TECHNICAL PUBLICATION SJ 88-2

GROUND-WATER FLOW MODEL OF BREVARD, INDIAN RIVER, ORANGE, OSCEOLA, AND SEMINOLE COUNTIES, FLORIDA

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January, 1988

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ABSTRACT

The ground-water flow system in a 6,112 square-mile area of the Floridan aquifer has been modeled using a finite difference approximation. The area covered includes all or parts of Brevard, Indian River, Orange, Osceola, and Seminole counties. The calibration and verification process involved simulating the observed response of the upper permeable zone of the Floridan aquifer to estimated stresses under both steady-state and transient conditions. Good results were obtained for steady-state simulations of the potentiometric surface prior to development and in September 1979. Simulations of potentiometric response under transient conditions were also successful. However, these results are greatly influenced by uncertainty over monthly withdrawals from irrigation wells and the fact that storage in the confining layers is not accounted for in this model. The ability of the model to simulate short-term, transient, aquifer response may, therefore, require further consideration of these factors.

INTRODUCTION

PURPOSE AND SCOPE

The Tertiary limestone aquifer (Floridan) is an important source of water in Brevard, Indian River, Orange, Osceola, and Seminole (BIOS) counties. Approximately 236 million gallons per day of water was withdrawn from the aquifer in 1980. Demands for water from the aquifer are increasing. A numerical model of the artesian ground-water flow system in the BIOS area was developed in an effort to realize several specific benefits. These are:

1. Develop a more sophisticated and realistic water budget of the area than has previously been available.

2. Provide an improved description of the regional hydrogeologic characteristics of the Floridan aquifer system in the study area.

3. Develop a tool with which to assess the regional impacts of large-scale stresses on the ground-water flow system.

4. Provide a starting point for development of a model capable of predicting the movement of saline ground water in the BIOS area.

METHODOLOGY

This report presents the results of the effort to develop a ground-water flow model of the Floridan aquifer system in the BIOS area (Figure 1). A steady-state model of a 13,700 square mile region that includes the BIOS area was used as a starting point. This model was developed by Tibbals (1981). That portion of the model covering the BIOS area was separated from the regional model and refined. Simulation of several different historical potentiometric configurations suggests that the refined model is capable of accurately predicting the response of the flow system in the BIOS area to known stresses under steady-state conditions. The model's utility for conducting transient simulations has certain limitations due to the fact that confining-layer storage has been ignored.

PREVIOUS INVESTIGATIONS

The geology of the study area has been described by a number of investigators including Matson and Sanford (1913), Applin and Applin (1944), Cooke (1939 and 1945), Puri and Vernon (1959), Stringfield (1966) and White (1958 and 1970). In general, these references cover the geology of much or all of the state. A number of other investigations described the geology and hydrology of the smaller geographic areas comprising the study region. These include Neill (1955) and Brown et al. (1975) in Indian River County, Lichtler et al. (1968) in Orange County,

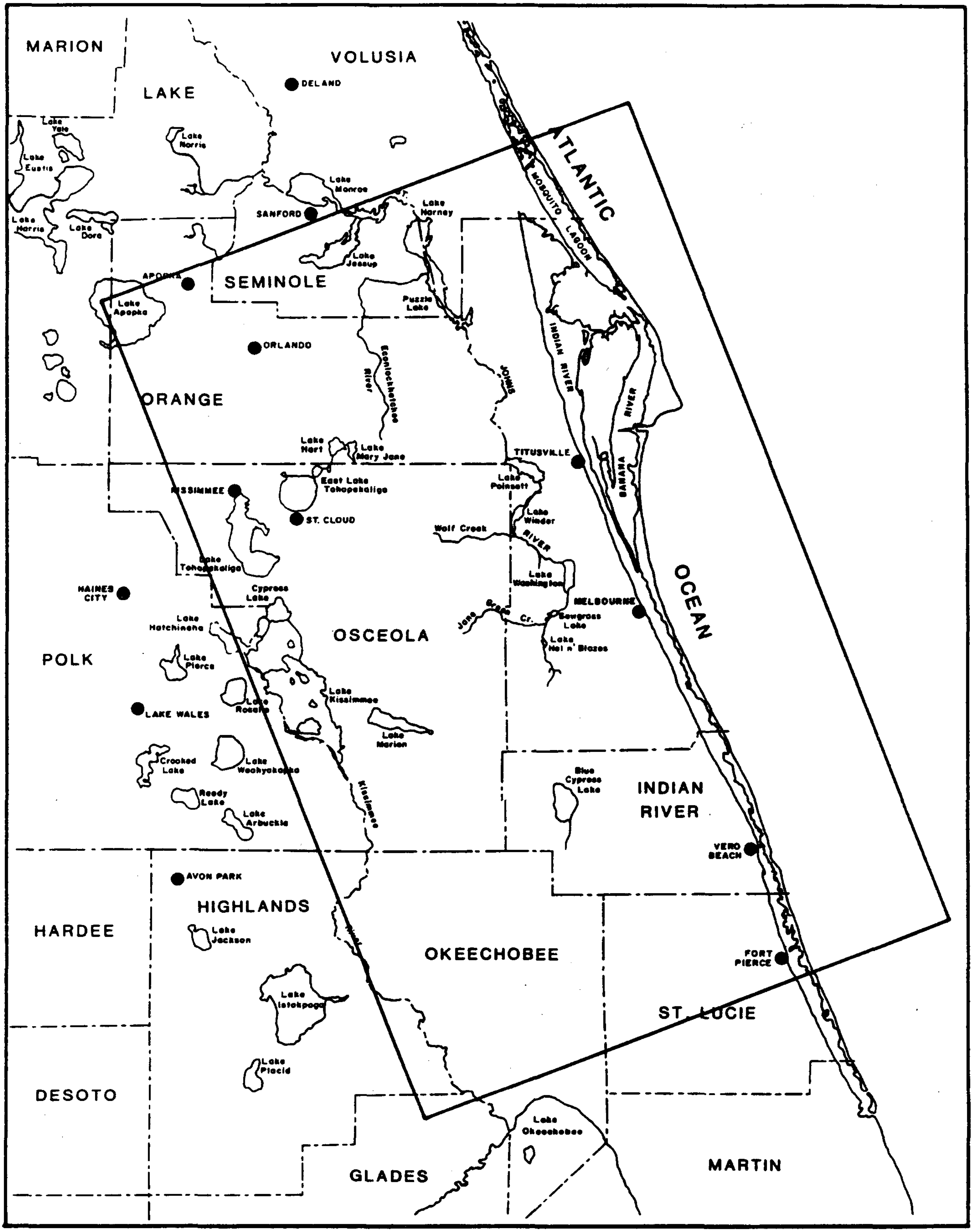


Figure 1: BIOS Study Area

Barraclough (1962), Tibbals (1977), and Frazee (1980) in Osceola County. Information on the water resources of the St. Johns River Basin has been presented by Snell and Anderson (1970) while Lichtler (1972) appraised the water resources of a seven-county area in east-central Florida including the five covered by the present analysis. Toth (1988) recently prepared a report on salt-water intrusion in the coastal portions of Indian River, Brevard, and Volusia counties.

Two large-scale ground water modeling studies including all or part of the BIOS study area have been conducted. Tibbals (1981) developed a model of the ground-water flow system for the Floridan aquifer in all or part of nineteen counties in east-central Florida. The model was calibrated for steady-state conditions prior to large-scale regional ground-water development (hereafter referred to as predevelopment conditions). Data used in Tibbals' model was used as a starting point for the development of the BIOS model. Planert and Aucott (1985) developed a similar model of the Floridan aquifer in Osceola, eastern Orange, and southwestern Brevard counties. Their study assessed the effects of several alternative water-supply development scenarios on the movement of the saline/fresh water interface.

HYDROGEOLOGIC SETTING

The hydrogeologic character of the study area has been shaped by repeated advancements and recessions of the sea. The result is a sequence of unconsolidated sediments and calcareous deposits two to three thousand feet in thickness (Miller, 1982). This sequence is divided into two distinct aquifer systems, a surficial aquifer of late and post-Miocene sediments and an artesian aquifer of limestones and dolomites of the Eocene epochs (Floridan aquifer).

SURFICIAL AQUIFER

The surficial aquifer represents the uppermost water-bearing layer in the region. It is composed primarily of fine to medium-fine sand. Water in these deposits comes largely from direct infiltration of precipitation, although upward leakage from the artesian aquifer, irrigation water, and septic-tank effluent also provide variable amounts of recharge. Water leaves the system through seepage to lakes and streams, evapotranspiration, pumpage, and leakage to the underlying artesian aquifer. The sands of the surficial aquifer generally grade into less permeable clays, silts, and dense limestone of the Hawthorn Formation which in turn acts as a confining layer between the surficial and the artesian aquifers. This formation ranges in thickness from 25 to 50 feet in the north and northwestern portions of the study area to as much as 300 feet in southern Indian River County. In the coastal area, thin, discontinuous beds of shell or shell fragment, limestone, or sand and gravel often form a secondary artesian aquifer. These deposits usually are above or within the upper portion of the Hawthorn.

Overall, because of its relatively low yields, the surficial aquifer is only a minor source of water supply. However, the aquifer is the primary source of drinking water in much of Brevard and Indian River counties. In these areas the artesian aquifer contains water that is nonpotable due to chloride concentrations which exceed the EPA recommended public drinking water standard of 250 mg/l.

TERTIARY LIMESTONE AQUIFER (FLORIDAN)

The Floridan aquifer represents the principal water-bearing unit in the BIOS study area. It is composed of approximately 2500 feet of limestone and dolomitic limestone including the basal Hawthorn Formation and the Ocala, Avon Park, Lake City, and Oldsmar limestones. The top of the Floridan as used in this study is defined as the top of the first vertically consistent consolidated rocks. The base of the aquifer is defined by the first vertically consistent anhydrite beds or, in their absence, the top of the transition of the generally permeable carbonate sequence to the much less permeable gypsiferous and anhydritic carbonate beds of chalk.

The many cavities and solution channels that characterize the Floridan aquifer system allow it to produce large quantities of water. The vertical movement of water is restricted at certain depths by layers of less permeable materials. A low-permeability layer of major consequence occurs locally in the lower Avon Park Limestone and according to Tibbals (1981) serves to separate the Floridan aquifer into upper and lower permeable zones (Upper and Lower Floridan aquifer). Tibbals (1981) considers the upper permeable zone to include the basal Hawthorn Formation, the Ocala Limestone, and the upper Avon Park Limestone. The lower permeable zone conists of the Lake City and Oldsmar limestones. Because the present study builds directly on Tibbals (1981) the same description for the upper and lower permeable zones will be used here (Figure 2). Subsequent work by Miller (1984), however, differs from Tibbals (1981) in the delineation of the lower permeable zone or Lower Floridan aquifer. The former identifies the Lower Floridan as beginning in the lower Lake City Limestone, with the upper Lake City Limestone considered part of the overlying confining layer.

The Floridan aquifer receives water by downward leakage from the surficial aquifer in areas where the water table elevation is higher than the potentiometric surface of the Floridan aquifer. Water is released from the Floridan aquifer by upward leakage, spring discharge, and pumping. Figure 3 shows the location of recharge and discharge areas of the Floridan aquifer system in the study area as presented by Phelps (1984). The greatest recharge occurs in the Orlando area, while most of the coastal

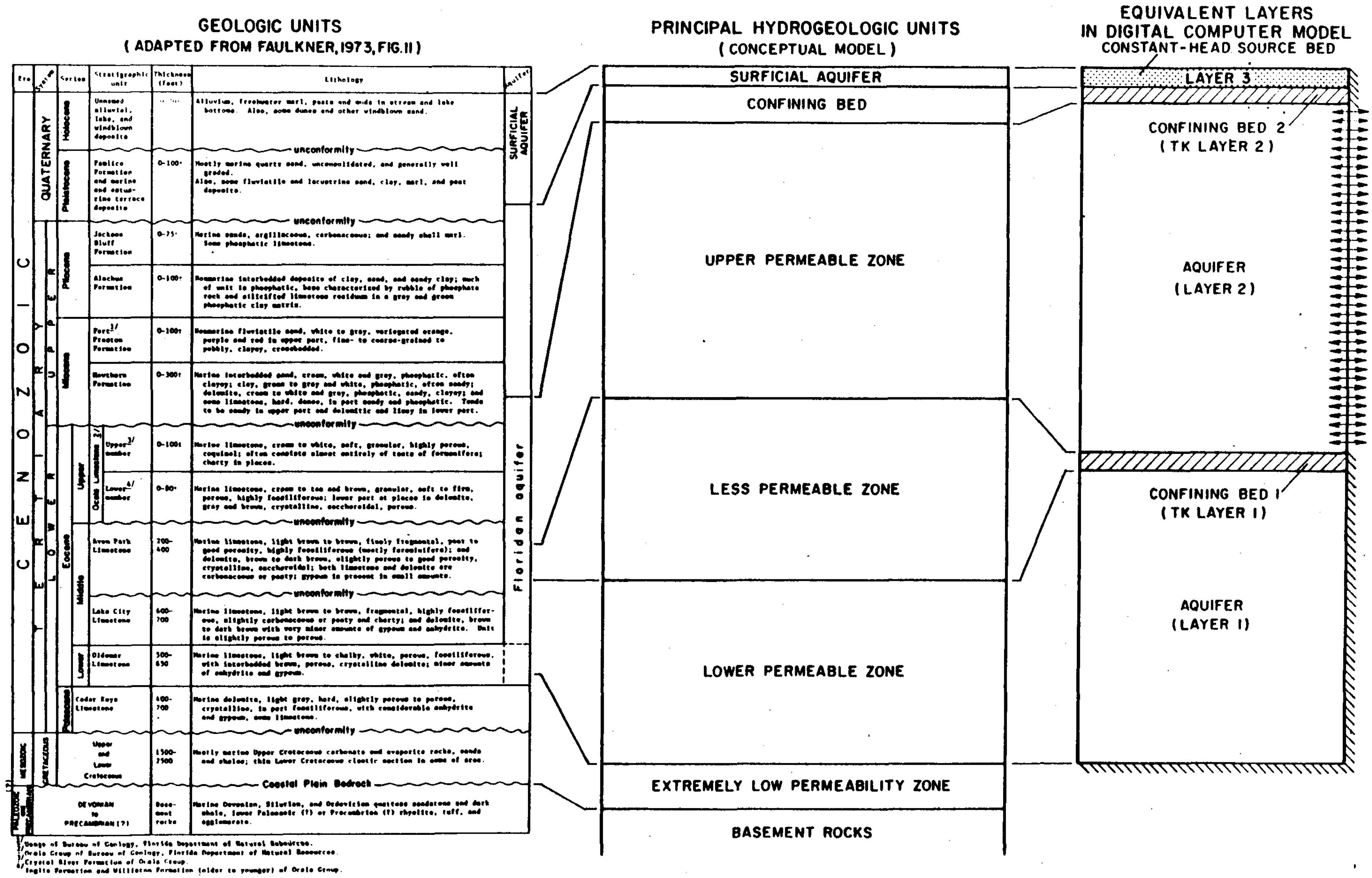


Figure 2: Conceptual Model of the Principal Hydrogeologic Units (Tibbals, 1981)

