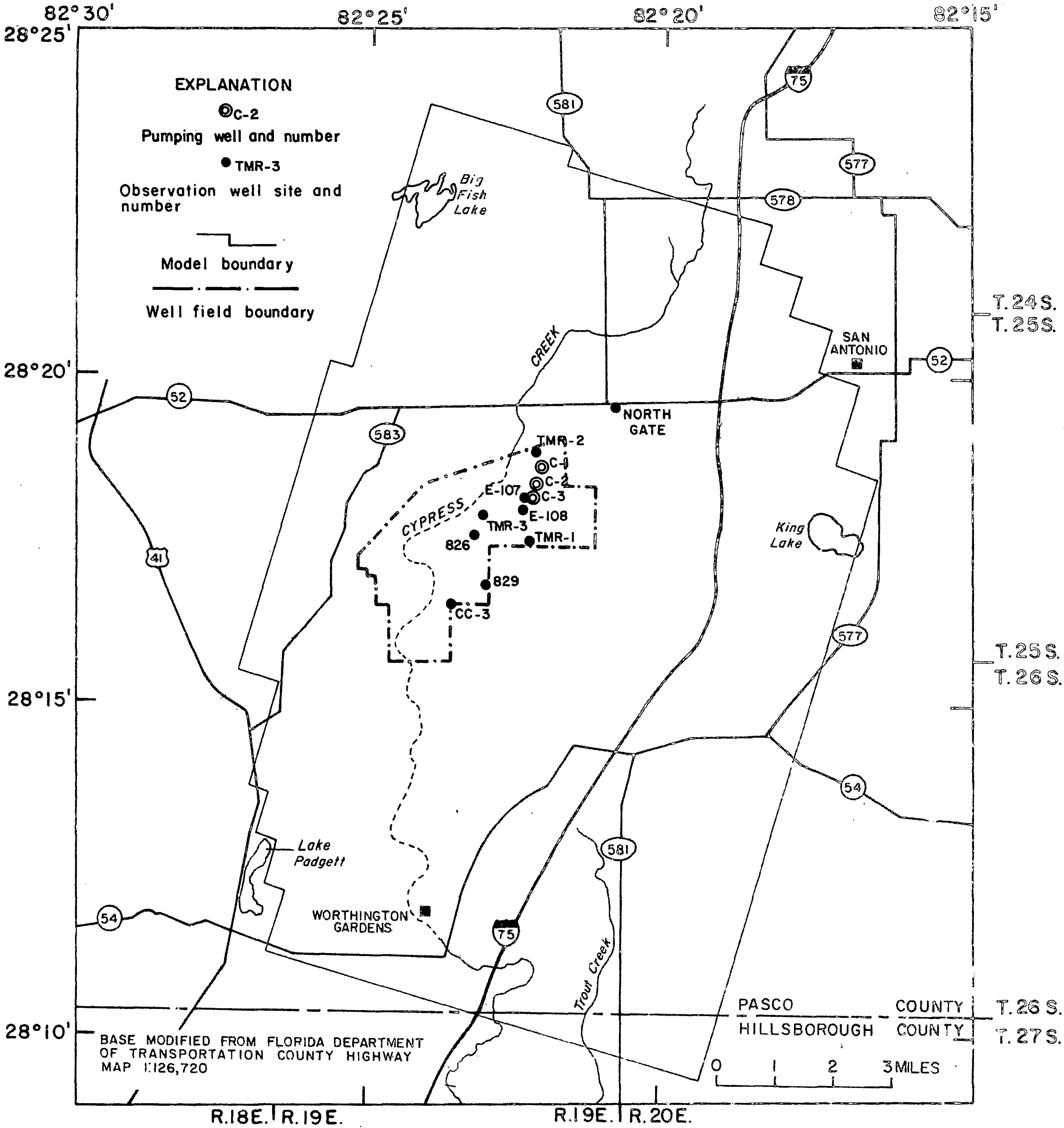


Figure 21.--Location of pumping wells and observation wells at Cypress Creek well field during period July 15 - September 15, 1976.

Table 1.--Comparison of observed water-level data with data from model simulation of pumpage during July 15 - September 15, 1976

Observation well site	OBSERVED DATA July 15 - September 15, 1976				MODEL DATA				
	Water table (H_o) on July 15 (ft above sea level)	Potentiometric surface on July 15 (ft above sea level)	Static head difference, H_o - potentiometric, on July 15 (ft)	Average head difference, H_o - potentiometric, during August (ft)	Node row, column	Water table (H_o) on July 15 (ft above sea level)	Potentiometric surface on July 15 (ft above sea level)	Static head difference, H_o - potentiometric, on July 15 (ft)	Average head difference, H_o - potentiometric, during August (ft)
North Gate	87.1	76.0	11.1	11.0	9,7 9,8 10,7 10,8	87.8	78.6	9.2	10.7
TMR-2	73.6	72.6	1.0	0.5	15,9 15,10 16,9 16,10	72.2	71.1	1.1	5.7
E-108	67.7	69.2	-1.5	3.0	15,14 15,15 16,14 16,15	67.4	69.2	-1.8	3.1
TMR-3	62.7	67.8	-5.1	-2.0	19,16	63.0	67.1	-4.0	-2.4
TMR-1	69.3	69.5	-0.2	1.0	13,17 14,17	68.2	69.5	-1.3	1.2
CC-3	(no data)	62.4	---	---	19,25 20,25	64.0	63.2	0.8	1.0
E-107	68.8	69.4	-0.6	7.5	15,13 16,13	68.8	69.7	-0.9	7.4
826	63.7	65.5	-1.8	0.0	19,18	64.0	66.0	-2.0	-1.0
829	67.8	64.9	2.9	3.0	16,22 16,23 17,22 17,23	67.3	65.2	2.1	2.6

Table 2.--Actual and simulated pumpage from wells C-1, C-2, and C-3 in the Cypress Creek well field during the period July 15 to September 15, 1976

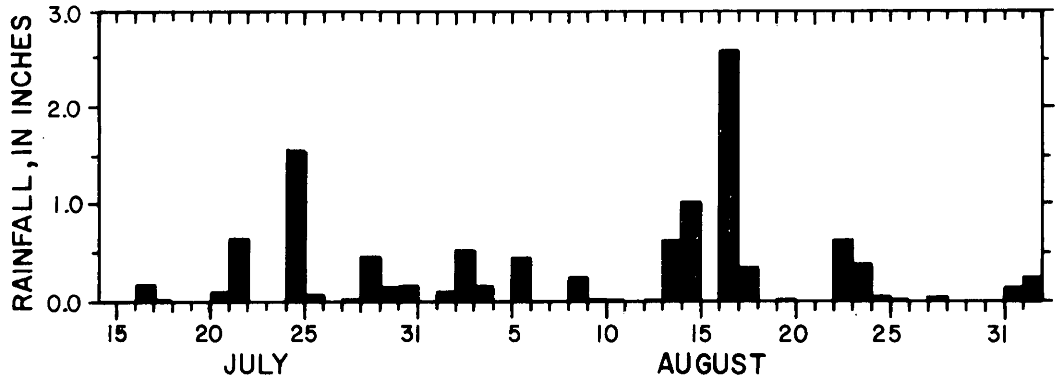
Date	ACTUAL PUMPAGE Mgal/d			SIMULATED PUMPAGE Mgal/d			Pumping period no.
	C-1	C-2	C-3	C-1 Row 15, Col. 10	C-2 Row 15, Col. 12	C-3 Row 15, Col. 13	
7/15/76	2.498	2.161	0	2.3	2.3	0	1
16	2.686	2.958	0				
17	1.842	2.099	0				
18	1.981	1.765	0				
19	2.322	0.552	0	2.5	0.3	0	2
20	2.772	0.036	0				
21	3.098	2.879	3.467	3.1	2.9	3.5	3
22-26	0	0	0	0	0	0	4
27	2.596	2.307	2.368	3.2	3.0	3.0	5
28	3.030	2.740	2.772				
29	3.058	2.827	2.840				
30	3.293	2.990	3.023				
31	3.461	3.159	3.195				
8/ 1	2.630	2.391	2.396				
2	3.193	2.895	2.940				
3	3.210	2.905	2.926				
4	3.230	2.910	2.939				
5	3.193	2.911	2.926				

Table 2.--Actual and simulated pumpage from wells C-1, C-2, and C-3 in the Cypress Creek well field during the period July 15 to September 15, 1976 - continued

Date	ACTUAL PUMPAGE Mgal/d			SIMULATED PUMPAGE Mgal/d			Pumping period no.
	C-1	C-2	C-3	C-1 Row 15, Col. 10	C-2 Row 15, Col. 12	C-3 Row 15, Col. 13	
8/ 6	3.616	3.309	3.331				
7	3.251	2.979	2.983				
8	2.813	2.578	2.610				
9	3.156	2.877	2.923				
10	3.301	3.006	3.027				
11	3.394	3.098	3.114				
12	3.176	2.879	2.884				
13	3.308	3.033	3.059				
14	3.244	2.960	3.095				
15	3.235	2.954	2.859				
16	3.296	3.013	3.028				
17	3.249	2.977	3.014				
18	3.340	3.059	3.062				
19	3.717	3.370	3.380				
20	3.326	3.020	2.998				
21	2.943	2.710	2.814				
22	3.300	3.012	3.012				
23	3.349	3.037	3.053				
24	3.397	3.098	3.121				
25	3.340	3.041	3.075				
26	3.248	2.967	2.997				
27	3.409	3.109	3.162				
28	3.348	3.084	3.107				

Table 2.--Actual and simulated pumpage from well C-1, C-2, and C-3 in the Cypress Creek well field during the period July 15 to September 15, 1976 - continued

Date	ACTUAL PUMPAGE Mgal/d			SIMULATED PUMPAGE Mgal/d			Pumping period no.
	C-1	C-2	C-3	C-1 Row 15, Col. 10	C-2 Row 15, Col. 12	C-3 Row 15, Col. 13	
8/29 30 31	3.417 3.247 3.336	3.165 2.971 3.051	3.201 3.002 3.086				
9/ 1	0.694	0.662	0.564	0.7	0.6	0.6	6
2-15	0	0	0	0	0	0	7



A comparison of observed water-level data with data from the simulation model is given in table 1. It will be noted that the values in the observation wells are represented in the model by values ranging from single-node values to the mean value of 4 adjacent nodes. The number of nodes involved depends upon the location of the observation well in relation to the finite-difference grid. Because of the steeply curvilinear nature of the drawdown profile near a pumping well, the straight-line averaging of drawdowns in nodes containing and adjacent to a pumping well will introduce slight errors. During all of August when the wells were recording maximum drawdowns, the head separation in the model was reasonably close to observed values except at well TMR-2. Thus, the use of the two-dimensional model to simulate major pumping, and thereby to test the accuracy of the calibration, seems justified. This will be shown to apply even to well TMR-2.

Figures 22-27 are hydrographs showing observed and computed water-level changes in nine observation wells in the Cypress Creek well field and vicinity during July 15 to September 15, 1976. During the maximum-drawdown period of August, there is essentially no change in the computed water levels at the nine wells; they are at steady state. However, the observed data for the wells show mutually similar fluctuations during this period, with a range in the fluctuations of about 1 ft. These fluctuations follow similar fluctuations in the water table, which in turn seem to correlate with rainfall.

Well CC-3 is more than 2 mi from the nearest pumping well, and the effects of pumpage on water levels in this well appear to be negligible (fig. 22). The North Gate well (fig. 23) is more than 1.5 mi from the nearest pumping well, and the observed data show no apparent effects from the pumpage. However, the model computed a maximum drawdown of 1.5 ft at this well. This is an indication that leakance or transmissivity values in the model may be in error in this area. Another possible source of error arises from the fact that the well is located at the intersection of four relatively large grid blocks (1,000 x 4,000 ft each). Thus, an area of more than 0.5 mi^2 is involved in the calculation of drawdown at a point. This illustrates the need for reducing block sizes in the finite-difference grid for those areas where more accuracy and refinement of the data are desirable.

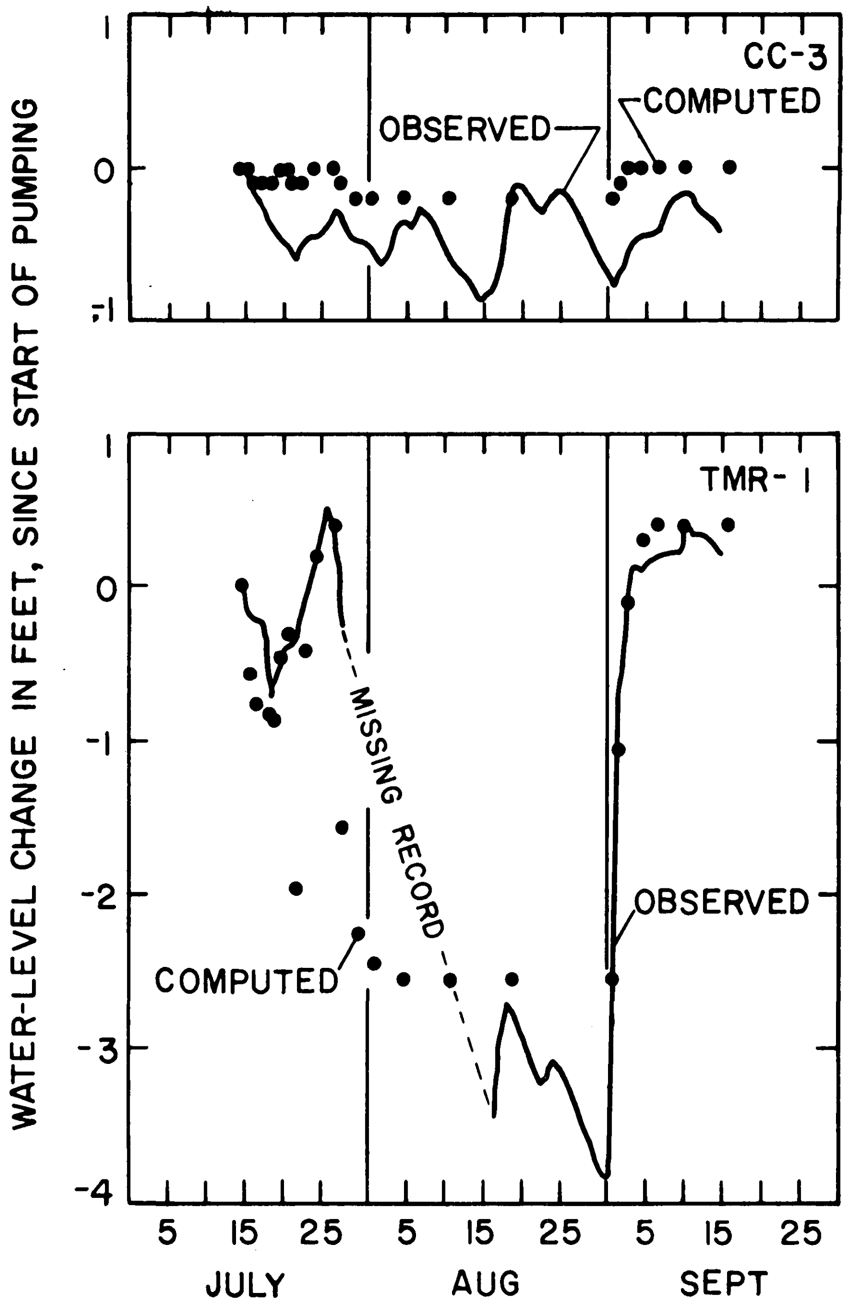


Figure 22.--Comparison of computed and observed changes in potentiometric surface in wells CC-3 (top graph) and TMR-1 (bottom graph), July 15 - September 15, 1976.

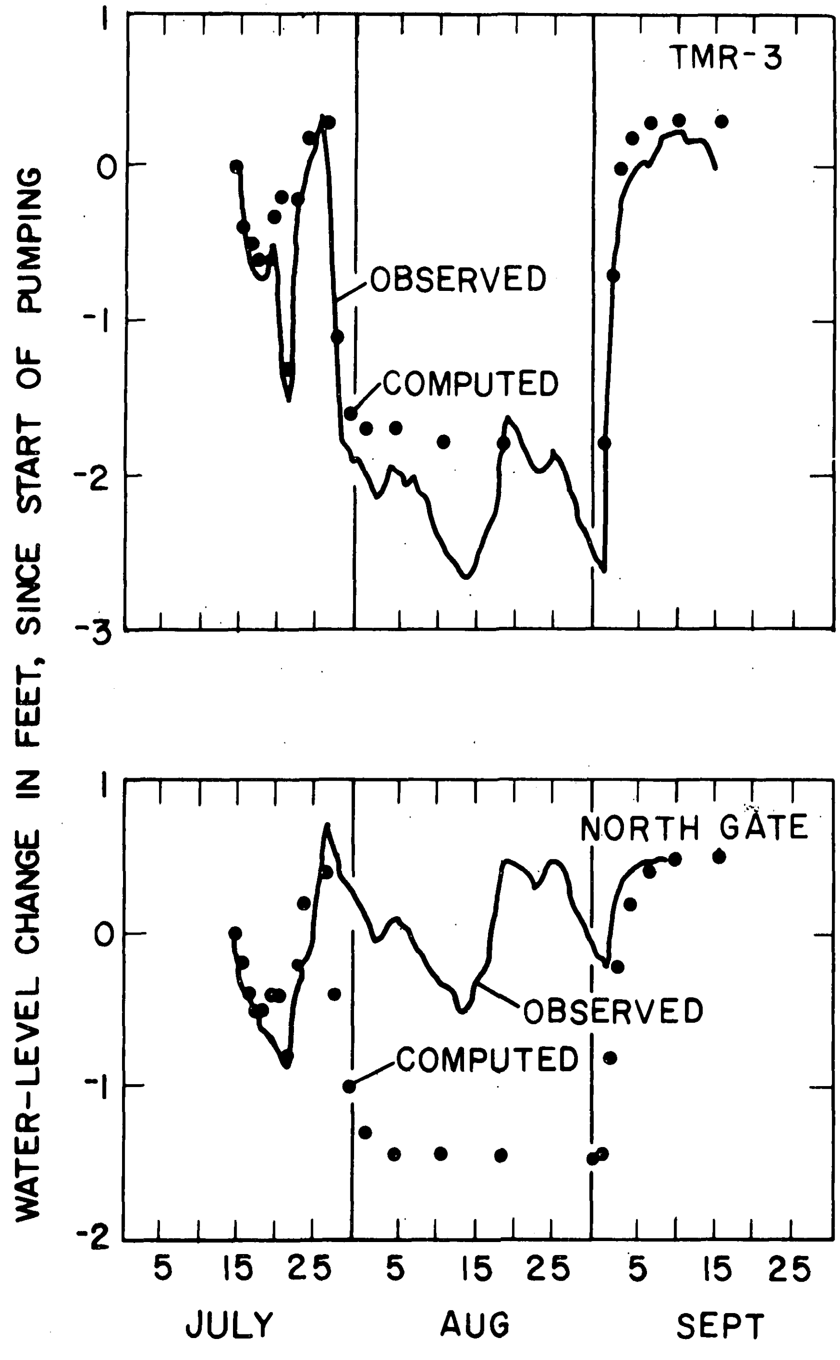


Figure 23.--Comparison of computed and observed changes in potentiometric surface in wells TMR-3 (top graph) and NORTH GATE (bottom graph), July 15 - September 15, 1976.

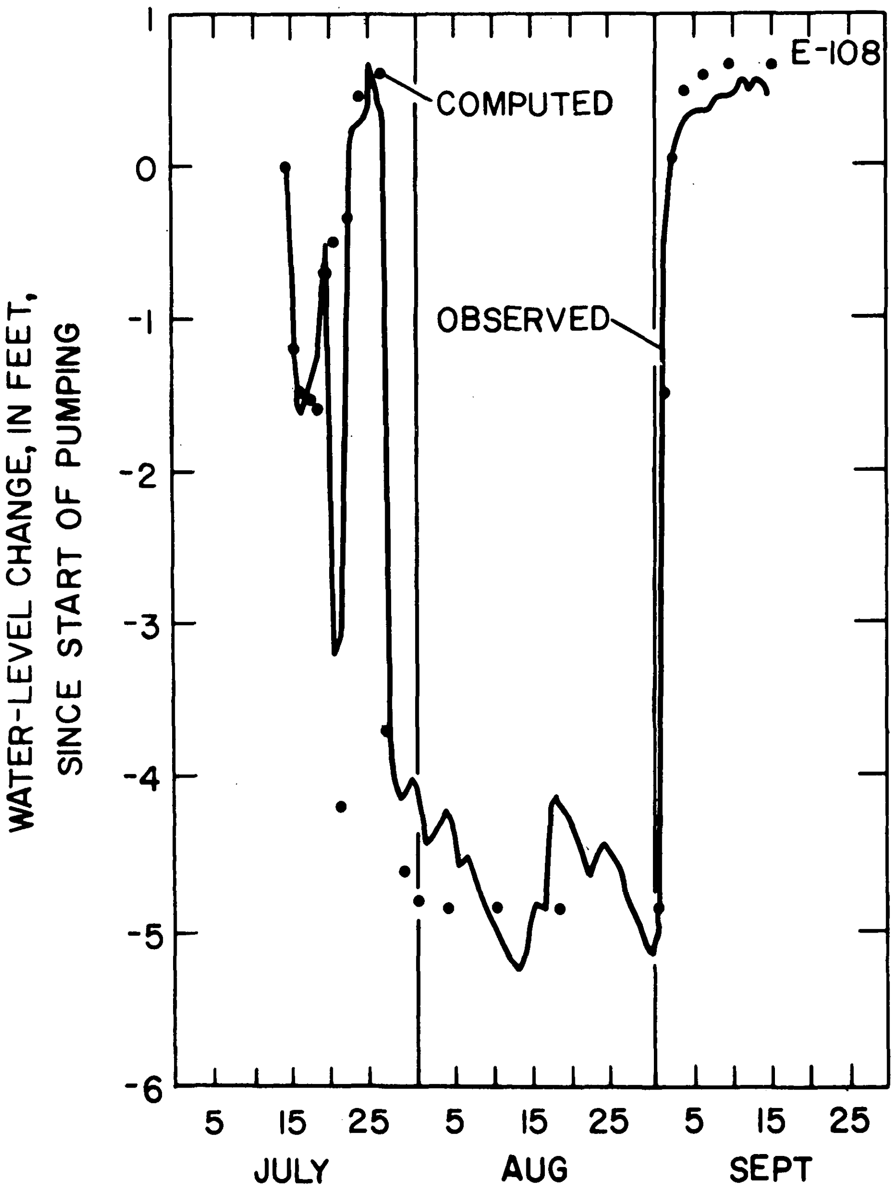


Figure 24.--Comparison of computed and observed changes in potentiometric surface in well E-108, July 15 - September 15, 1976.