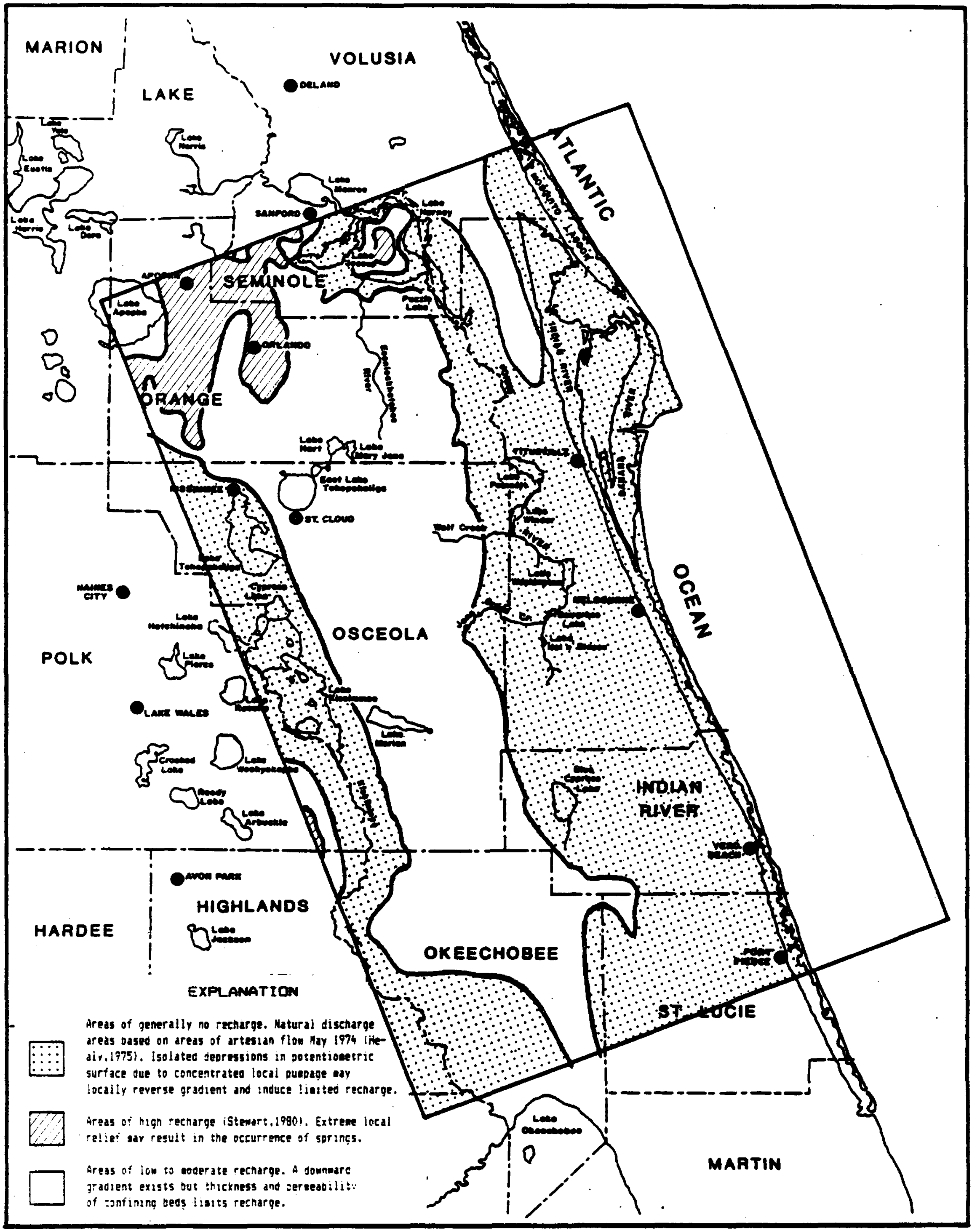


Figure 3 : Recharge and Discharge Areas of the Floridan Aquifer in the BIOS Area (Phelps, 1984)

zone acts as a discharge area. The majority of wells in the study area withdraw water from the upper permeable zone. A notable exception is in the Orlando area of western Orange County where many public supply wells are drilled into the lower permeable zone.

DIGITAL COMPUTER MODEL

FINITE DIFFERENCE APPROACH

Unsteady ground-water flow in three dimensions in a leaky artesian aquifer can be represented mathematically as:

$$\frac{\partial}{\partial x}\left(Txx\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(Tyy\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(Tzz\frac{\partial h}{\partial z}\right)+W-\frac{K'}{b'}(h-h')=S\frac{\partial h}{\partial t}$$

where

Txx, Tyy, Tzz:		transmissivity in the three coordinate directions;
h	:	hydraulic head in the artesian aquifer;
W	:	source or sink term;
k'	:	confining bed hydraulic conductivity;
b'	:	confining bed thickness;
h'	:	hydraulic head in the source aquifer;
S	:	storage coefficient of the aquifer; and
t	:	time.

A finite-difference approximation of the partial differential equation is used to simulate the ground-water system in this study. This requires that the system be subdivided into a set of smaller subregions or blocks. Each block is defined by a set of hydrogeologic properties that are considered representative of the entire block. By discretizing the time period being simulated into a number of finite time increments, the partial differential equation can be replaced at each block by an algebraic finite difference equation. Combining these individual equations results in a system of equations described collectively as a matrix equation. An iterative procedure, the strongly implicity procedure (SIP), is used to solve the matrix equation. As with all iterative methods, a solution is obtained by a process of successive approximation. Starting with an initial guess of the matrix solution, an iterative process is used to make refinements to the approximation until a correct solution is found.

Largely because of the vastly time-consuming nature of the aforementioned process, computers must be used to carry it out. Numerous computer codes have been developed to simulate ground-water flow. The computer source code used in this study is adapted from the three-dimensional ground-water flow model developed by Trescott (1975) and Trescott and Larson (1976) and modified by Steven Larson and James Tracy (written communication, September 1979) to include the head-controlled flux boundary condition. The code was further modified by C.H. Tibbals of the U.S. Geological Survey, Orlando, Florida to facilitate data handling, error analysis, and output, and by Anthony Navoy, also of the USGS, to include plotting of hydraulic cross-sections (Tibbals, 1981).

SYSTEM CONCEPTUALIZATION AND FINITE DIFFERENCE GRID

Figure 2 presents a conceptual model of the principal hydrogeologic units in the study area and their equivalent representation in the computer model. Briefly, the ground water system is defined as three aquifers separated by semiconfining formations and underlain by an impermeable base. Each aquifer is represented by a single layer of blocks. Such a representation is considered valid because flow in these aquifers is assumed to be predominantly horizontal. The two semiconfining layers are not represented by layers of blocks. Rather, they are only simulated as "membranes" between aquifer layers and referred to as "TK" layers. Vertical resistance to flow between aquifers is simulated by input of areally-variable leakance values to the TK layers in order to characterize the vertical hydraulic conductivity and thickness of the confining beds. Any appreciable horizontal hydraulic conductivity of the confining beds is reflected in the transmissivity values of the overlying and underlying aquifers.

The finite difference grid (Figure 4) consists of 438 grid blocks, each a uniform four miles by four miles or sixteen square miles in size. Because of boundary conditions there are only 382 active grid blocks covering an area of approximately 6,112 square miles.

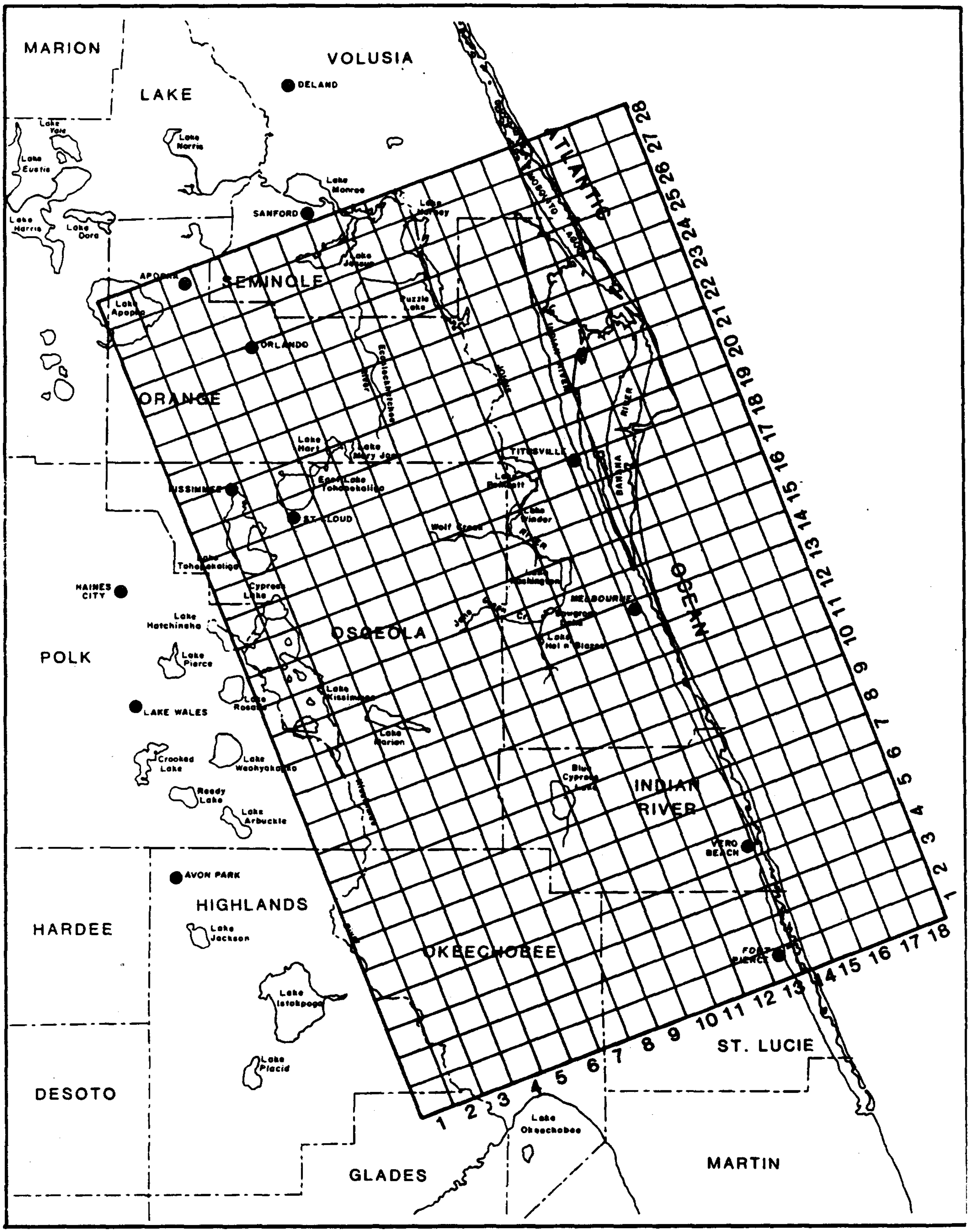


Figure 4: Finite Difference Grid Used to Model the BIOS Area

BOUNDARY CONDITIONS

Obtaining a unique solution to the ground-water flow equation requires that boundary conditions for the system be specified. Boundary conditions for layer 2, the upper permeable zone, under current conditions (1979 and 1980) are specified in Figure 5. "No-flow" boundaries are located where potentiometric contours are generally perpendicular to model boundaries. Unfortunately, such a configuration is not common in the area of interest. Rather, contours are parallel or near-parallel to model boundaries in most of the area. At these boundaries a head-controlled flux (HCF) was specified. This boundary condition allows the occurence of cross-boundary flow that is proportional to the head gradient across the boundary. The degree of proportionality (boundary leakance coefficient) and the head outside the boundary are input items that can be varied from node-to-node. The HCF boundary condition is also used to simulate point discharge from the Floridan aquifer at springs.

Some variation in boundary conditions was necessary for simulating both predevelopment and current (1980) potentiometric configurations. This is due to the fact that significant changes in head have occurred over the time span defined by these configurations. For example, under predevelopment conditions the northeast boundary is defined as "no-flow". Examination of more recent potentiometric contours suggests that there is cross-boundary flow in this area; consequently, an HCF boundary is used

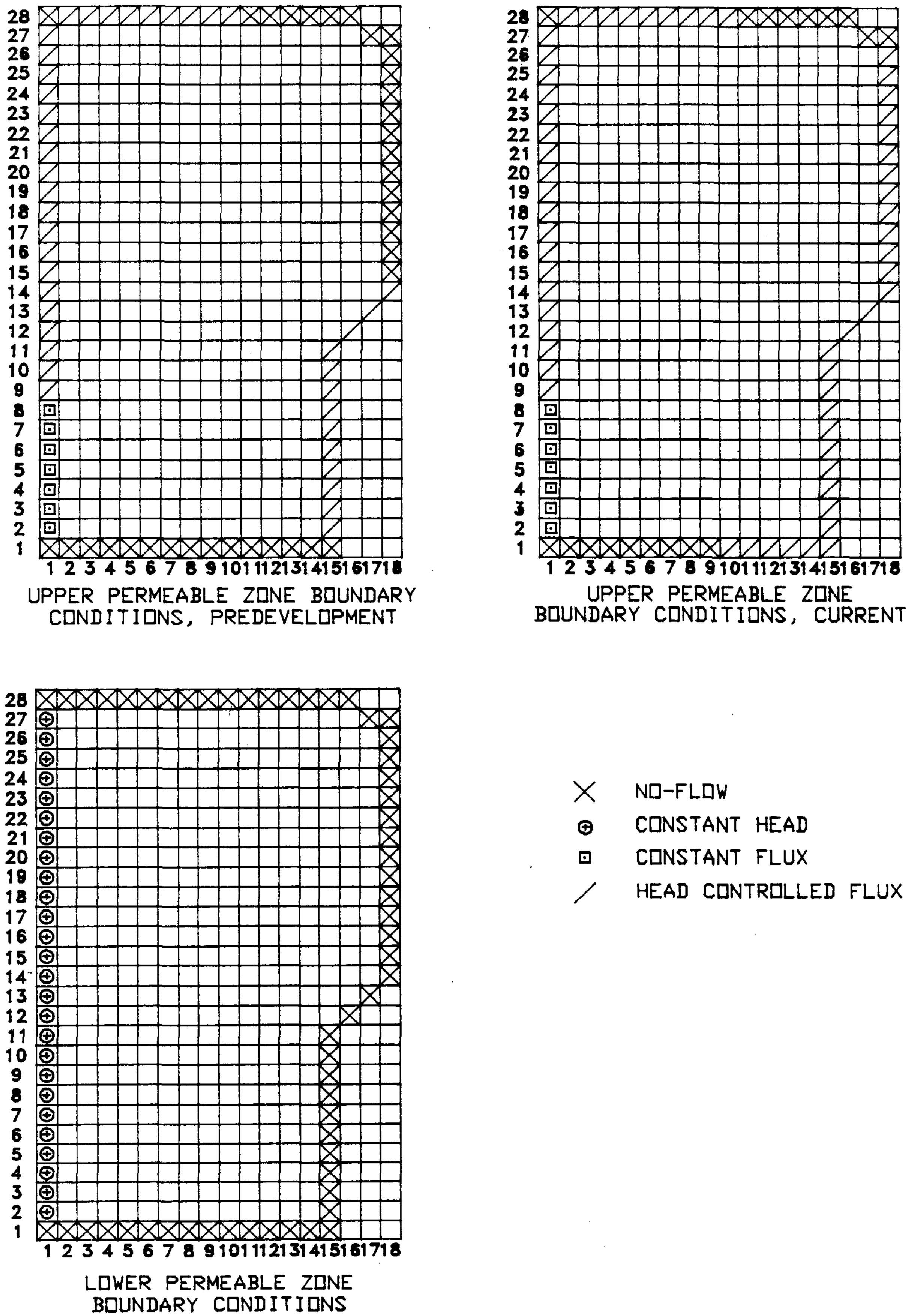


Figure 5: Boundary Conditions

for current simulations. Significant changes in head also necessitated changing the fixed boundary heads utilized with the HCF boundaries in most instances.

The lower permeable zone of the Floridan aquifer and its upper confining bed, defined in this study as the Lake City and Oldsmar limestones, and the low porosity zone of the Avon Park Limestone, respectively, act as a leaky base for the upper permeable zone of the aquifer. These units need to be included in the model if a true representation of the upper permeable zone is to be achieved. Unfortunately, few data on these lower units are available. In this study, the lower permeable zone is assigned a "no-flow" boundary everywhere along its perimeter except the western side. At this location a constant head boundary is used. The few data that exist for the lower permeable zone suggest that in recharge areas head in this zone is generally a few feet lower than the head in the upper zone and, in discharge areas, a few feet higher. Therefore, at grid blocks identified as discharge areas, head values are set two feet higher than observed in the upper permeable zone and at recharge areas they are set two feet lower.

The surficial aquifer is represented in this analysis as a constant head boundary to the underlying Floridan aquifer. The water table is fixed at a prescribed elevation. Thus leakage between the surficial and Floridan aquifers is proportional to the difference in head between the two aquifers. Water-table elevation was determined by superimposing the finite difference grid on U.S. Geological Survey topographic maps and estimating an average water table elevation based on the average elevation of surface water features within each grid block. The perimeter of this aquifer layer is designated as a "no-flow" boundary.

HYDROGEOLOGIC INPUT DATA

Table 1 presents a summary of the type of hydrogeologic data required in developing the numerical model. Development of this data involved making initial estimates based on extrapolation of observed values followed by refinement during the calibration procedure. With few exceptions, the final data set used was that developed by Tibbals (1981) in his analysis. The reader is referred to that study for details on how the data set was developed. Figures 6 through 8 present the calibrated data.

Tibbals (1981) study was confined to a steady-state simulation and consequently did not require estimates of storage coefficients. The present analysis includes transient simulations in which storage coefficients must be specified. Storage coefficient data in the study area is limited. The final storage coefficient matrix (Figure 8) used in this analysis was determined by multiplying the estimated thickness of the upper permeable zone by a specific storage of 3.3×10^{-6} ft^{-1}. This falls within the range of values of specific storage reported by Hickey (1977) for limestones and dolomites in Pinellas County. The thickness of the upper zone is considered equal to the estimated thicknesses of the Ocala Limestone plus half of the Avon Park Limestone. The lower layer was arbitrarily assigned the same matrix.

No storage capabilities were assigned to the surficial aquifer or either of the confining layers. The specification of

Table 1. Model Input Data

Hydrologic parameter	Aquifer layer	TK Layer (confining bed)
Head	1, 2, 3	-
Storage coefficient[1/]	1, 2, 3	-
Transmissivity	1, 2, 3	-
Leakance		1, 2
Head-controlled flux boundary conditions:		
Boundary head	1, 2, 3	-
Boundary leakance coefficient	1, 2, 3	-

1 The storage coefficient input for layer 3 is -1 which has no physical meaning except to instruct the computer model to treat layer 3 as a constant-head source bed.