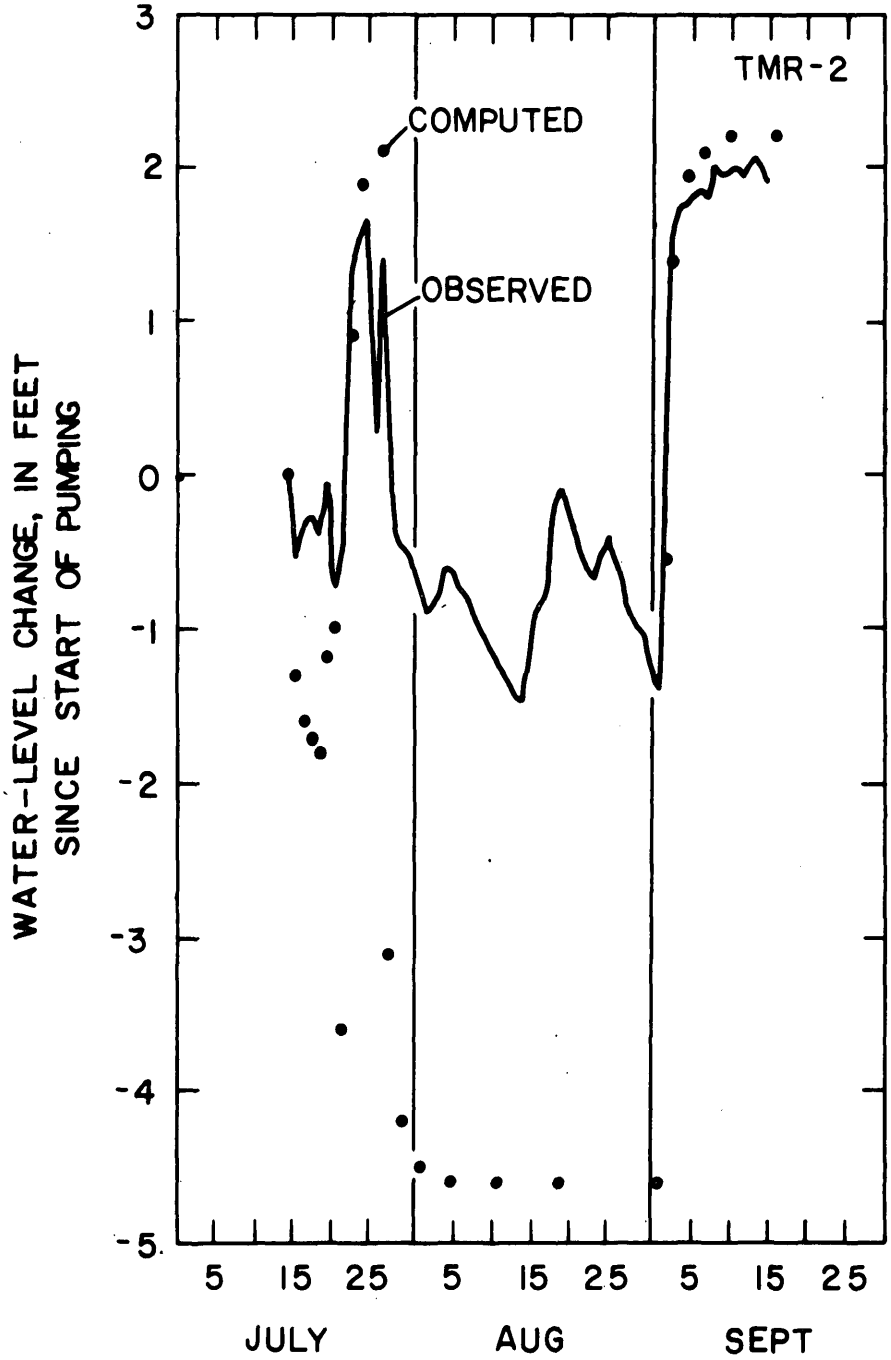


Figure 25.--Comparison of computed and observed changes in potentiometric surface in well TMR-2, July 15 - September 15, 1976.

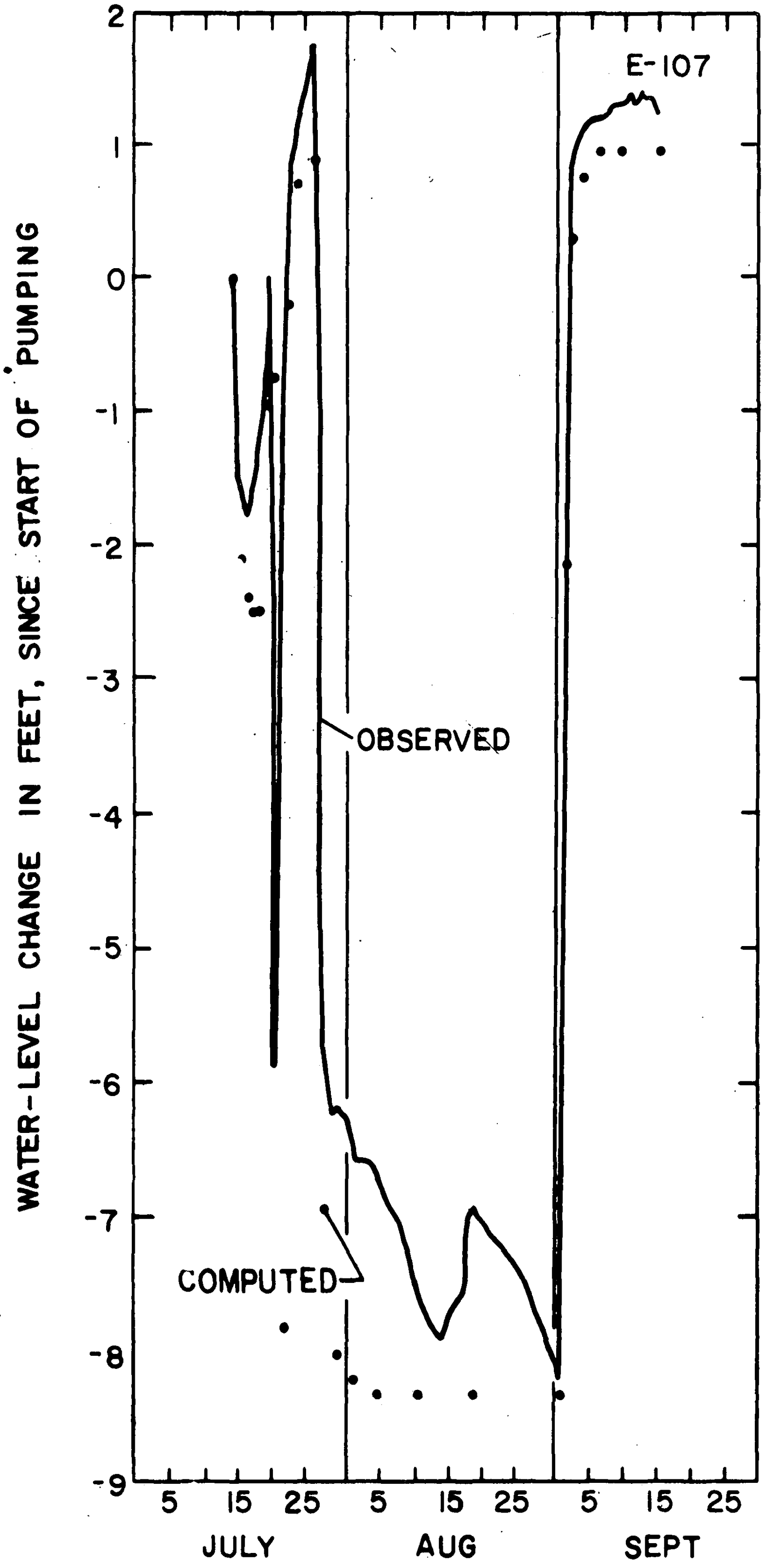


Figure 26.--Comparison of computed and observed changes in potentiometric surface in well E-107, July 15 - September 15, 1976.

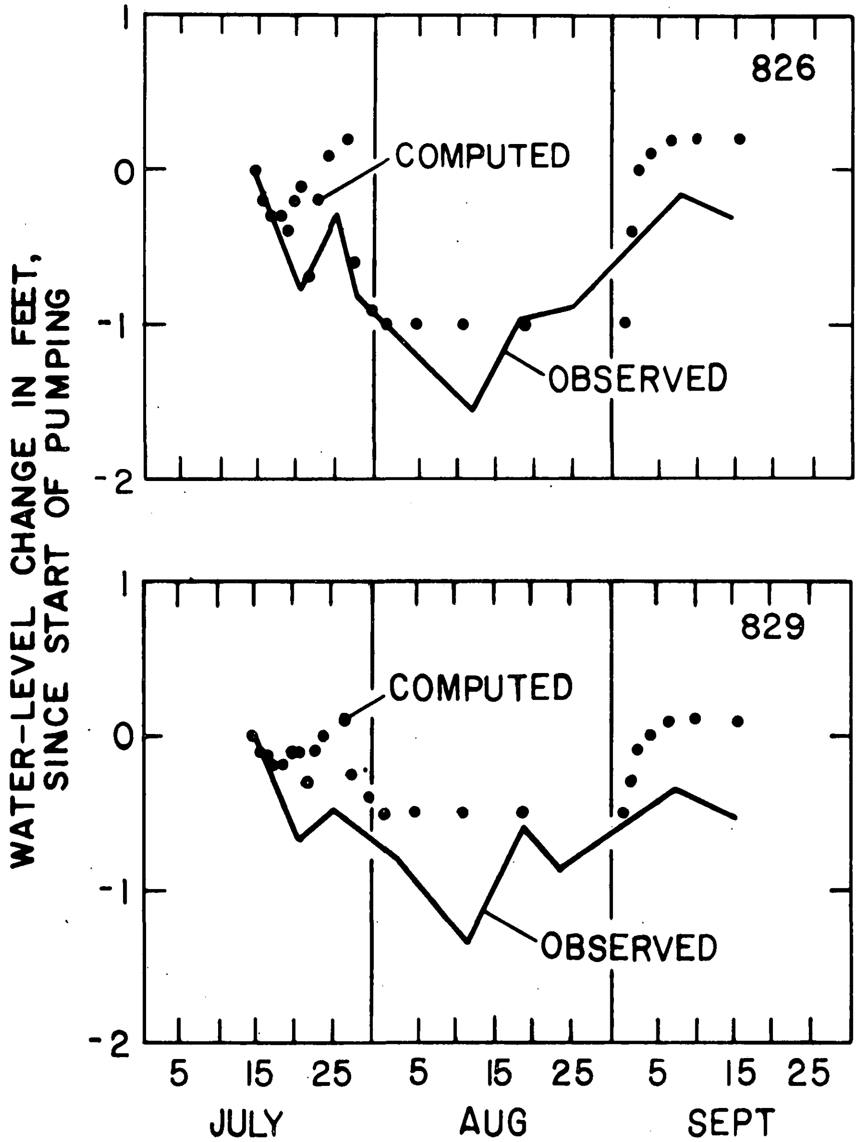


Figure 27.--Comparison of computed and observed changes in potentiometric surface in wells 826 (top graph) and 829 (bottom graph), July 15 - September 15, 1976.

The hydrographs of wells TMR-1 (fig. 22), TMR-3 (fig. 23), E-108 (fig. 24), and E-107 (fig. 26) show a good fit between computed and observed water-level changes. The poorest fit between computed and observed data is for TMR-2 (fig. 25) which is located north of the pumping wells and at the boundary line of the well field. Problems with larger grid blocks (1,000 x 2,000 ft) and in properly locating this observation well on the grid with respect to pumping well C-1, cannot account for the computed drawdown during August being 3.5 ft greater than the observed drawdown of approximately 1 ft. The reason for the poor fit is apparent when considering the data for well TMR-2 in table 1 and the data in figure 25.

The water table in the shallow well at the TMR-2 site was observed to decline nearly as much as did the drawdown in the confined-aquifer well. The average water table in the well during August was about 1/2 ft higher than the average potentiometric surface. Assuming that the wells have been properly constructed and grouted, this is a strong indication of a high leakance in the area. Although the use of the model is not appropriate where such large, sustained changes occur in the water table, the fact that the model computed over twice the amount of the observed drawdown, while the head separation was maintained at nearly 6 ft during August, could mean that model leakance values are too low for this area. A different value for transmissivity could also be indicated for this area.

Simulation of Pumpage, January 20-28, 1976

A final test of the model calibration consisted of simulating the pumpage from production well C-10 which took place during January 20-28, 1976. The pumpage was simulated using two different models: the two-dimensional model already described in this report; and a quasi-three-dimensional model simulating flow in two two-dimensional aquifers separated by a semiconfining layer.

Two-Dimensional Model. -- Figure 28 shows the location of well C-10 and eight observation-well sites. Six observation-well sites were equipped with pairs of recorder wells which continually measured the water table and the potentiometric surface during the pumping period; these included wells 829, 831, 826, E-108, E-107, and North Gate. At site CC-3, only the potentiometric surface was measured, and at site TB-13 only the water table was measured. During January 20-28, well C-10 was pumped at an average daily rate of 3.46 Mgal.

Rainfall data collected at well C-10 show that the only rainfall during the period January 18-28 occurred on January 27. This rainfall, in the amount of 0.15 in, occurred after maximum drawdowns in the potentiometric surface due to pumping had essentially been reached.

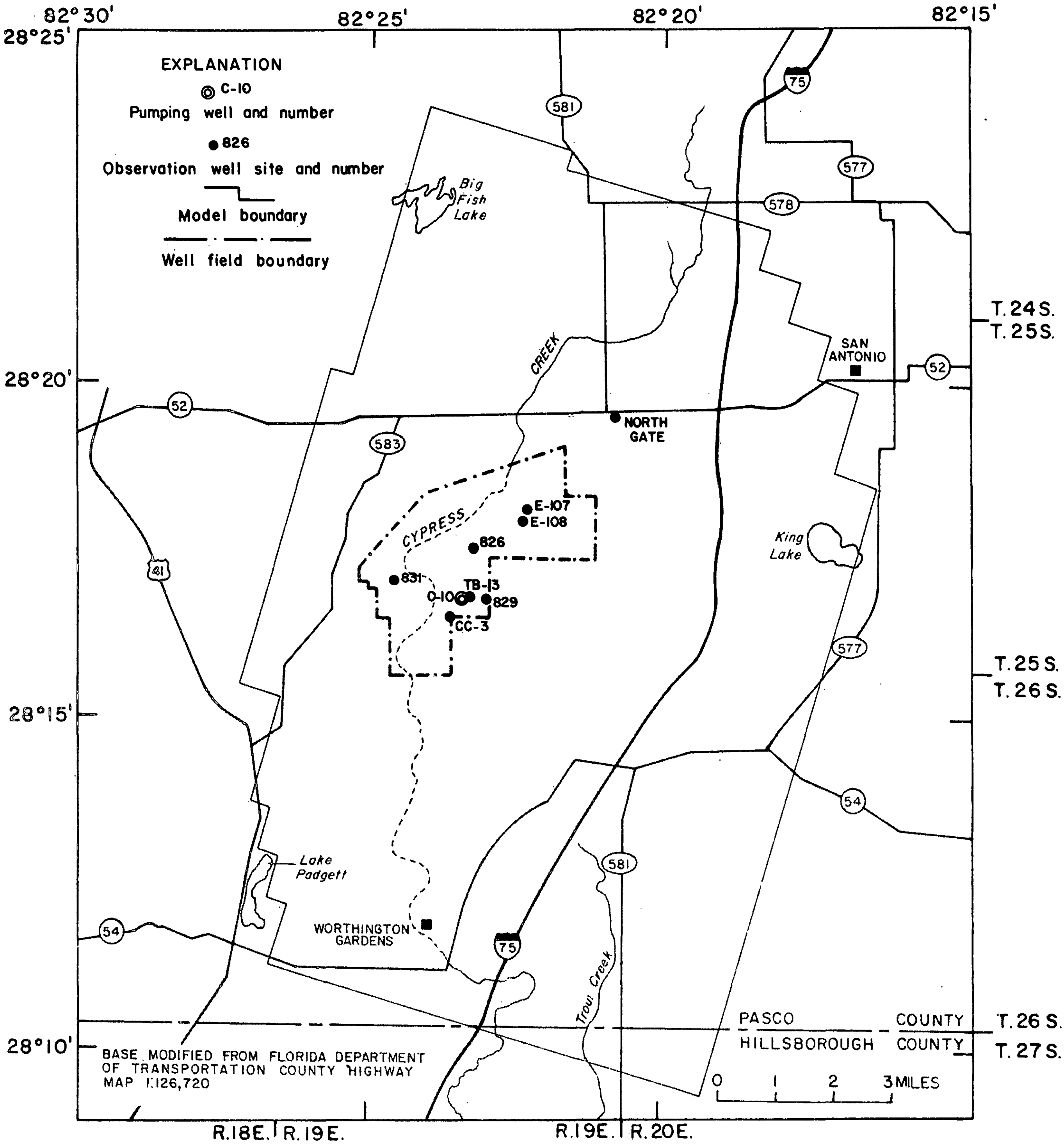


Figure 28.--Location of pumping well and observation wells at Cypress Creek well field during period January 20-28, 1976.

Analyses of long-term hydrographs show that the average rate of decline of the potentiometric surface during periods of no pumping and little or no rainfall is not the same for all the sites. The rates range from about 0.06 to about 0.09 ft/d for wells E-107 and E-108 respectively; continuous long-term records were not available for three of the sites (wells 826, 829, and 830) shown in figure 28. Rates of decline in three water-table wells (wells E-107, E-108, and TB-13) having continuous long-term records were more difficult to interpret, and average rates were not determined.

The September 1974 water table in the calibration model was replaced by a new water table estimated from measurements in 12 observation wells on January 20 (just prior to the start of pumping). Rainfall data and analyses of well hydrographs indicated that a condition of steady flow across the semiconfining layer existed at this time. Values were estimated for the constant-head nodes based on the January 20 position of the potentiometric surface. The model was run to steady state with no pumping, and the computed potentiometric surface was compared to observed potentiometric heads just prior to the start of pumping. Computed potentiometric heads in nodes corresponding to six of the eight deep-well sites shown in figure 28 (including well C-10) were within 1 ft of observed values; the mean of the differences between computed and observed heads for all eight wells was 1.15 ft, with a standard deviation of ±1.27 ft. The computed potentiometric surface was entered into the model as the starting head in a pumping simulation.

The potentiometric surface, when corrected for the regional downward trend, was observed to be essentially at steady state toward the end of the 8-day pumping period. Therefore, the pumping model was run to a condition of steady state. In order to account for the naturally-declining potentiometric surface, the prepumping daily rate of decline for each well where data existed was multiplied by the 7-day pumping period preceding the rainfall event. This correction factor was added to the computed drawdown at each respective site. The results of the pumping simulation are summarized in the following table:

Observation-well site (potentiometric surface)	Maximum drawdown during pumping period (ft)	Average prepumping rate of decline (ft/d)	Computed drawdown plus correction factor (ft)	Percent of observed value $\left(\frac{\text{computed}}{\text{observed}} \times 100\right)$
831	1.3	(no data)	0.5+?	---
826	2.5	(no data)	0.4+?	---
E-108	0.7	0.09	0.2+0.6=0.8	114
829	3.1	(no data)	1.1+?	---
E-107	0.6	0.06	0.2+0.4=0.6	100
CC-3	3.0	0.07	1.2+0.5=1.7	57

The good correlation between computed and observed values at wells E-108 and E-107 may be due to the fact that they are sufficiently far away from the pumping well, 9,000 ft and 10,200 ft, respectively, so that the water table near E-108 and E-107 has not been significantly lowered as a consequence of pumping from the artesian aquifer. As the pumping well is approached, a greater amount of drawdown in the water table would be expected. However, the distribution and magnitude of this drawdown is dependent not only on the shape of the cone of depression in the Floridan aquifer, but also on the areal distribution of leakance of the semiconfining layer and the transmissivity and storage coefficient of the surficial aquifer.

Water table well TB-13 is 600 ft from the pumping well. The decline in water level in well TB-13 was about 2 ft more than it would have been had well C-10 not been in operation. Well CC-3 is about 2,000 ft from the pumping well, and the computed drawdown in the potentiometric surface at this well was only 57 percent of the observed value. It is reasonable to assume that part of this discrepancy may be attributed to the development of a significantly large drawdown in the water table near well CC-3.

No conclusions can be reached regarding the computed drawdowns in wells 831, 826, and 829. The deficiencies in the two-dimensional model in simulating flow in the Floridan aquifer when there is a significant natural or induced decline in the water table are readily apparent. Another model is needed which would simultaneously solve the flow equations in both aquifers.

<u>Quasi-three-dimensional Model</u>. -- The January 20-27 pumping period also was simulated with a quasi-three-dimensional model. This finite-difference model simulates two-dimensional flow in two aquifers separated by a semiconfining bed. The effects of vertical leakage through the semiconfining bed are incorporated into the vertical component of the hydraulic conductivity of adjacent aquifers. As with the two-dimensional model: (1) transient leakage from the semiconfining bed is considered to be negligible; (2) there is no horizontal flow in the semiconfining bed; (3) flow in each aquifer occurs in a horizontal plane in a single-layer, horizontally isotropic medium. The reader is referred to Trescott (1975) for a complete description and documentation of this model.

The same parameters used in the two-dimensional simulation, including grid size, starting heads in both aquifers, and transmissivity of the Floridan aquifer, were used in the quasi-three-dimensional simulation. The constant-head boundaries in the Floridan aquifer were replaced by constant-flux boundaries to allow boundary heads to vary. Lateral boundaries in the surficial aquifer were zero-flux. Leakance values were read in and incorporated into the vertical component of hydraulic conductivity of the adjacent aquifers. Additional data for the quasi-three-dimensional transient simulation included: an estimated rate of evapotranspiration of water from the surficial aquifer, and estimated surficial-aquifer parameters of hydraulic conductivity and storage coefficient. The 7-day pumping period was essentially devoid of rainfall, and recharge from precipitation was not considered.