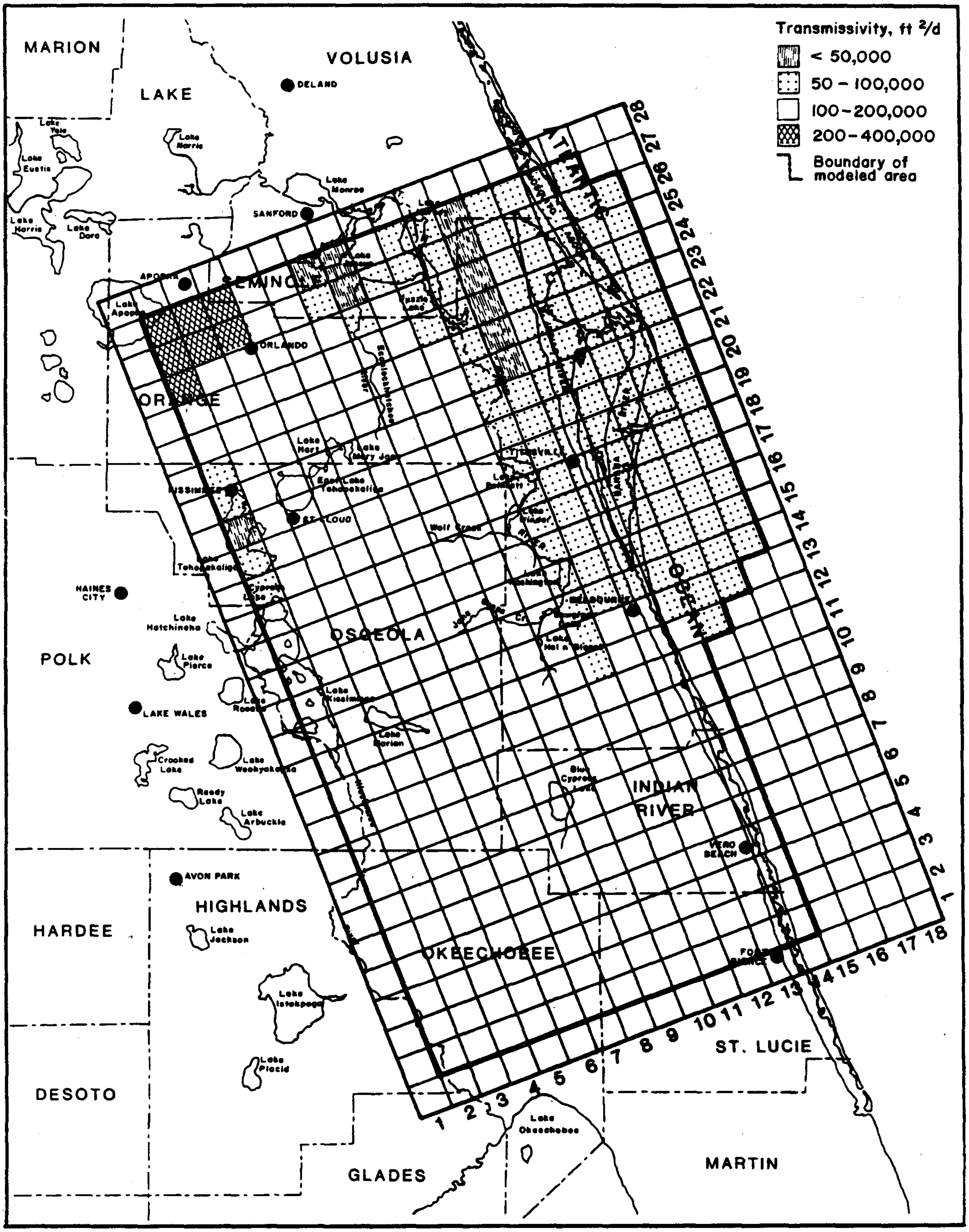


Figure 6: Transmissivity of the Upper Permeable Zone Based on Model Calibration

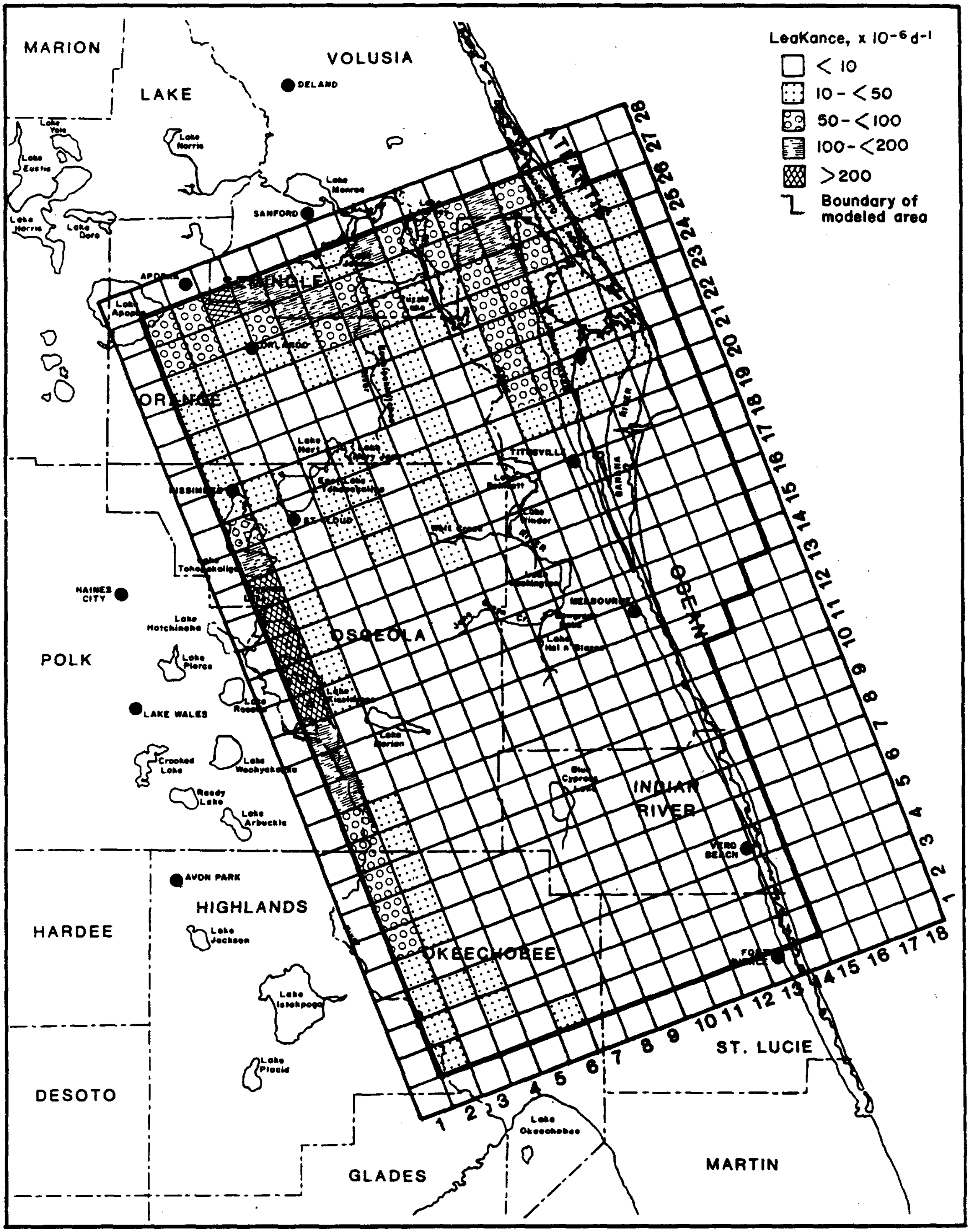


Figure 7: Leakance of the Upper Confining Unit Based on Model Calibration

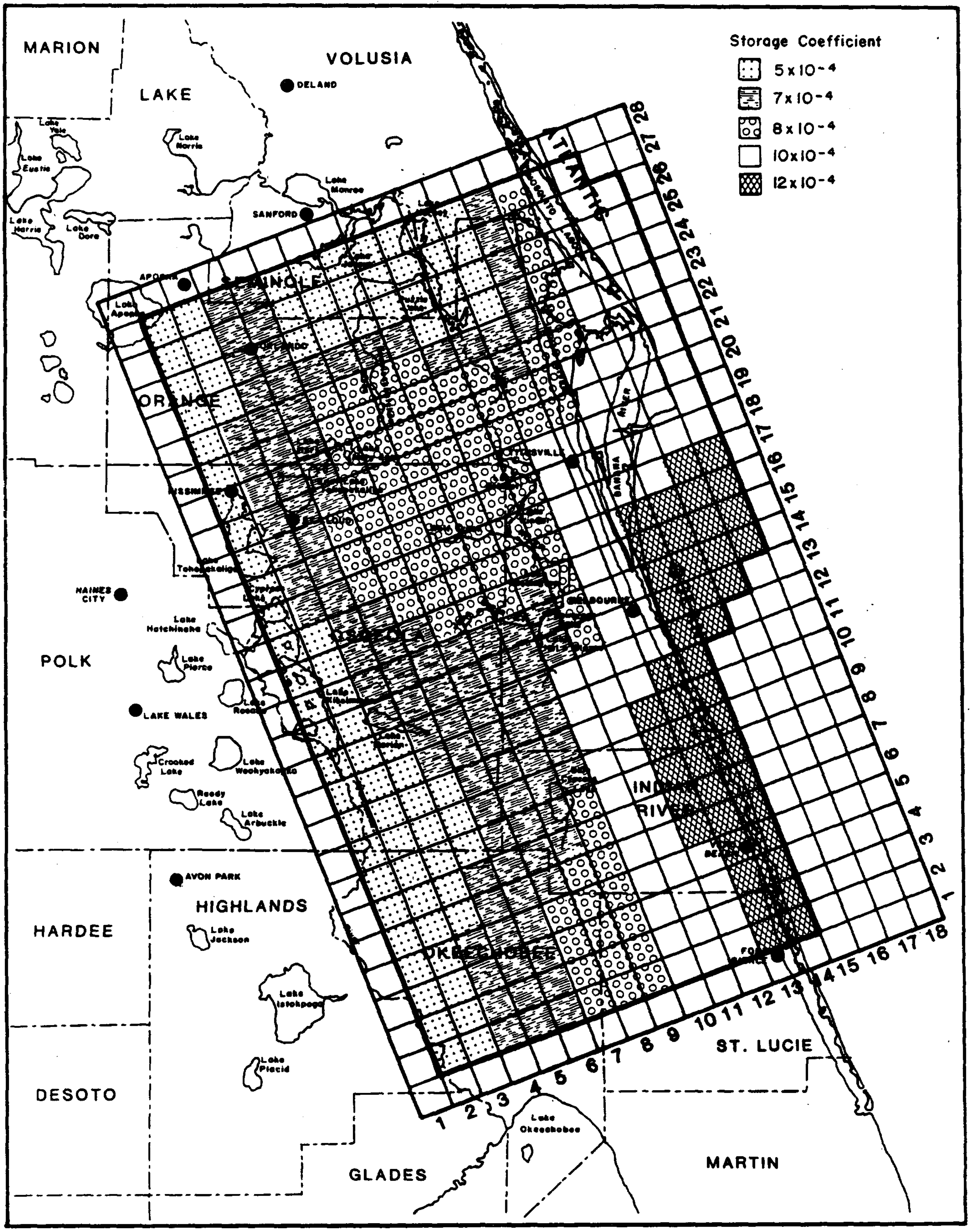


Figure 8: Storage Coefficient of the Upper and Lower Permeable Zones Used in the BIOS Model

a constant head in the surficial aquifer precluded the assignment of storage to this layer. Storage in the confining layers was ignored primarily for practical reasons. Several layers of nodes are required to adequately represent a confining layer with storage capabilities (Trescott, 1975). This results in a substantial increase in storage and computation time. Instead, as previously mentioned, the confining layers are represented as "TK" layers which simulate the vertical resistance to flow between aquifers.

WATER USE

The Floridan aquifer provides water for a great variety of uses including public and industrial supply, agricultural irrigation, heating and cooling, and recreation. Simulation of the hydrologic response of the aquifer during the 1980 water year requires that estimates of the volume of water withdrawn for these uses throughout the BIOS area be made. The quantity and quality of data on water use varies, ranging from good for non-agricultural uses to poor for agricultural uses. A brief discussion of how 1980 water use was estimated for this study follows.

NONAGRICULTURAL WATER USE

Nonagricultural water uses include water used for public supply, industrial purposes, thermoelectric power generation, heating and air conditioning (heat pumps), and for recreational uses such as golf course maintenance. Data on nonagricultural water use is collected annually by the water management district. This data is the basis of the water use estimates used in this study (Marella, 1982). The actual location of ground-water withdrawals was determined through consultation with the users and field inspection.

Table 2 presents a summary of all estimated water use, including nonagricultural uses, in the BIOS area for the 1980 water year. The year is subdivided into time periods of varying lengths, each representing a different pumping period in the model simulations. Nonagricultural withdrawals from the Floridan aquifer average 170 million gallons per day, with peak withdrawals of 196 mgd occurring in June.

There is a degree of uncertainty associated with these figures. Withdrawal estimates for public, industrial, and thermoelectric power generating uses are considered accurate since these data are collected regularly by the users themselves. Two other types of nonagricultural uses -- recreational and heat pumps -- must be estimated.

Recreational water use in the study area is almost exclusively for golf course maintenance. Total annual withdrawals were estimated by multiplying pump capacities by estimated hours of operation per year (Marella, personal communication, 1985). Average withdrawal rates for each month in the water year were estimated based on results published by the Southwest Florida Water Management District as part of their Benchmark Farms project (Duerr and Trommer, 1982). Withdrawals were estimated as 5 percent of total water use in each of the months of January, February, July, August, and September; 10 percent each in the months of March, April, June, October, November, and December; and fifteen percent during May. Total recreational water use in the study area averages 3.2 million gallons per day.

TABLE 2. Estimated Daily Ground-Water Withdrawals in BIOS Area, Water Year 1980

WATER USES (MGD)

Pumping Period	Nonagricultural*	Heat Pumps & Lawn Irrigation	Agricultural	Total
September, 1979	121.56	29.01	0.00	150.57
Oct. thru Feb., 1980	134.27	21.86	52.92	209.05
March thru April	137.01	23.78	67.12	227.91
May	153.96	31.19	156.09	341.24
June	161.44	34.71	78.18	274.33
July	156.77	34.71	74.93	266.41
August	153.33	34.71	69.90	257.94
September	143.77	29.02	11.83	184.62

* Note: Does not include heat pump and lawn irrigation withdrawals

Heat pumps utilizing ground water for heating and cooling purposes represent a significant water-use in Brevard County. It has been estimated that 4,165 heat pump wells were withdrawing water from the Floridan aquifer in the County in 1980 (Marella, 1982). These, in addition to approximately 12,327 lawn irrigation wells withdraw an annual average of 27.34 MGD from the aquifer. (Details on how these numbers were estimated are presented in Appendix A). Referring to Table 2 it can be seen that the combined withdrawals by heat pump and lawn irrigation wells ranged from a low of 21.86 mgd in the October-February pumping period to a high of 34.71 mgd during the summer months of June, July, and August. The steady-state drawdown resulting from an average withdrawal of 27 mgd is presented in Figure 9.

AGRICULTURAL WATER USE

A variety of agricultural crops are grown in the BIOS area, but citrus and pasture predominate (Marella, 1982). Estimating the amount of water used to irrigate these crops is difficult. Historically, water use has been estimated using the modified Blaney-Criddle model for evapotranspiration (U.S. Soil Conservation Service, 1970). Supplemental irrigation water required by a crop is calculated taking into account irrigation method, the season a crop is grown, general crop location, and associated atmospheric conditions. Using this method estimated application

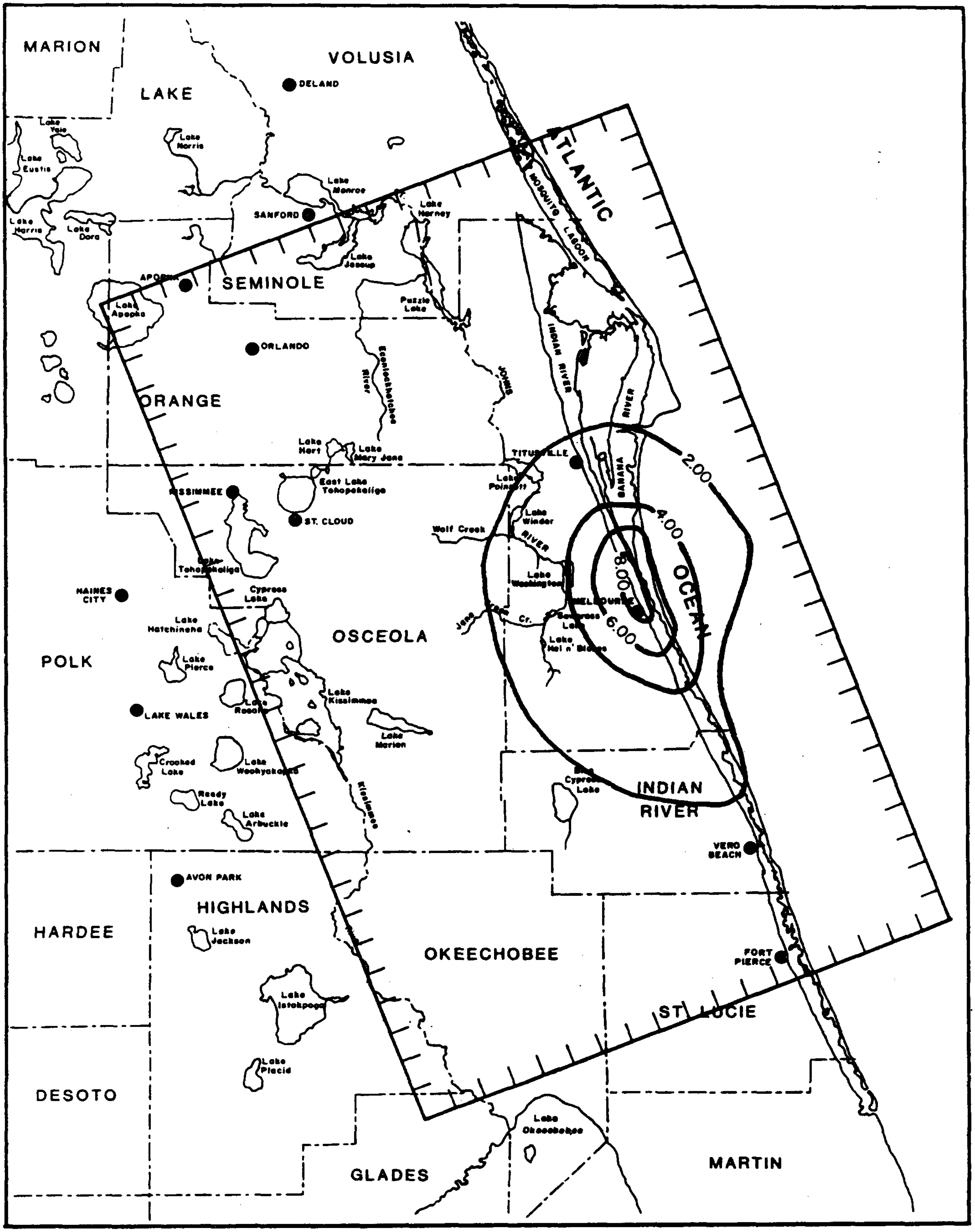


Figure 9: Simulated Steady-State Drawdown in the Upper Permeable Zone Due to Heat Pump and Lawn Irrigation Withdrawals of 27 MGD

rates for citrus in 1980 ranged from 32 inches/acre/year in Indian River and Brevard counties to 20 inches/acre/year in Orange County. Estimates for improved pasture irrigation range from 56 inches/acre/year in Osceola County to 46 inches/acre/year in Brevard County (Marella, 1982).