The storage coefficient for the Floridan aquifer was made the same as for the two-dimensional, July-September transient simulation: 0.0007. In order to provide for discharge by evapotranspiration, the quasi-three-dimensional model was modified with the help of Peter Trescott and Steven Larson (written commun., June 22, 1976). A maximum evapotranspiration rate of 9.6×10^{-8} ft/s was used in the simulation; this was based on an estimated 3 in of evapotranspiration per month for January conditions. Average land-surface altitudes were determined for each node, and the evapotranspiration rate was allowed to decrease as a linear function of depth of water table below land surface. Evapotranspiration directly from the surficial aquifer ceased below a depth to water of 15 ft. Uniform, estimated values of hydraulic conductivity of the surficial aquifer were used in each of several model runs; these values ranged from 1.34 ft/d to 13.4 ft/d. All available geologic-log data were used to determine the altitude of the bottom of the surficial aquifer in each node. (This parameter and the altitude of the water table at any given time allows the determination of saturated thickness which, multiplied by hydraulic conductivity, determines the aquifer transmissivity.) A uniform, estimated storage coefficient was used in most of the runs. In the final model run, a spatially variable storage coefficient was used.

In the initial quasi-three-dimensional simulation, a hydraulic conductivity of 13.4 ft/d and a storage coefficient of 0.25 were used. The results of subsequent simulations were markedly improved by lowering the values of both aquifer parameters. These two parameters were the only ones varied in the several model runs. The results of the final two simulations are given in table 3. In both simulations a uniform hydraulic conductivity of 1.34 ft/d was used. A uniform storage coefficient of 0.1 was used in one simulation, and a spatially variable distribution of storage coefficient ranging from 0.1 to 0.001 was used in the final run (see fig. 29).

The comparison of computed drawdowns in the water table and potentiometric surface with observed values (table 3) ranges from good at sites E-107 and E-108 to poor at other sites. Geologic logs show a rather thick and extensive clay and sandy clay layer overlying the water-bearing sand in the southern part of the well field. Certain other test holes show alternating layers of sand and clay in the surficial material. These logs, together with water-level altitudes, indicate confined conditions in the surficial aquifer in certain areas. The assignment of a storage coefficient of 0.001 to the area shown in figure 29 resulted in increased accuracy of computed drawdowns at some well sites, and in increased error at other sites.

A general decline of water levels in both aquifers would be expected in view of the losses from evapotranspiration and pumpage, and the absence of a recharge source. However, certain nodes in the layer representing the surficial aquifer showed an increase in head after the 7-day pumping period. Well site 826 in table 3 illustrates this condition. This condition should account for at least some of the discrepancies between computed

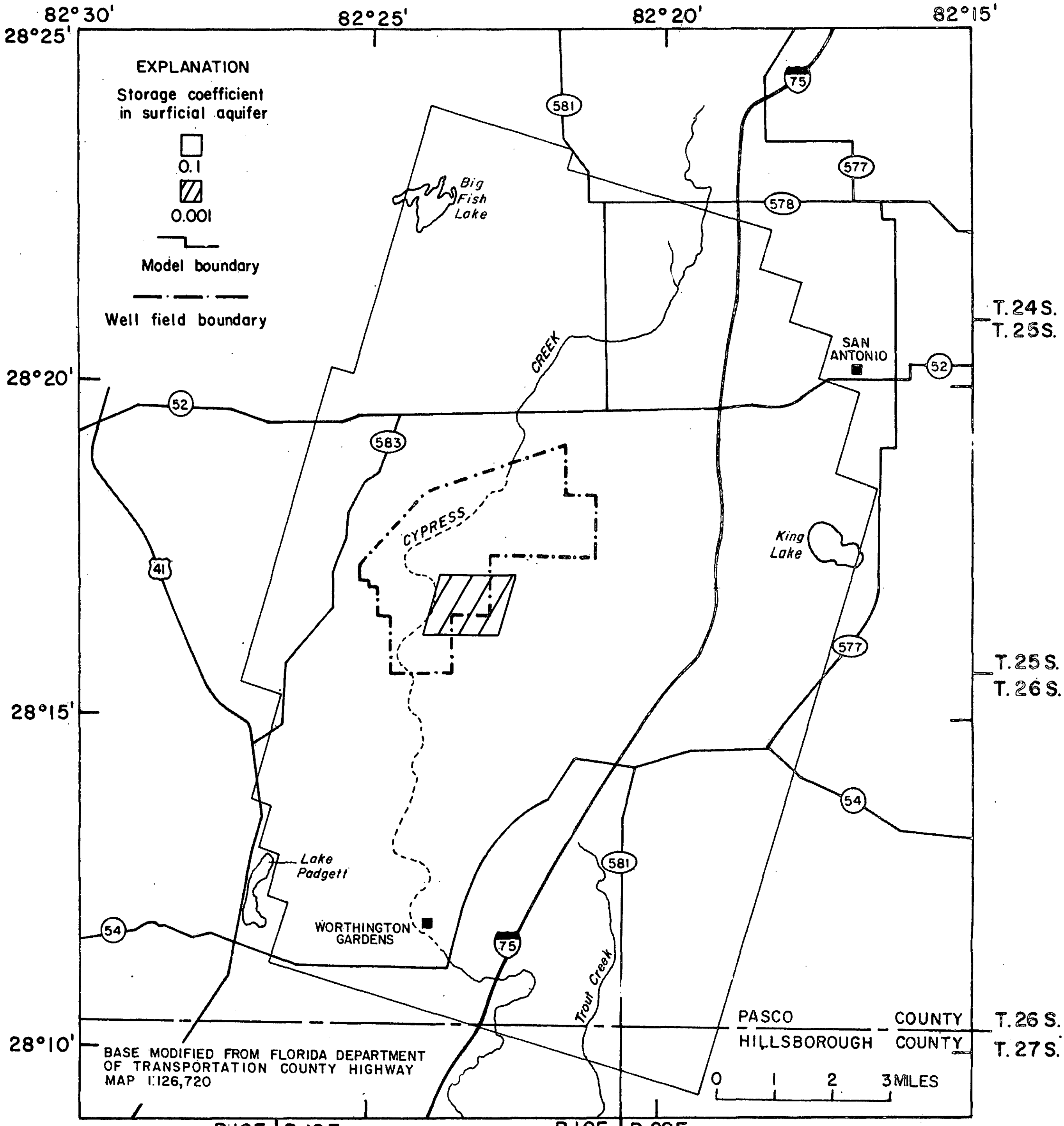


Figure 29.--Distribution of storage coefficient in surficial aquifer for quasi-three-dimensional model input.

Table 3.--Comparison of computed drawdowns in potentiometric surface and water table with observed values

[Simulation period is January 20-27 using quasi-three-dimensional model. Table compares the results of a uniform storage coefficient in the surficial aquifer with a variable distribution (see fig. 27).]

Observation well site	Total observed drawdown in potentiometric surface (ft)	Computed drawdown in potentiometric surface (ft)		Total observed drawdown in water table (ft)	Computed drawdown in water table (ft)		Percent of observed value $\left(\frac{\text{computed}}{\text{observed}} \times 100\right)$			
							Potentiometric surface		Water table	
		S = 0.1 (uniform)	S = 0.1 and 0.001		S = 0.1 (uniform)	S = 0.1 and 0.001	S = 0.1 (uniform)	S = 0.1 and 0.001	S = 0.1 (uniform)	S = 0.1 and 0.001
831	1.30	0.84	1.02	0.30	0.42	0.42	65	78	140	140
826	2.50	0.51	0.79	0.35	-0.35	-0.26	20	32	-100	-74
E-108	0.75	0.45	0.63	0.30	0.29	0.31	60	84	97	103
829	3.10	0.32	2.24	0.30	1.13	5.00	10	72	377	1667
E-107	0.60	0.43	0.57	0.60	0.47	0.47	72	95	78	78
CC-3	3.10	1.31	1.79	--	0.80	3.68	42	58	---	---
TB-13	--	2.92	3.68	2.10	1.02	5.70	---	---	48	271
North Gate	0.26	0.37	0.40	0.27	0.46	0.47	142	154	170	174

and observed values given in table 3. The increase in head cannot be explained. Possible, major contributing causes may include the following: 1. A poor estimate of the water table, which would allow significant flow as the water table adjusts to a new, stable condition. 2. Poor estimates of the surficial-aquifer characteristics of hydraulic conductivity and storage coefficient. 3. Errors in the original calibration which would result in faulty leakance values (the vertical component of hydraulic conductivity as used in this model).

The results of the quasi-three-dimensional modeling effort in this report are very preliminary in nature. They do, however, point out the need for careful collection and analysis of data from the surficial aquifer. If existing data are carefully evaluated, and additional data collected in critical areas, much-improved estimates of the surficial-aquifer parameters of water-level configuration, hydraulic conductivity, and storage coefficient can be obtained. With the increased accuracy thus obtained, an acceptable calibration and subsequent predictive modeling with the quasi-three-dimensional model should be possible.

Model Sensitivity to Changes in Parameters

Two parameters that affect ground-water flow in the Floridan aquifer are the leakance (K'/b') of the semiconfining layer, and transmissivity (T). The relative importance of each parameter in affecting ground-water flow in the two-dimensional simulation model can be evaluated by a sensitivity analysis. The analysis tests the sensitivity of the model to significant changes in the scale of the parameter values; the relative distribution of the parameter values (in space) does not change. This type of analysis could be helpful in the design of further aquifer testing. Information derived from such analyses concerning the importance of aquifer parameters can be useful in making resource-management decisions.

In the steady-flow calibration model, the source term, W, includes only leakage across the semiconfining layer. Under this condition, the calibration can only uniquely define the ratio $T(x,y)/[(K'/b')(x,y)]$. Changes in the scale of the parameter values that result in the same ratio between the two parameters will always produce identical computed heads. It was desirable, therefore, to test the sensitivity of the model to changes in T and K'/b' under the condition of heavy pumping stress. The model will be sensitive, in the area affected by the withdrawals, to changes in parameter values regardless of the ratio between the parameters. The sensitivity should be greatest in the areas of greatest drawdown resulting from the withdrawals.

Transient simulations were chosen to best illustrate the results of the sensitivity tests. A uniform storage coefficient of 7×10^{-4}, used in the transient simulations described previously, was used in the sensitivity tests. This parameter was not varied during the tests because of the high degree of confidence placed on the selected value.

Figure 30 shows the location of production wells C-1 through C-10 in the Cypress Creek well field. A total, hypothetical pumping rate of 30 Mgal/d, or about 2,100 gal/min for each of the 10 wells, was used. The observed May 1975 water table, and the potentiometric surface computed by the calibrated steady-flow model were used as initial conditions for each of the sensitivity tests. The water table was held constant over time during all simulations. An initial time step of approximately 0.5 min was used in the model, and subsequent time steps were increased by a factor of 4.0. Heads were computed for a total period of 121 days from the start of pumping, but for all practical purposes all simulations had reached steady state before 30 days.

Figures 31 through 34 show the results of the sensitivity tests at four selected nodes. Each figure shows the time-drawdown curves for five separate model simulations. The graphs clearly show the greater sensitivity to changes in T as the pumping wells are approached. Figure 34 shows the sensitivity results at node 9,22 which is 8,500 ft from the nearest pumping well. Here, the model is more sensitive to changes in K'/b'.

Examples of Predictive Modeling

The two-dimensional model is used to show how the potentiometric surface might respond to large, manmade stresses on the system. The hypothetical stresses include a combined withdrawal rate of 30 Mgal/d from 10 production wells, and a rise in the water table in the vicinity of two proposed reservoirs. It is very important to note that the resulting predicted drawdowns in the Floridan aquifer are based upon the artificial condition of a fixed water table--a condition which definitely cannot be maintained during the dry season of the year.

Effect of 30 Million Gallons per Day Withdrawal

The estimated water table for May 12, 1975, and the simulated May 12 potentiometric surface (discussed in previous section of report) were used for the initial conditions in the model. Citrus irrigation pumping rates, totaling 2.7 Mgal/d, were distributed as described previously. With the system at steady state, a pumping stress of 30 Mgal/d was imposed on the Floridan aquifer. Each day's pumpage was distributed evenly among the 10 wells shown in figure 30; these wells represent production wells C-1 through C-10. The model was run to steady state, and the resulting cone of depression is shown in figure 35. It is significant that the cone spread farther in a northeasterly direction from the pumping center. Both leakage and transmissivity are relatively low in this area of the model. The situation was complicated because the spreading cone of depression reached the no-flow boundary in the northeast; this caused an exaggerated drawdown in the vicinity of the boundary.

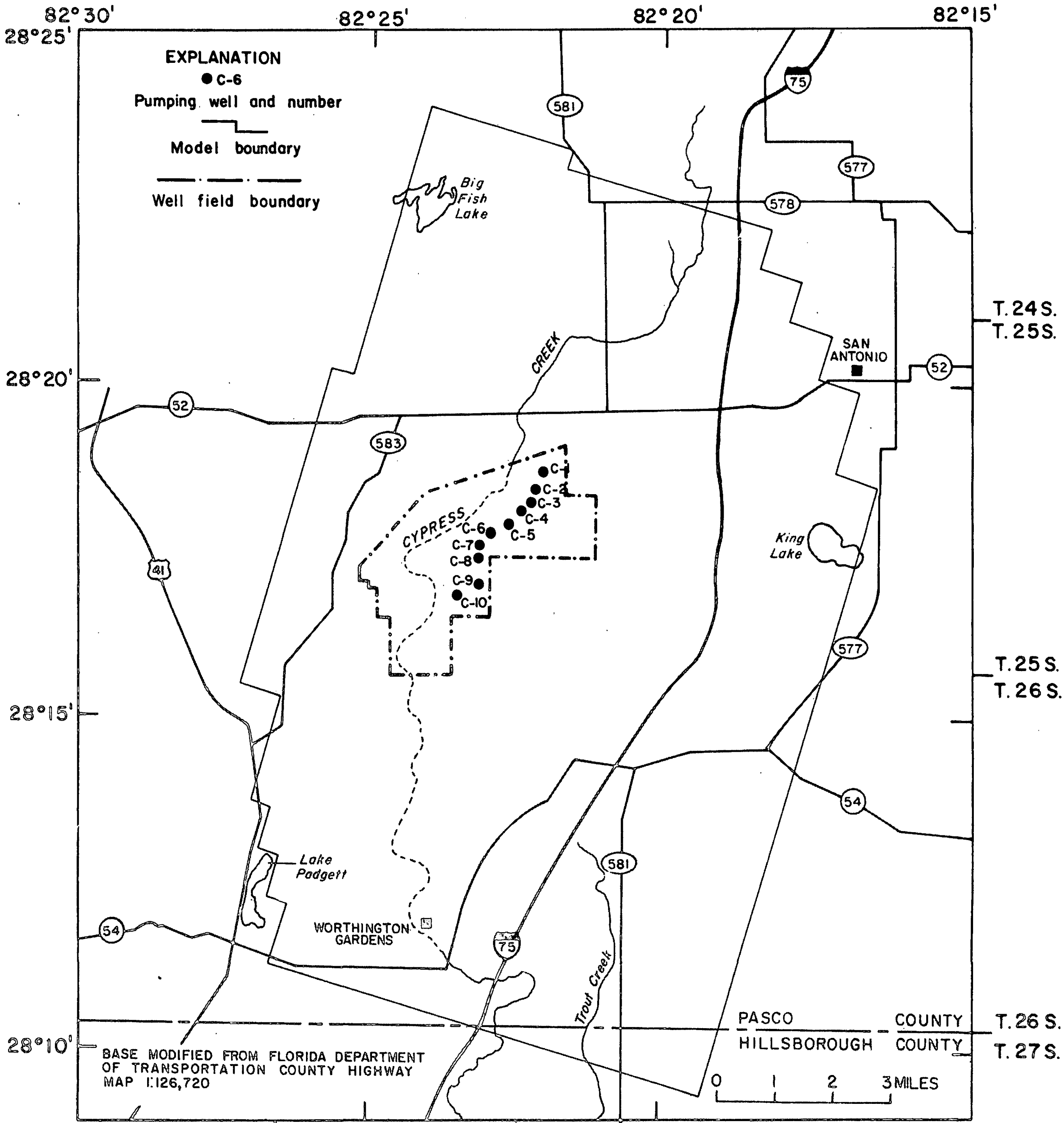


Figure 30.--Location of production wells C-1 through C-10 used for hypothetical pumpage of 30 Mgal/d.

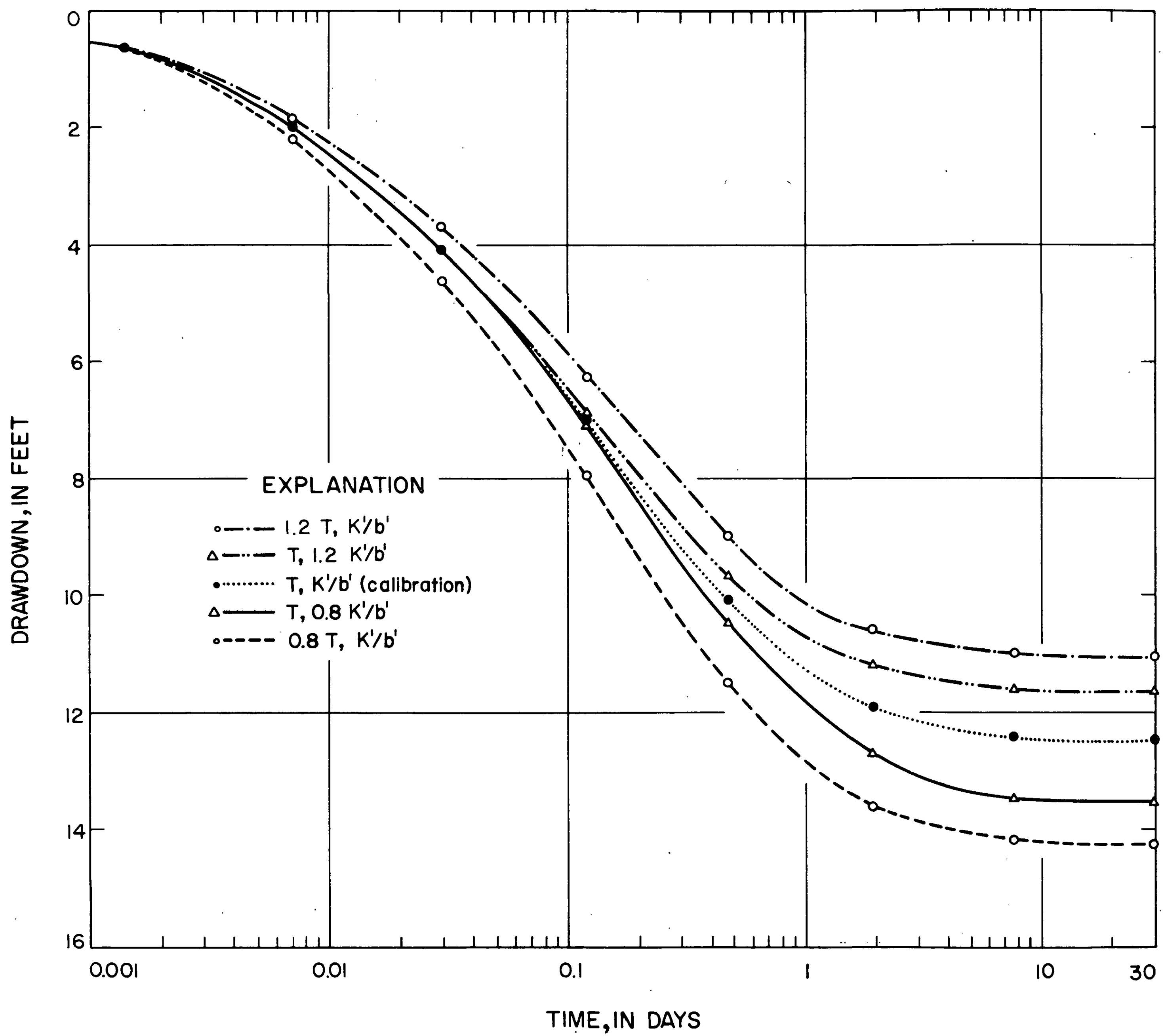


Figure 31.--Time-drawdown curves for node (18,17), 500 feet southwest of pumping well C-6.