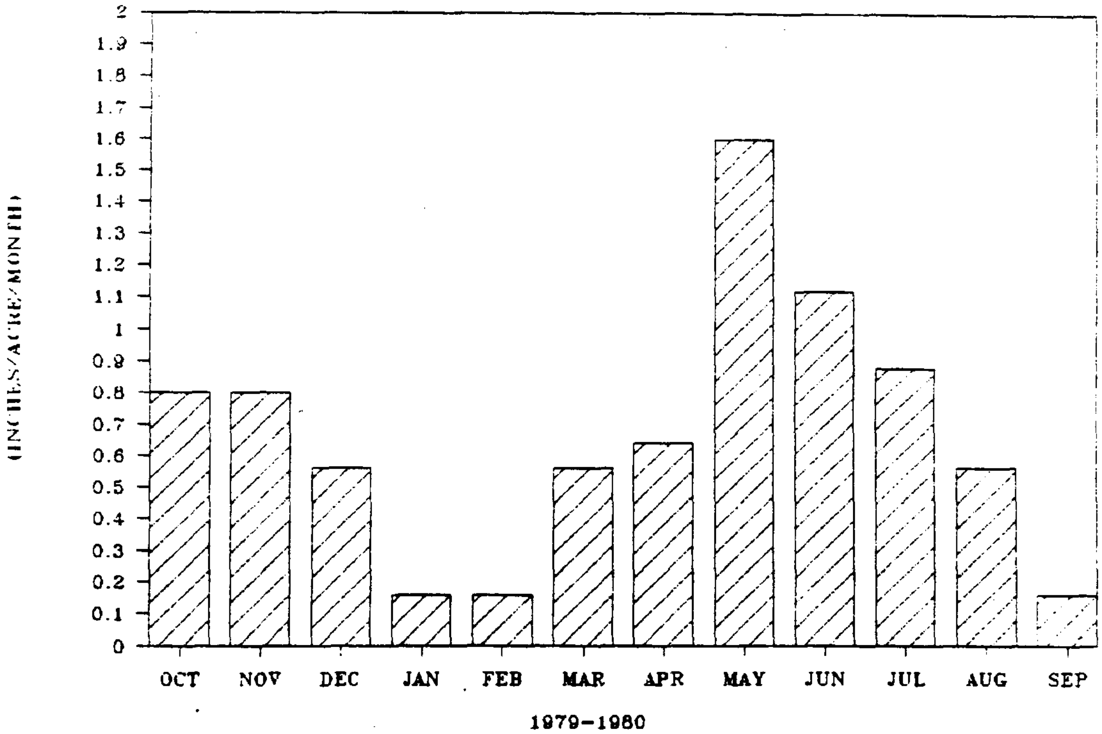
Initial simulations using the calibrated ground-water model suggested that irrigation withdrawals of these magnitudes are unrealistically high. Data collected by the Southwest Florida Water Management District (Duerr and Trommer, 1982) supported this conclusion. In that study, ground-water withdrawals were measured at a number of farms over a ten-year period in southwest Florida. Application rates for citrus measured at 24 locations averaged 7.5 inches/acre/year in 1980 and approximately 6 inches/acre/year over the ten years of the study.

Based on the aforementioned simulations and the data collected by SWFWMD, agricultural withdrawals were adjusted to reflect more realistic values. All withdrawals were classified as either citrus or pasture. Application rates for the 1980 water year were reduced to 8 inches/acre/year for citrus and 6 inches/acre/year for improved pasture everywhere except Indian River and St. Lucie counties. All irrigation water is assumed to come for the Floridan aquifer.

Estimating irrigation withdrawals in Indian River and St. Lucie counties presents some further problems. Unlike the other counties in the study area, a large percentage or irrigation water in these two counties is supplied by surface water. For example, surface water accounted for approximately 80 percent of the irrigation water used for citrus in Indian River County in 1980 (Marella, 1982). Consequently, even if total applications for each acre were known, percentages supplied by each source are also required to properly simulate the system. Given the limited data available, the following approach was taken in this study.

Each drainage district in the two counties was classified according to whether irrigation water was supplied primarily by surface water or by combined surface and ground sources (Pete Spike and Brian Combs, personal communications, 1985). In Indian River County, surface water was considered the principal source of irrigation water in both the Fellsmere Farms and the St. Johns drainage districts; it was assumed that there were no ground-water withdrawals in these areas. Elsewhere in the County irrigation water was assumed to be supplied in equal volumes by surface and ground sources. In St. Lucie County combined sources were considered characteristic in the Fort Pierce Farms and North St. Lucie River drainage districts. Due to the prevalence of flood and seepage irrigation in these counties, annual applications per acre were estimated at twelve inches, six inches from ground and six inches from surface sources.

Irrigation withdrawals vary seasonally. These variations influence potentiometric levels in the Floridan aquifer. Consequently, the 1980 water year was subdivided into different pumping periods for simulation purposes. Annual irrigation withdrawals for citrus and pasture were subdivided into monthly withdrawals based on observed variations reported by the SWFWMD (Duerr and Trommer, 1982). Figure 10 presents the monthly



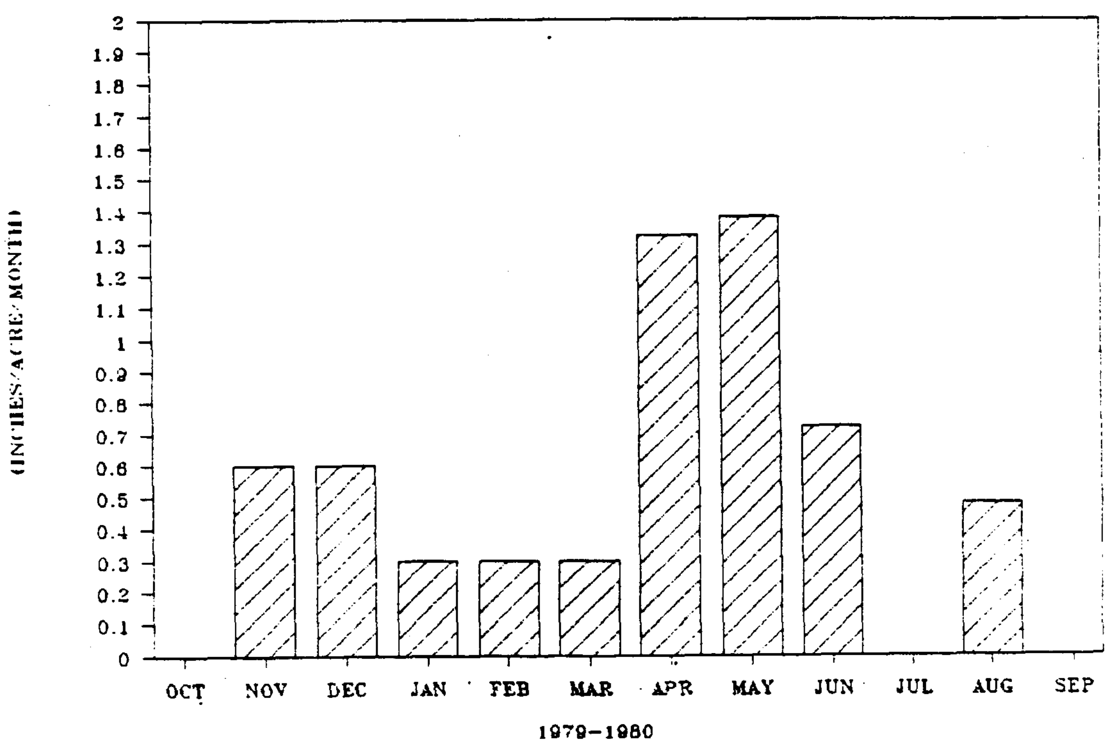


Figure 10: Monthly Irrigation Withdrawals Used in Model - Citrus (top) and Pasture (bottom)

TABLE 3. Estimated Daily Agricultural Withdrawals from Ground Water, Water Year 1980

COUNTY(S)	ESTIMATED GROUND-WATER WITHDRAWALS (MGD)							
	October thru February	March thru April	May	June	July	August	September	Average
Brevard								
Citrus	7.11	6.53	20.00	9.76	13.43	9.47	2.10	8.65
Pasture	2.77	6.15	10.72	4.68	0.00	3.57	0.00	3.77
Indian River								
Citrus	13.39	13.25	35.37	15.18	26.38	18.45	3.84	16.13
Okeechobee								
Pasture	2.01	4.46	7.14	4.02	0.00	2.61	0.00	2.74
Orange								
Citrus	10.34	9.53	28.81	12.32	19.88	14.93	3.21	12.55
Osceola								
Citrus	1.93	1.84	5.44	2.69	3.55	2.60	0.59	2.36
Pasture	8.14	18.15	29.37	16.10	0.00	10.56	0.00	11.11
St. Lucie								
Citrus	7.23	7.21	19.24	13.43	11.69	7.71	2.09	8.75
Total	52.92	67.12	156.09	78.18	74.93	69.90	11.83	66.06

irrigation withdrawals used in this study for the two principal agricultural crops. Table 3 provides a breakdown of daily agricultural withdrawals in each portion of the study area by county and by simulation period.

MODEL CALIBRATION

The ground-water model being utilized in this study was developed by Tibbals (1981). The original model was calibrated by reproducing the steady-state potentiometric surface in the upper permeable zone of the Floridan aquifer prior to development as estimated by Johnston and others (1980) (Figure 11). However, Tibbals' (1981) model covered a larger area (13,700 $mi.^2$) than is considered in this report (6,112 $mi.^2$). With the revision of the model to include only a portion of the original area, it was necessary to recalibrate the model. Once again the estimated steady-state potentiometric surface prior to development was simulated.

Figure 12 and 13 present the simulated predevelopment potentiometric surface in the upper permeable zone and associated deviations from estimated water levels at each node on the finite-difference grid, respectively. The average absolute difference between estimated and simulated head is 1.3 feet in the upper zone. Deviations of less than three feet were simulated at 92 percent of the active nodes.

The accuracy with which the model reproduces ground-water flow at HCF boundaries and spring discharges is directly dependent on the accuracy of simulated heads. If the simulated head at an HCF node matches the observed head, the calculated

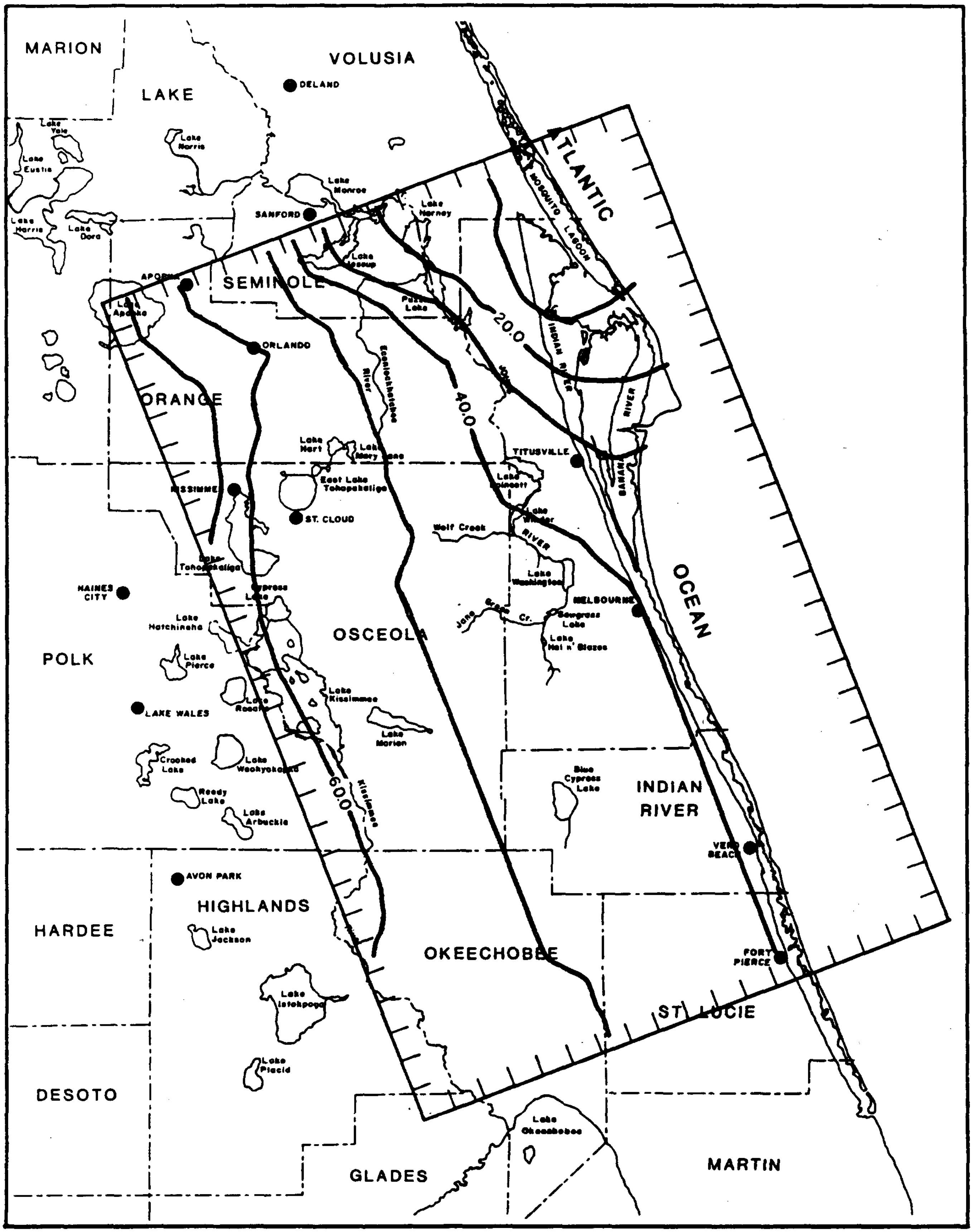


Figure 11: Estimated Potentiometric Surface of the Floridan Aquifer Prior to Development (from Johnston et al., 1980)

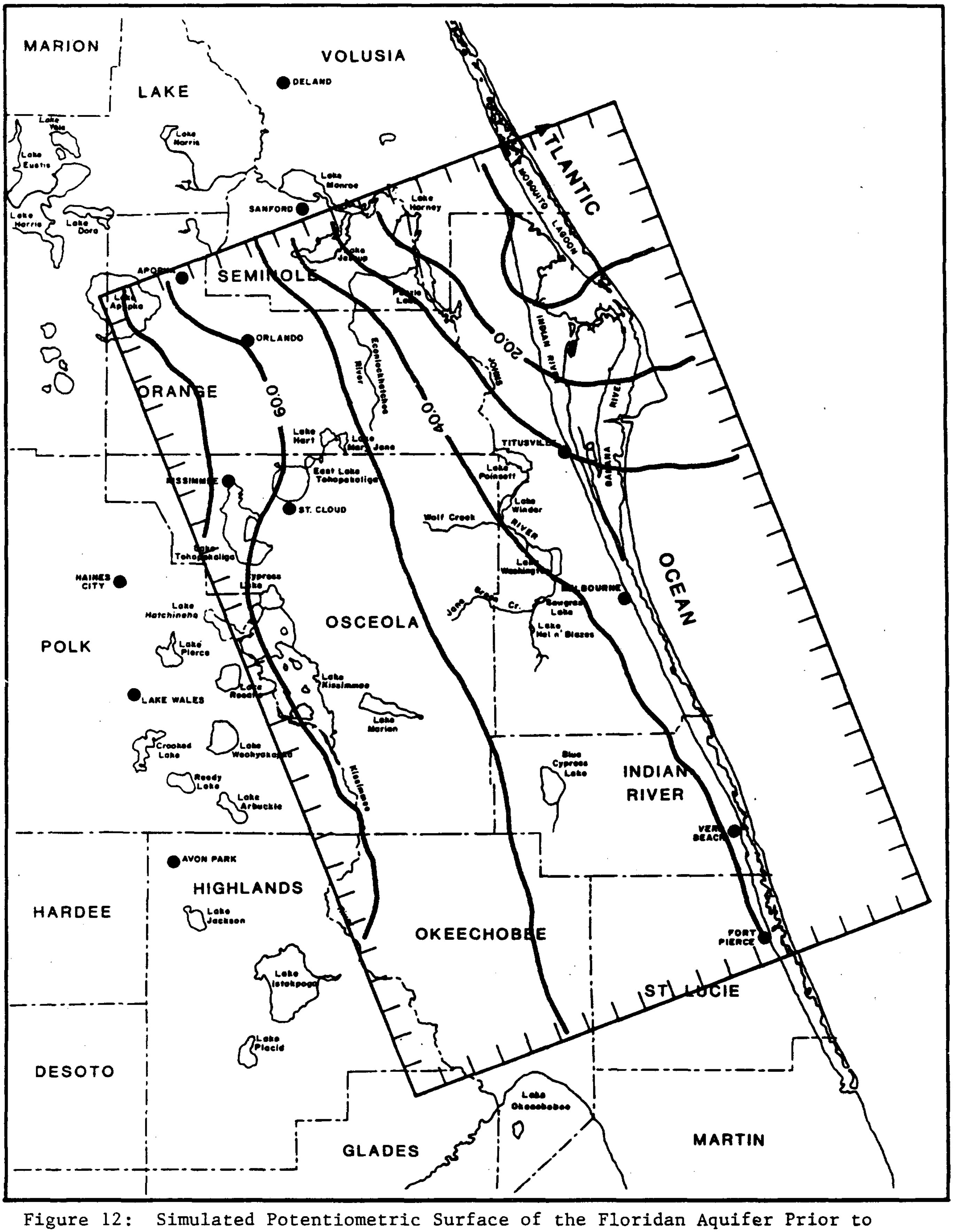


Figure 12: Simulated Potentiometric Surface of the Floridan Aquifer Prior to Development

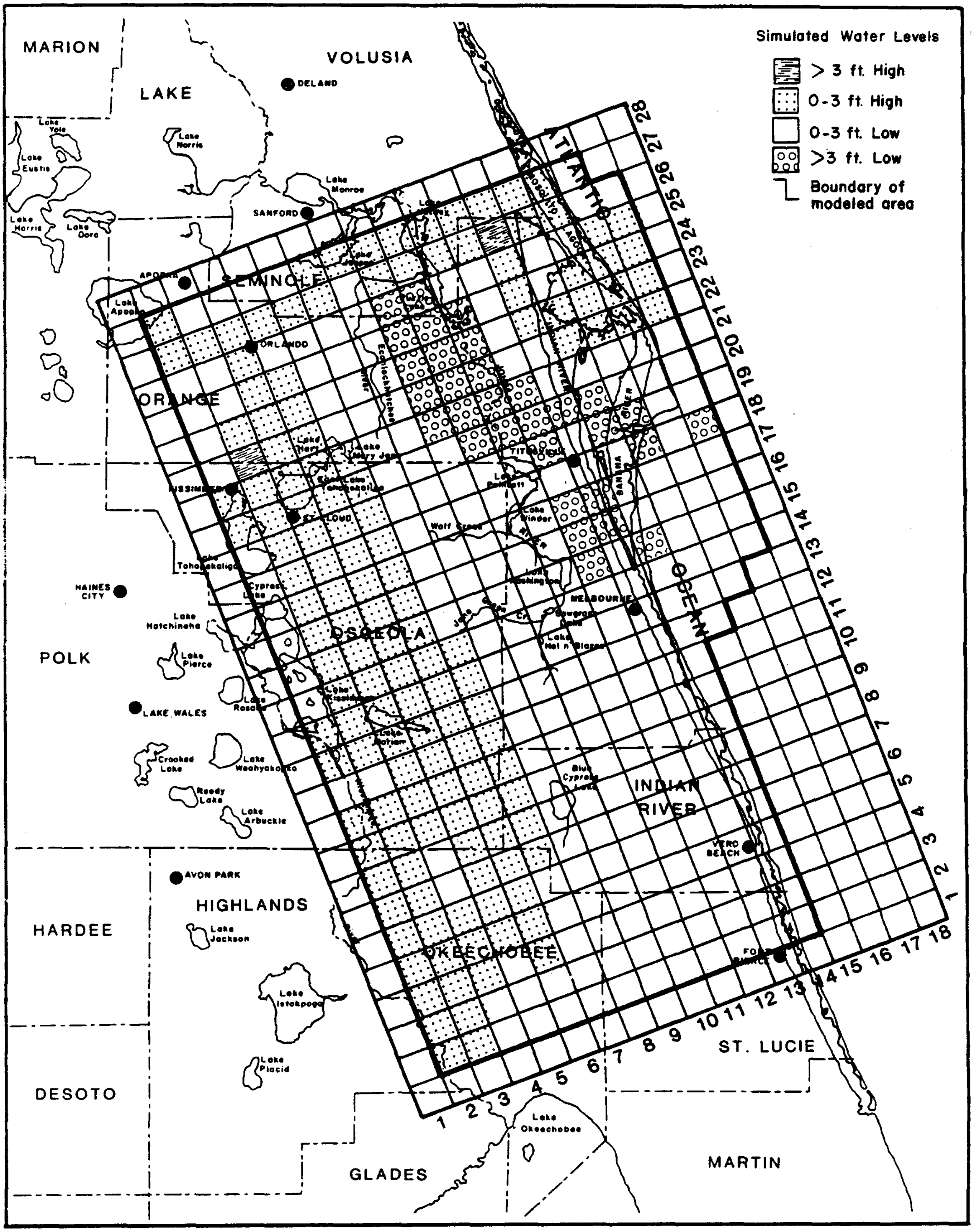


Figure 13: Difference Between Estimated and Simulated Potentiometric Surface Prior to Development

discharge will match as well. Consequently, evaluation of the accuracy of simulated boundary or spring flows cannot be used as an independent test of the viability of the model.

MODEL VERIFICATION

Before any real confidence could be placed in the model, additional tests had to be conducted. In the first step of the testing process initial estimates of hydrologic-system parameters were refined until the model was capable of reproducing an observed condition; in this case, the estimated potentiometric surface prior to development. Studies have shown, however, that similar results can be obtained using any number of different sets of data (Gillham and Farvolden, 1974). By utilizing the calibrated model to simulate a different observed condition, much greater confidence can be placed in the model. Simulation of water levels within plus or minus five feet is considered a good match. This error range is based on consideration of probable errors in averaging heads and aquifer properties over 16 square-mile grid blocks and map error, which is normally one-half the contour interval (in this case, 2.5 feet).

The verification procedure involved simulating a number of different observed hydrologic conditions. The conditions simulated were:

1. steady-state September 1979 potentiometric surface;
2. May 1980 potentiometric surface; and
3. September 1980 potentiometric surface.

In addition, comparisons were made between observed and simulated hydrographs at fourteen upper permeable zone wells and two lower permeable zone wells for a period between January and September 1980. Sample statistics for each of the calibration/ verification scenarios are presented in Table 4.

SEPTEMBER 1979 POTENTIOMETRIC SURFACE

Hydrographs of several wells in the study area suggest that the flow system in the upper permeable zone was at or near steady-state conditions in late September and October 1979 (see Figure 14). Unfortunately, no potentiometric surface map was produced for September 1979. Water levels recorded at observation wells show that the potentiometric surface at that time was on the average two feet higher than the September 1980 potentiometric surface. Based on this observation, a September 1979 potentiometric surface was estimated by adding two feet to the observed September 1980 surface (see Figure 15). Obviously only limited confidence can be put in the estimated surface. However, this estimate is considered reasonable enough to allow a general comparison for model verification purposes.

Figure 16 presents the simulated September 1979 potentiometric surface (the associated deviations from estimated levels are represented in Appendix B). Agricultural withdrawals were assumed to be low to non-existent and were not included in this scenario. Total withdrawals were estimated at 146 MGD. Agreement between estimated and simulated levels is relatively

TABLE 4. Statistics of Model Calibration and Verification

STATISTIC	SIMULATION			
	Pre-development	Sept. 1979	May 1980	Sept. 1980
number of active nodes in upper permeable zone	382	382	382	382
maximum residual*	6.5	11.6	5.4	7.5
minimum residual*	- 3.7	- 8.7	-6.7	-4.2
mean residual	0.59	1.03	-0.22	1.10
median residual	0.60	1.00	-0.10	1.00
standard deviation of residuals	1.60	3.76	2.22	2.10
mean absolute residual	1.32	3.14	1.74	1.86
correlation co-efficient	0.995	0.962	0.983	0.986