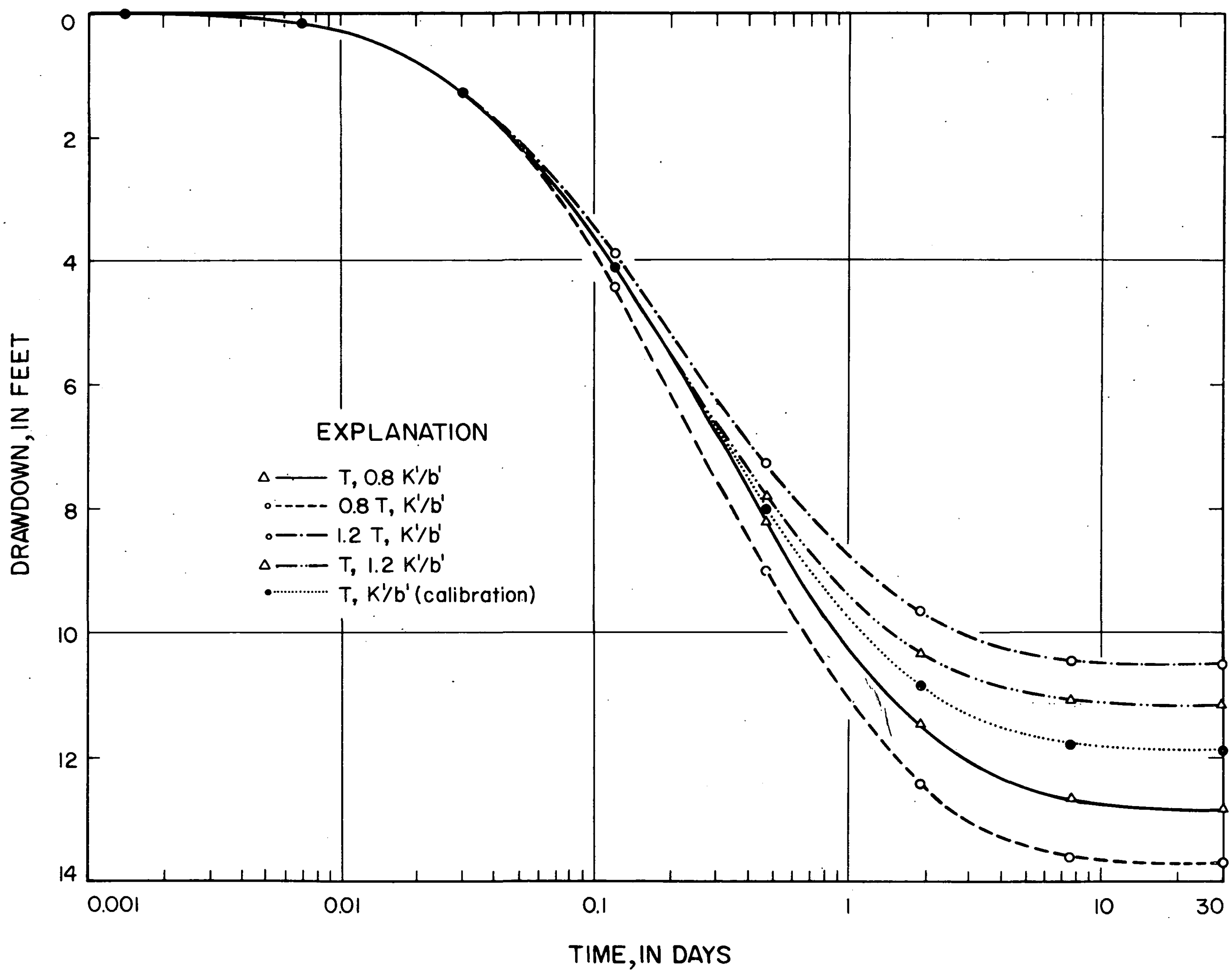


Figure 32.--Time-drawdown curves for node (16,11), 1,500 feet southwest of pumping well C-1.

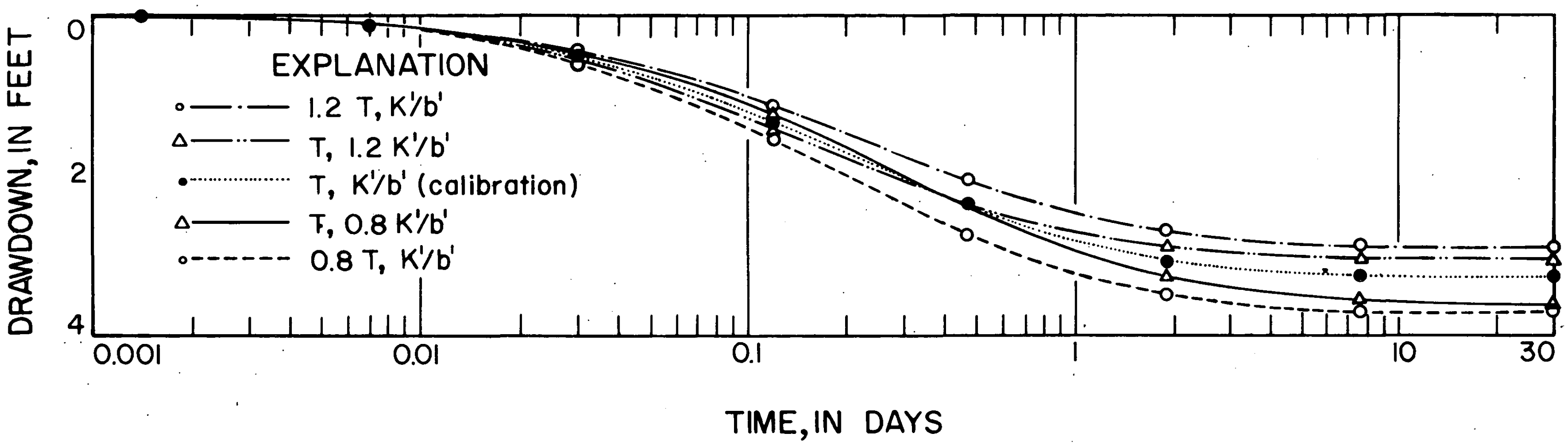


Figure 33.--Time-drawdown curves for node (20,24), 1,500 feet southwest of pumping well C-10.

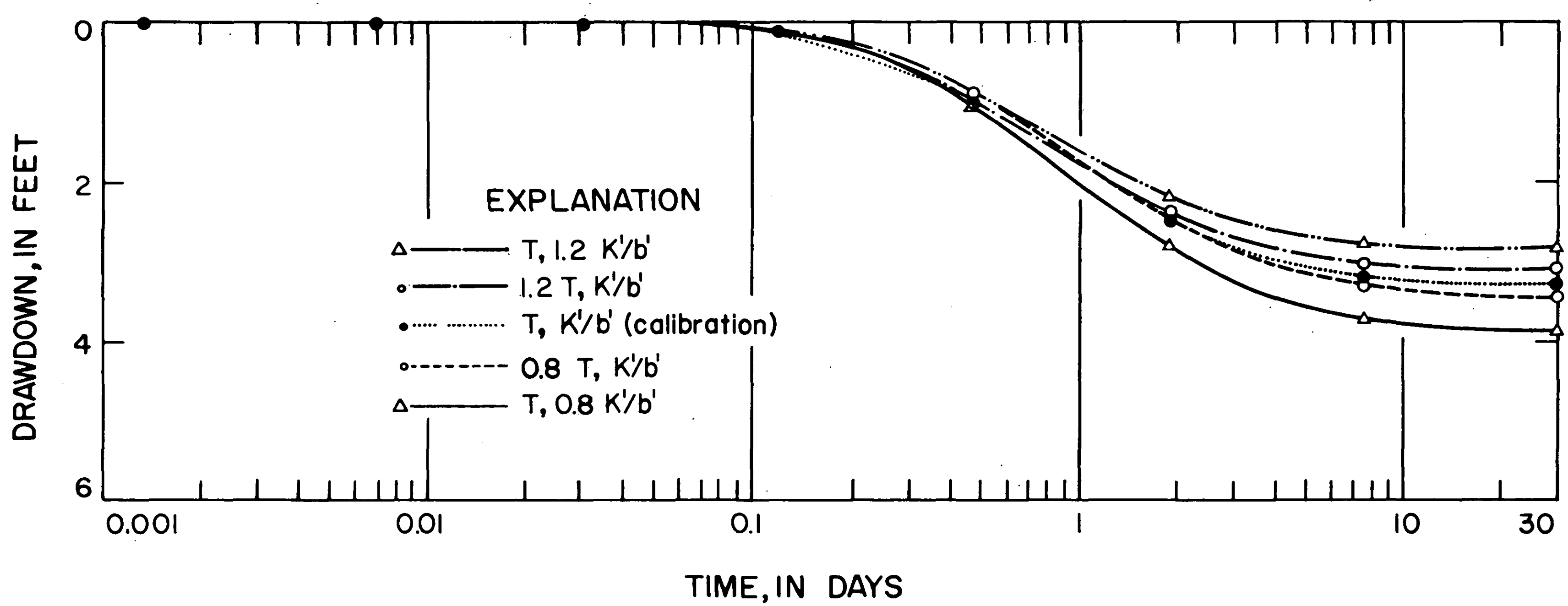


Figure 34.--Time-drawdown curves for node (9,22), 8,500 feet east of pumping well C-9.

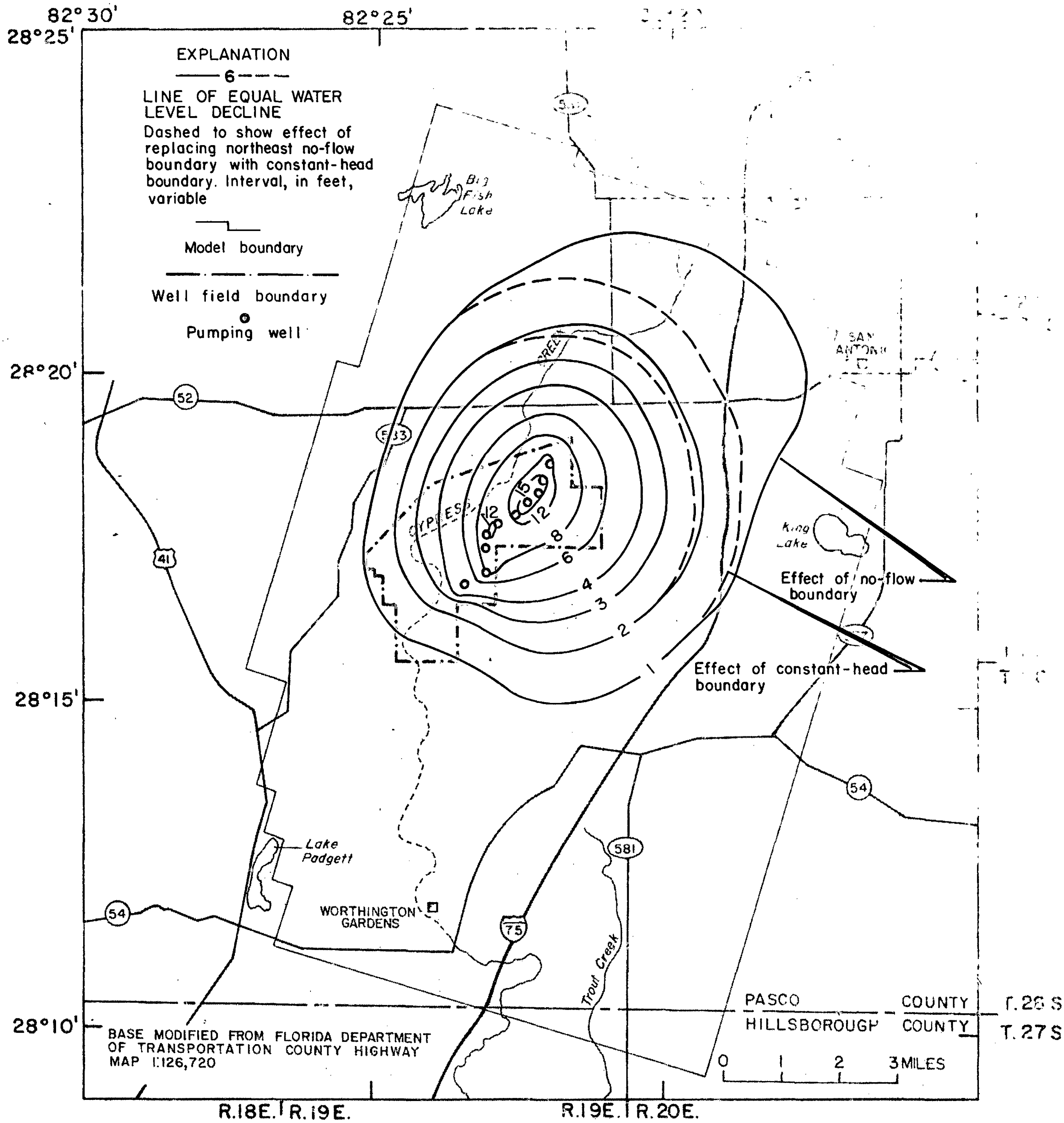


Figure 35.--Steady-state drawdown computed as response to 30 Mgal/d withdrawal from 10 wells in Cypress Creek well field based on various assumed boundary conditions and assumption that the water table, estimated from May 12, 1975, observations, is fixed and cannot decline.