* residuals = observed water level minus simulated water level

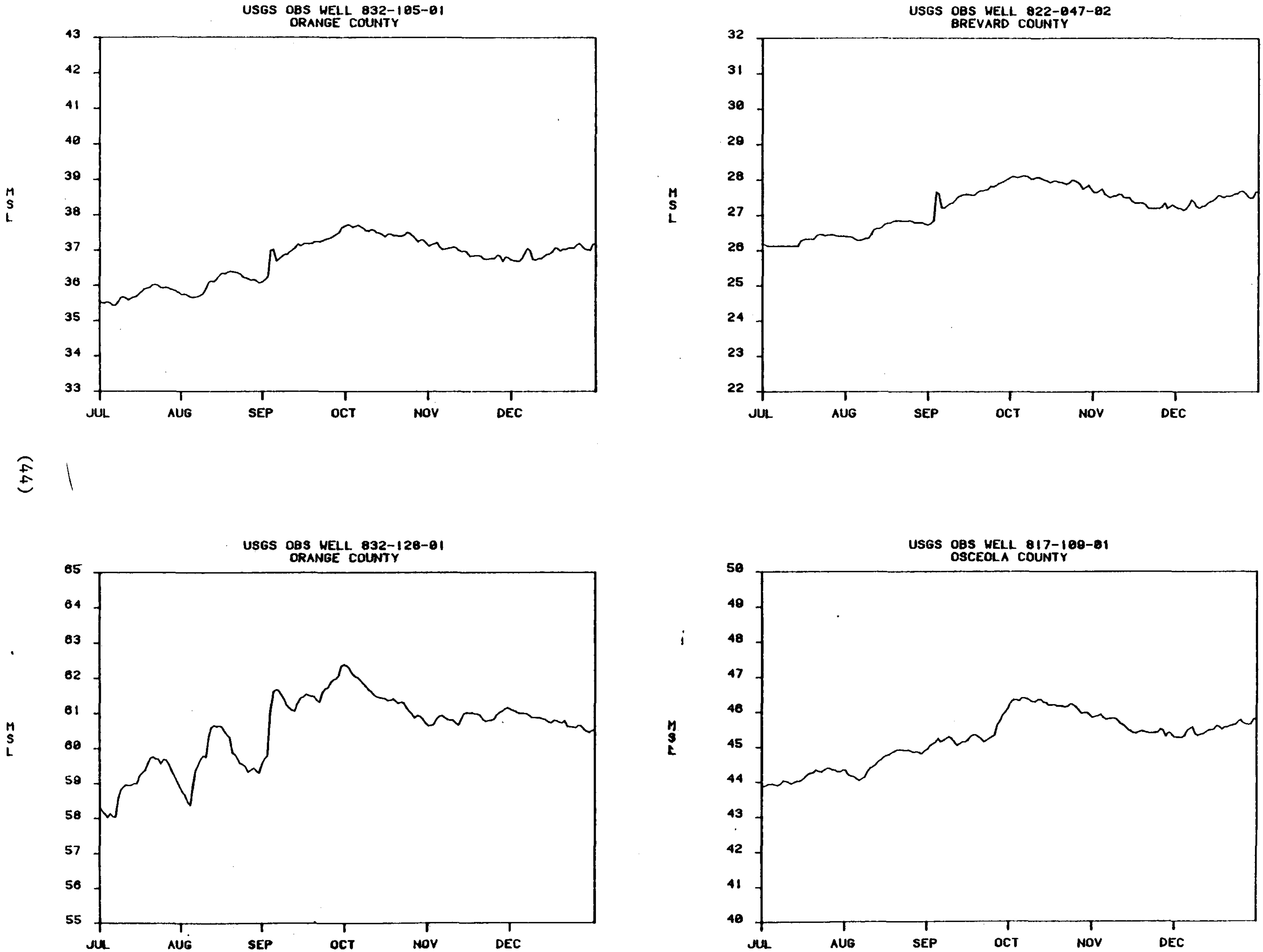


Figure 14: Hydrographs at Selected Wells for Fall 1979

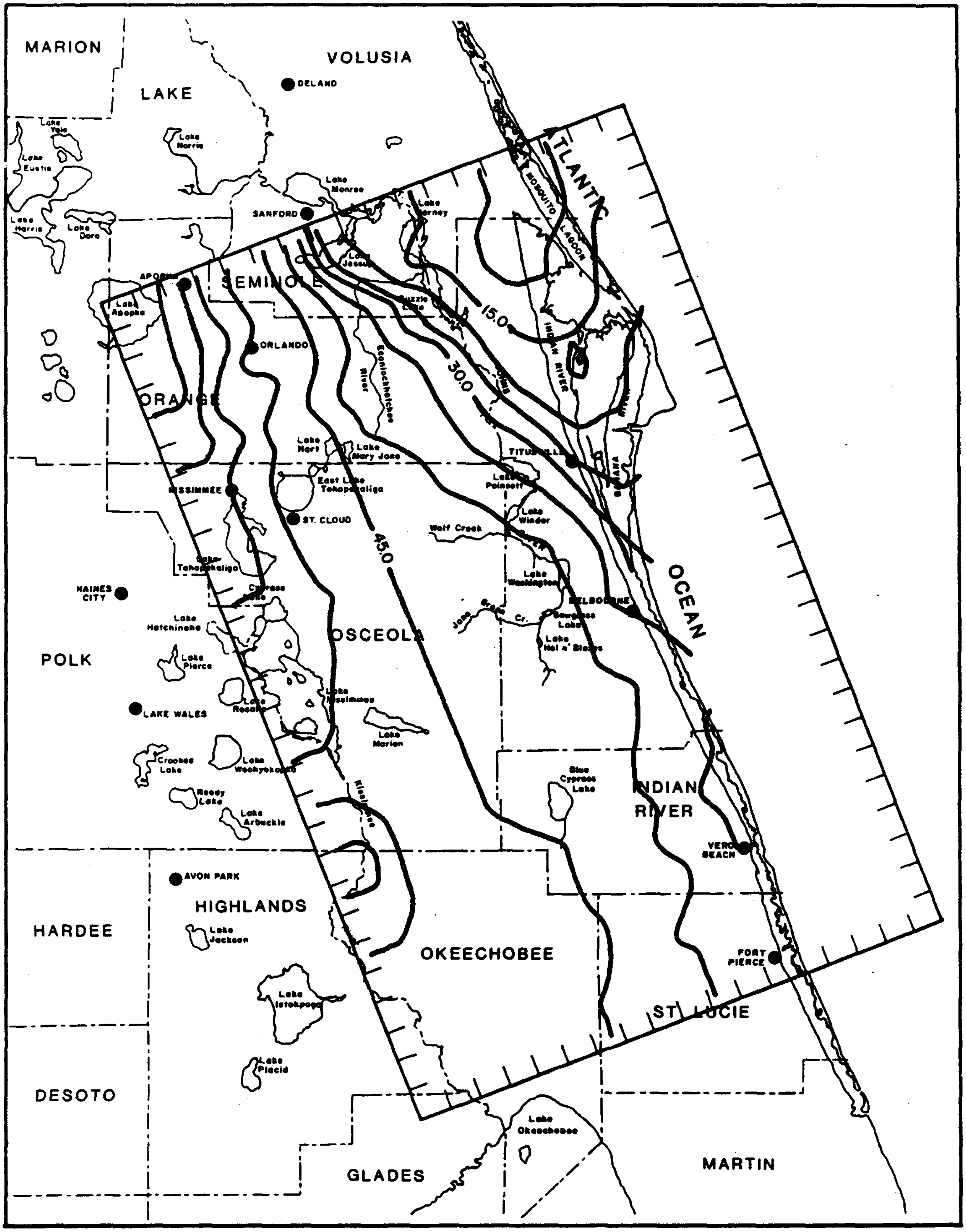


Figure 15: Estimated Potentiometric Surface of the Floridan Aquifer, September 1979

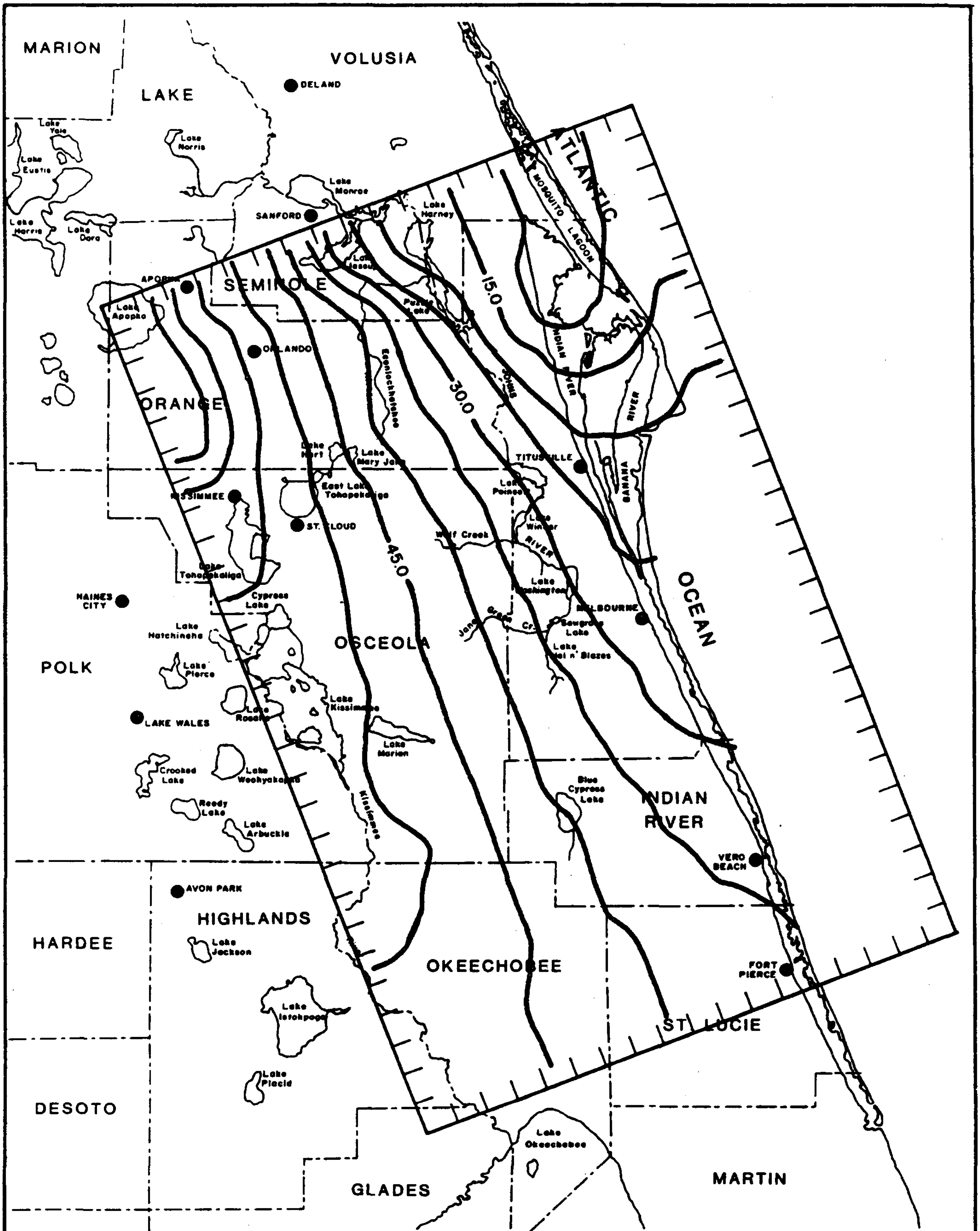


Figure 16: Simulated Potentiometric Surface of the Floridan Aquifer, September 1979

good overall, with an average absolute difference of approximately three feet (see Figure 17). Simulated levels were within five feet of estimated levels at eighty-four percent of all active upper zone nodes. The most extreme deviations occur in the southern Brevard County area. A number of factors may be influencing the results in this particular area. Of particular note is that this is the area of greatest heat pump and lawn irrigation withdrawals from the Floridan. Uncertainty over these withdrawals is certainly a factor.

Simulation of the September 1979 potentiometric surface resulted in a good comparison between simulated recharge values and those previously estimated (Figure 18). Simulated results indicate that the greatest recharge occurs in the northwestern portion of the area, Orange and Seminole counties. Lesser amounts occur throughout Osceola County. Ground-water discharge occurs throughout the entire eastern half of the area except in northern Brevard County where some recharge occurs. The presence of a thick confining unit in southern Brevard and Indian River counties is evident by the minimal amount of water being discharged through upward leakage in these areas.

MAY 1980 POTENTIOMETRIC SURFACE

The May 1980 potentiometric surface was simulated to test the ability of the model to predict water levels under transient conditions. Starting from the steady-state September 1979 potentiometric surface, three different pumping periods (October

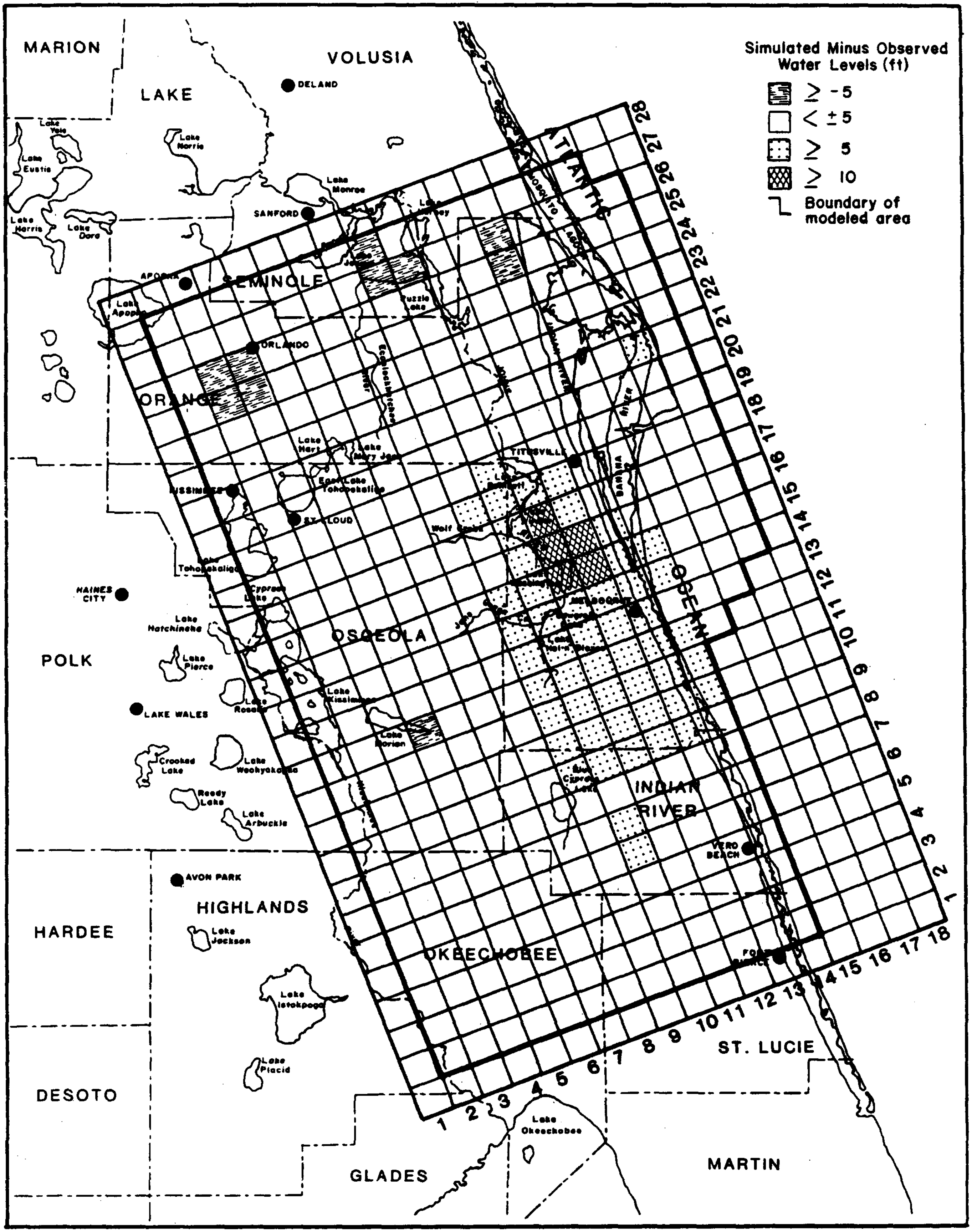


Figure 17: Difference Between Estimated and Simulated Potentiometric Surface, September 1979