The entire boundary along the north and northeast perimeter of the model was then changed to constant head, and the pumping simulation was re-run. Figure 35 shows that the 1-ft and 2-ft lines of equal drawdown have receded toward the pumping center. It is logical to assume that had the northeastern part of the boundary been far enough away not to be affected appreciably by the cone of depression, the 1-ft and 2-ft lines of equal drawdown would lie somewhere between the two positions shown. This same reasoning could be applied at any no-flow boundary nodes which might be affected by pumping stress.

Effect of Proposed Reservoirs

Flood-control and water-diversion facilities have been proposed for the Cypress Creek well-field area. One benefit envisioned by the construction of flood-detention reservoirs is increased recharge to the Floridan aquifer. Figure 36 shows the approximate location of two proposed levees across Cypress Creek. Stages of 60 ft for the upper pool and 52 ft for the lower pool were chosen to show the effect of moderate-size pools on the dry-season potentiometric surface of the Floridan aquifer. The open-water areas behind the levees are shown in figure 36.

The steady-state conditions of May 12, 1975, were again used for initial conditions in the model. In order to account for the effect of the two pools on the water table, the water table underlying and adjacent to the pools was simply raised to the same altitude as the pool stage. No attempt was made to account for bank storage effects from presumably previously higher pool stages. The water table was raised as much as 7 ft in nodes immediately behind the upper levee and as much as 4 ft behind the lower levee.

The model was run to steady state with the altered water table, both with and without the 30 Mgal of pumpage obtained each day from the well field. Both runs show an identical rise of the potentiometric surface in the area of the pools. In figure 36, the rise has been superimposed on the cone of depression developed from pumping the 30 Mgal/d without the pools.

Mass Balance Data

With the only pumpage being that from citrus irrigation at a rate of 0.5 in/yr (on a unit-area basis), the two-dimensional model at steady state shows leakage into the Floridan from the surficial aquifer of about 6.5 in/yr and leakage upward into the surficial aquifer of about 4 in/yr. The net inflow to the Floridan is about 2 in/yr, equalling net outflow. With the model simulating well-field withdrawal of 30 Mgal/d (about 5 in/yr) and at steady state, downward and upward leakage rates change substantially

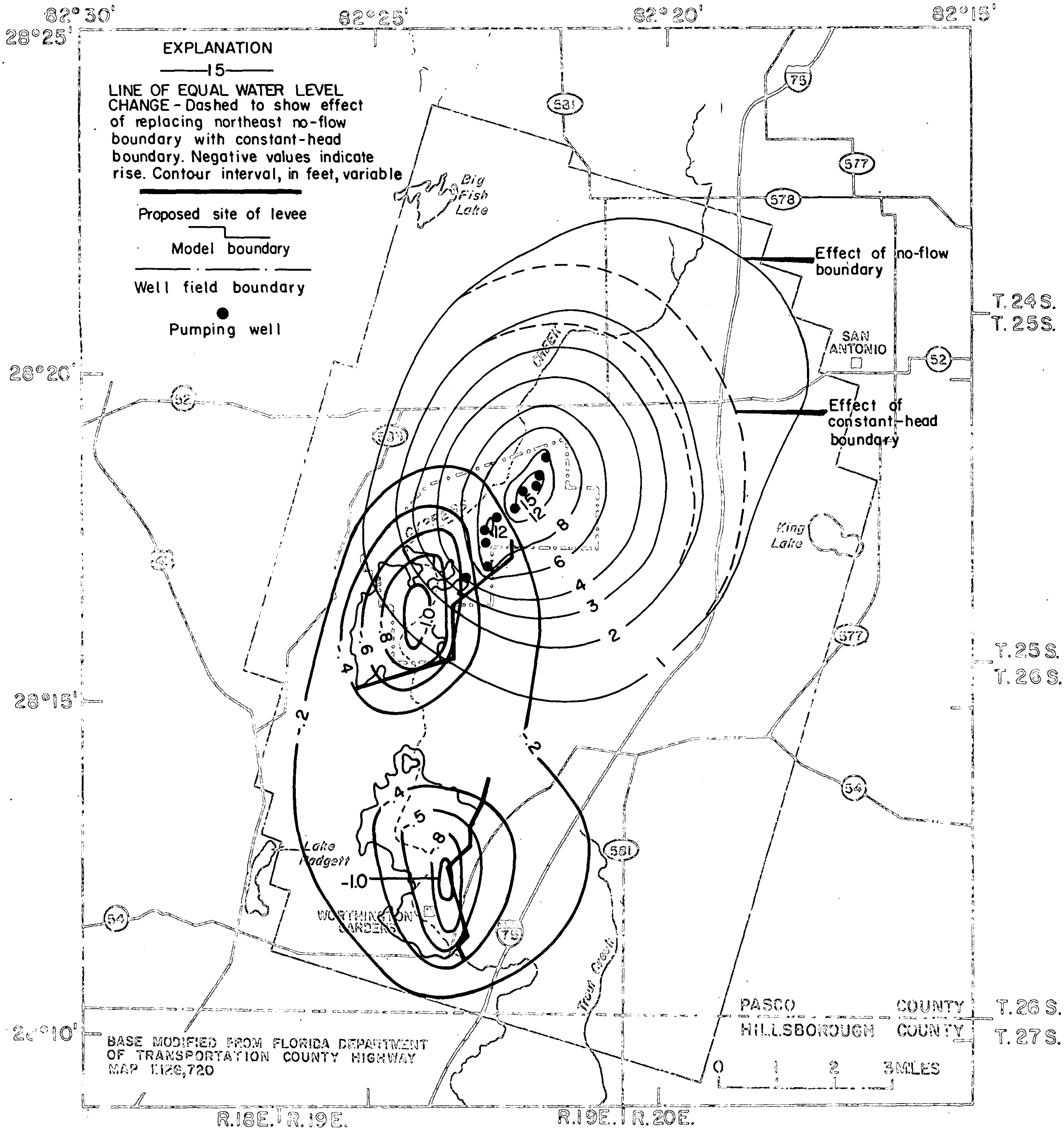


Figure 36.--Computed effect of proposed pools: 60-foot stage in upper pool; 52-foot stage in lower pool. Water-level rise in the Floridan aquifer is superimposed on cone of depression developed by 10 wells withdrawing 30 Mgal/d.

to 10 in/yr and 2.5 in/yr, respectively. Constant-head outflow is essentially unchanged. If the water levels in the surficial aquifer were allowed to decline, as in the quasi-three-dimensional model, it is reasonable to expect that outflow would decline. The 5 in/yr withdrawal would come from capturing natural outflow, reducing evapotranspiration from the surficial aquifer, reducing runoff from the surficial aquifer, or inducing more ground-water inflow by moving ground-water divides.

SUMMARY AND CONCLUSIONS

1. In order to develop a model of the Cypress Creek well-field area, the hydrogeologic system was conceptualized as follows: The water table in the surficial sand aquifer is separated from the Floridan aquifer by a semiconfining clay layer. The major part of water for the well field comes from two cavernous zones of a dolomitic section of the Avon Park Limestone, approximately 400 ft and 500 ft below sea level in the well-field area.

The clay beds in the lower part of the surficial aquifer range from 2 to 25 ft in thickness in the well field. The thickness and vertical hydraulic conductivity of these clay beds are the main controls on the vertical movement of water.

All recharge to the Floridan aquifer in the area is derived from the overlying sandy surficial aquifer by downward percolation through the semiconfining clay bed. Part of this recharge is returned to the surficial deposits within the area as upward leakage, and most of the remainder leaves the area as it flows downgradient in the Floridan aquifer.

2. A two-dimensional digital model of the conceptualized hydrogeologic system in the Cypress Creek well-field area was developed. Aquifer-test and geophysical data were used to evaluate the hydraulic characteristics of the system and to obtain initial estimates of hydrologic parameters for model input. The model was calibrated by simulating September 16, 1974, conditions, assuming steady-flow conditions across boundaries. Leakance, a measure of the hydraulic connection between the aquifers, was the main hydrologic parameter varied to achieve a satisfactory calibration. Leakance values derived from the model were mapped for a 120-mi^2 area encompassing the well field. The values ranged from about 10^{-6} to 10^{-2} $(ft^3/d)/ft^3$. The model results supported the conceptualization of the hydrologic system and greatly improved the understanding of areal variations of leakance.

3. Accuracy of the calibrated model was tested by simulating steady-flow conditions for the May 1975 dry period and by simulating conditions of actual pumpage in the well field, July 15 to September 15, 1976. Additional data needed to improve model calibration and understanding of the flow system include: (a) More observation wells in areas not affected by

irrigation pumping effects. (b) More wells in the area northeast of the well field to define the thickness and water-level configuration of the surficial aquifer. (c) Better definition of leakance and transmissivity in the areas where little or no head difference exists between the surficial and Floridan aquifers under steady-flow conditions.

4. The model was also tested by attempting to simulate the potentiometric surface of the Floridan aquifer under actual pumping stresses during a dry period in January 1976. The model did not effectively simulate the hydrologic system under these conditions because of the requirement of fixed water levels in the surficial aquifer. Therefore, a quasi-three-dimensional model was used to simulate the system with declining water levels in the surficial aquifer. Preliminary three-dimensional model results indicate that better estimates of aquifer characteristics and water-level configuration for the surficial aquifer are needed in the entire modeled area for calibration and prediction analysis using the three-dimensional model.

5. The relative importance of transmissivity and leakance in affecting ground-water flow in the two-dimensional model was evaluated by a sensitivity analysis. The values of the two parameters were significantly changed in separate model runs under the condition of large, hypothetical withdrawals from the Cypress Creek well field. Time-drawdown curves at selected nodes show greater sensitivity to changes in transmissivity relative to leakance as the pumping wells are approached. This information can be useful in the design of further aquifer testing.

6. The use of the three-dimensional model for future prediction analysis for water management will necessitate expansion and redefinition of the boundaries of the model and estimation of new model parameters for the additional area that will be affected by the large-scale withdrawals.

7. Analyses of aquifer tests for aquifer parameter determination and model behavior in the Floridan aquifer in the Cypress Creek well-field area indicate that there are few benefits to be gained from running the tests beyond steady-state conditions. The time and money saved by running short-term tests could be applied to increasing the number of aquifer tests over the area. This would provide more of the data needed to improve model input parameters, calibration, and predictive results.

8. The accuracy and reliability of model results depends upon the accuracy of input data. Therefore, great care must be taken to ensure proper construction of wells in both the Floridan aquifer and surficial aquifer. Observation wells in the Floridan aquifer must be carefully checked for significant changes in head as drilling depths are increased. The head that is measured in the completed observation well must be representative of the average head in the entire aquifer. Observation wells in the surficial aquifer that have penetrated the clay layer overlying the limestone should be plugged back and screened in the sand so that a true water level in the surficial aquifer can be measured. If clay layers are

present in the surficial material, it is advisable to set an additional screen in an upper sand unit because of the possibility of the clay acting as a confining layer. The procedure of side-by-side installation of properly constructed wells in both the surficial and Floridan aquifers allows a direct comparison of differences between the water table and the potentiometric surface.

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