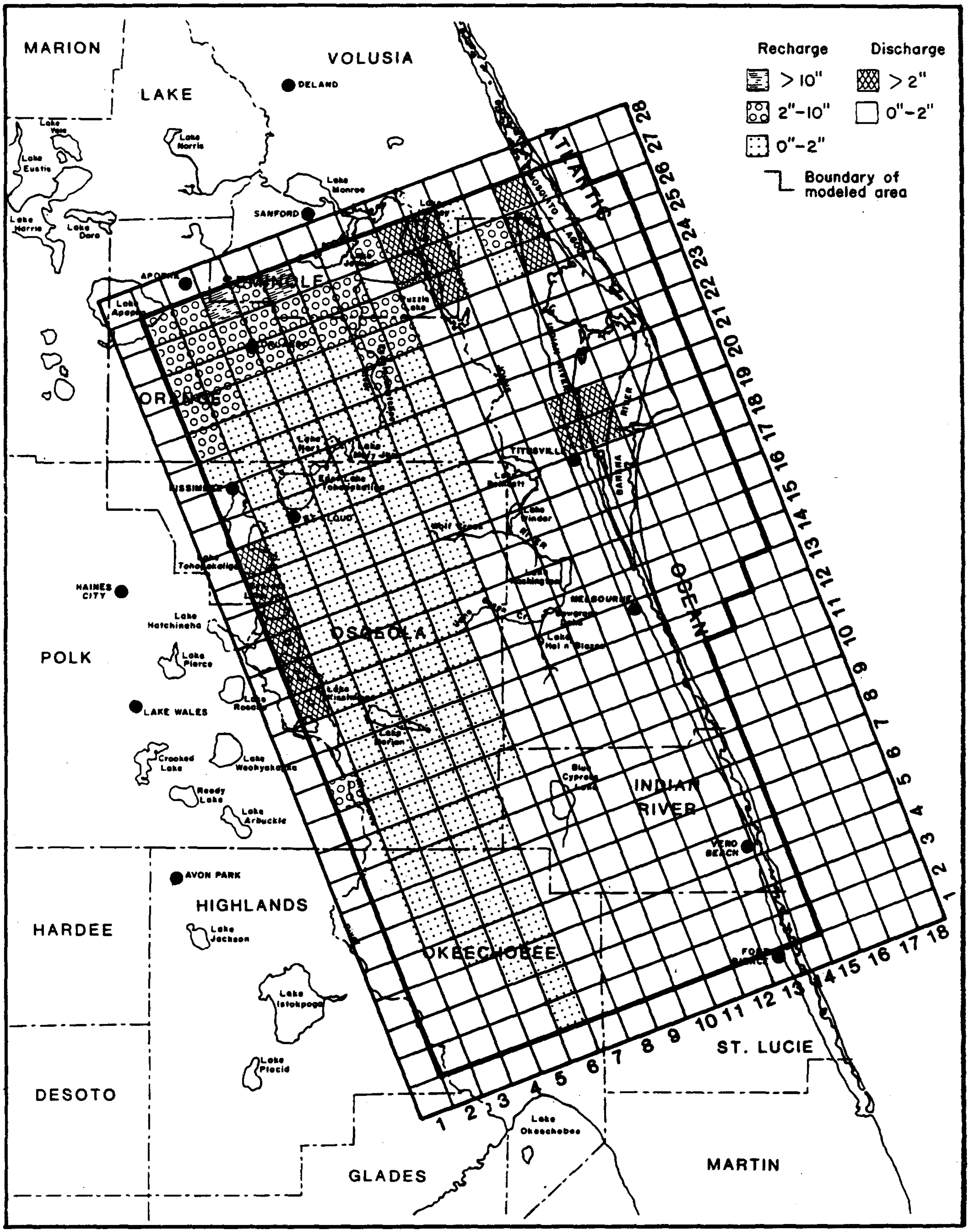


Figure 18: Simulated Rates of Recharge and Discharge to and from the Upper Permeable Zone Based on Model Calibration, September 1979

through February, March through April, and May) were simulated to achieve May 1980 conditions. Table 2 presents a breakdown of estimated ground-water withdrawals for these periods. Simulated drawdowns between September 1979 and mid-May 1980 were subtracted from the estimated September 1979 potentiometric surface to define May 1980 levels. This approach is valid for a leaky artesian ground-water system. Had the water levels predicted by the model been presented directly, errors in prediction of the September 1979 potentiometric surface would have been carried over into the succeeding transient simulations.

The simulated May 1980 potentiometric surface is presented in Figure 19. Water levels are within five feet of observed levels at 97 percent of the active nodes in the upper permeable zone. The average absolute difference in heads is 1.7 feet. Insufficient drawdown occurs along the western model boundary where water levels at 26 nodes are greater than three feet above observed levels (Appendix B). Excessive drawdowns were simulated in eastern Indian River County. These drawdowns may be due to the proportioning of agricultural irrigation withdrawals between ground and surface water sources.

As has been previously noted, there is a substantial degree of uncertainty about agricultural ground-water withdrawals in this area. Irrigation water needs are assumed to be met by equal amounts of surface and ground water. This assumption was made because no more definable practice could be documented. However, it has been suggested that the following alternative practice is

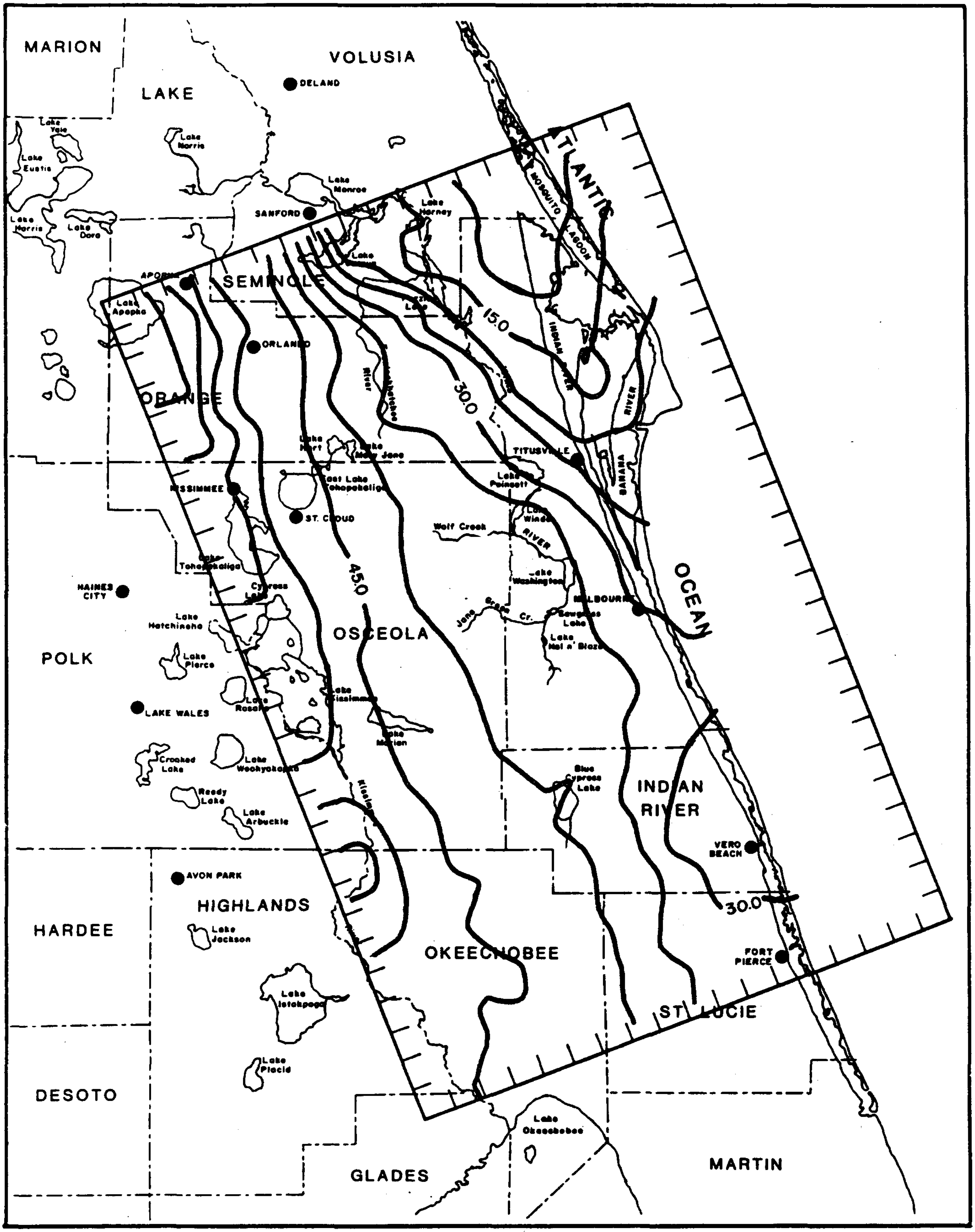


Figure 19: Simulated Potentiometric Surface of the Floridan Aquifer, May 1980

characteristic of many parts of the county (Brian Combs, personal communication).

Surface water is used as a primary source of irrigation water in the spring so that surface storage will be available for the heavy rains expected in the summer. If, as in the summer of 1980, the rains are deficient, summer irrigation water needs may have to be met in large part by ground water. In places where such a scenario is valid, the assumption of equal applications of surface and ground water could result in simulated drawdowns being excessive in the spring and low in the late summer. Examination of the hydrograph for well 742-022-01, located in eastern Indian River County, lends support to such a hypothesis (Figure 25).

The excessive drawdowns simulated in Indian River County may also be influenced by the fact that confining-layer storage is ignored in this model. The Hawthorn Formation ranges from 150 to 200 feet in thickness throughout the County. Tests using the USGS two-dimensional ground-water model (Trescott, Pinder, and Larson, 1976) suggested that drawdowns between October and May might be reduced as much as three to four feet in this area if confining-layer storage is considered. However, these results are not directly transferable to the present three-dimensional representation used in this study. The effects of storage in the confining layer certainly deserve consideration in future analyses.

SEPTEMBER 1980 POTENTIOMETRIC SURFACE

The September 1980 potentiometric surface was simulated by superimposing the simulated water-level response between mid-May and mid-September on the observed May 1980 potentiometric surface. The 122-day period was divided into five pumping periods, each including estimated ground-water withdrawals for each month (see Table 2). The resultant potentiometric surface is presented in Figure 20.

Agreement with observed water levels is within five feet at 95 percent of the active nodes. The average absolute difference is 1.9 feet. Again, the poorest results occurred in the area of Indian River County where water levels showed insufficient recovery. This may also possibly be explained by the assumption of equal applications of surface and ground water. If ground-water withdrawals during the summer months are underestimated, the recovery of water levels that occurs during September due to the relatively low agricultural demand at that time will be underestimated.

Water-level response along the western boundary continued to be relatively poor. This and the previous poor results achieved for this area point out the general insensitivity of the model near this boundary. Valid predictions about water-level response within one or two nodes of this boundary are thus unlikely.

September 1980 water levels were also simulated using a full 30-day pumping period. Recovery was greater under these conditions and resulted in improved agreement with observed

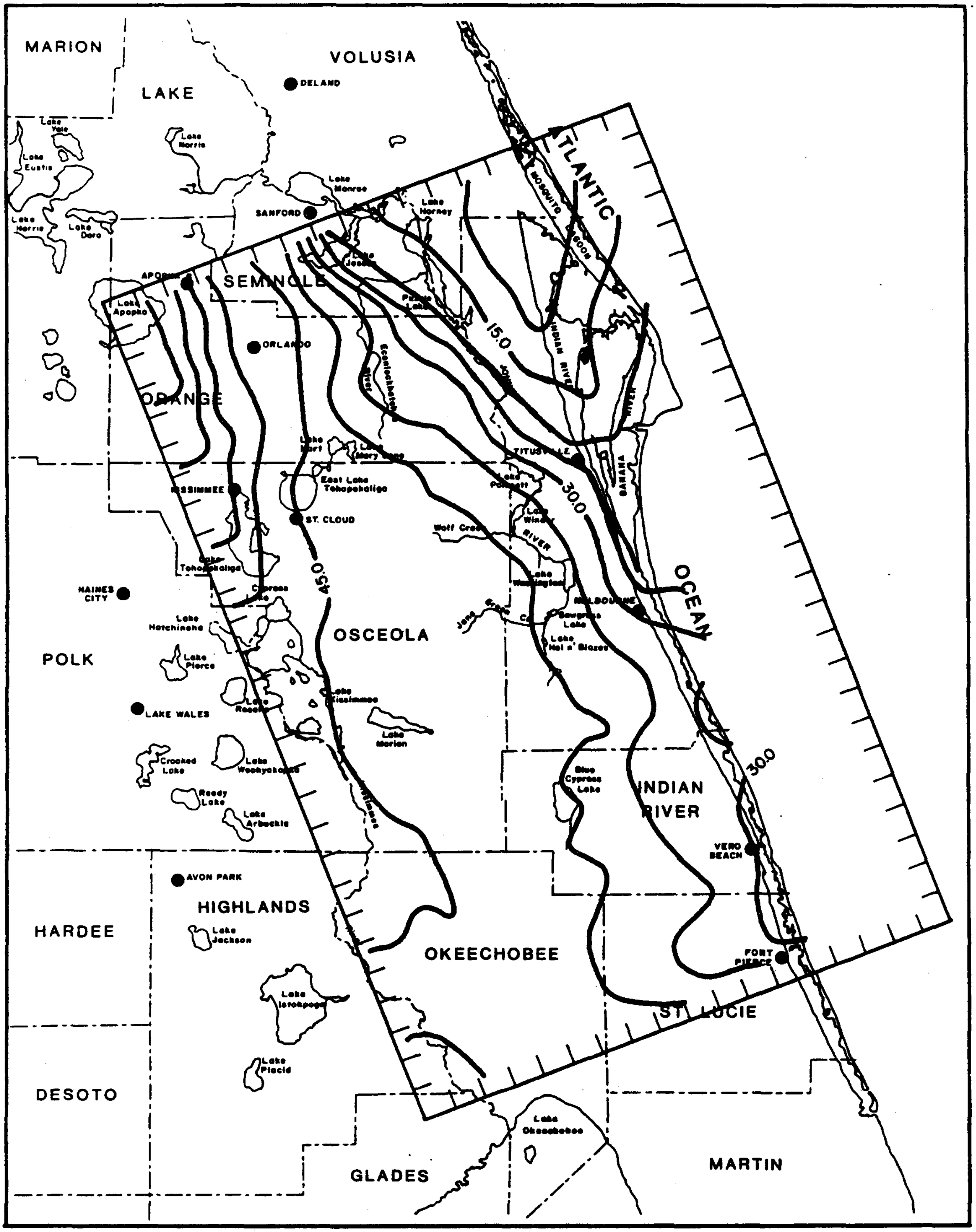


Figure 20: Simulated Potentiometric Surface of the Floridan Aquifer, September 1980

levels. Given that the water levels used to define the September 1980 potentiometric surface were measured over the course of a week in the middle of the month, the reliability of the model should be judged based on consideration of both these results.

HYDROGRAPHS

A final test of the validity of the BIOS model was to compare simulated hydrographs to those observed at sixteen locations in the study area. The wells used were those for which water levels were recorded on greater than a biannual basis. The locations of these wells are presented in Figure 21. The distribution of wells is clearly less than optimum, noting particularly the scarcity of data in the southern portion of the area. It should be remembered that simulated water levels are averages for an entire sixteen square mile grid block while the hydrographs represent water levels at a particular point. For this reason simulated declines might be expected to be somewhat less severe than those measured, particularly in areas with numerous individual withdrawal locations.

The hydrographs are presented in Figures 22 through 27. Of interest in these simulations was the ability of the model to simulate the observed water-level changes between pumping periods, not actual water levels. Consequently, the simulated hydrographs are plotted in a relative position for ease of comparison with the observed water level changes. The quality of

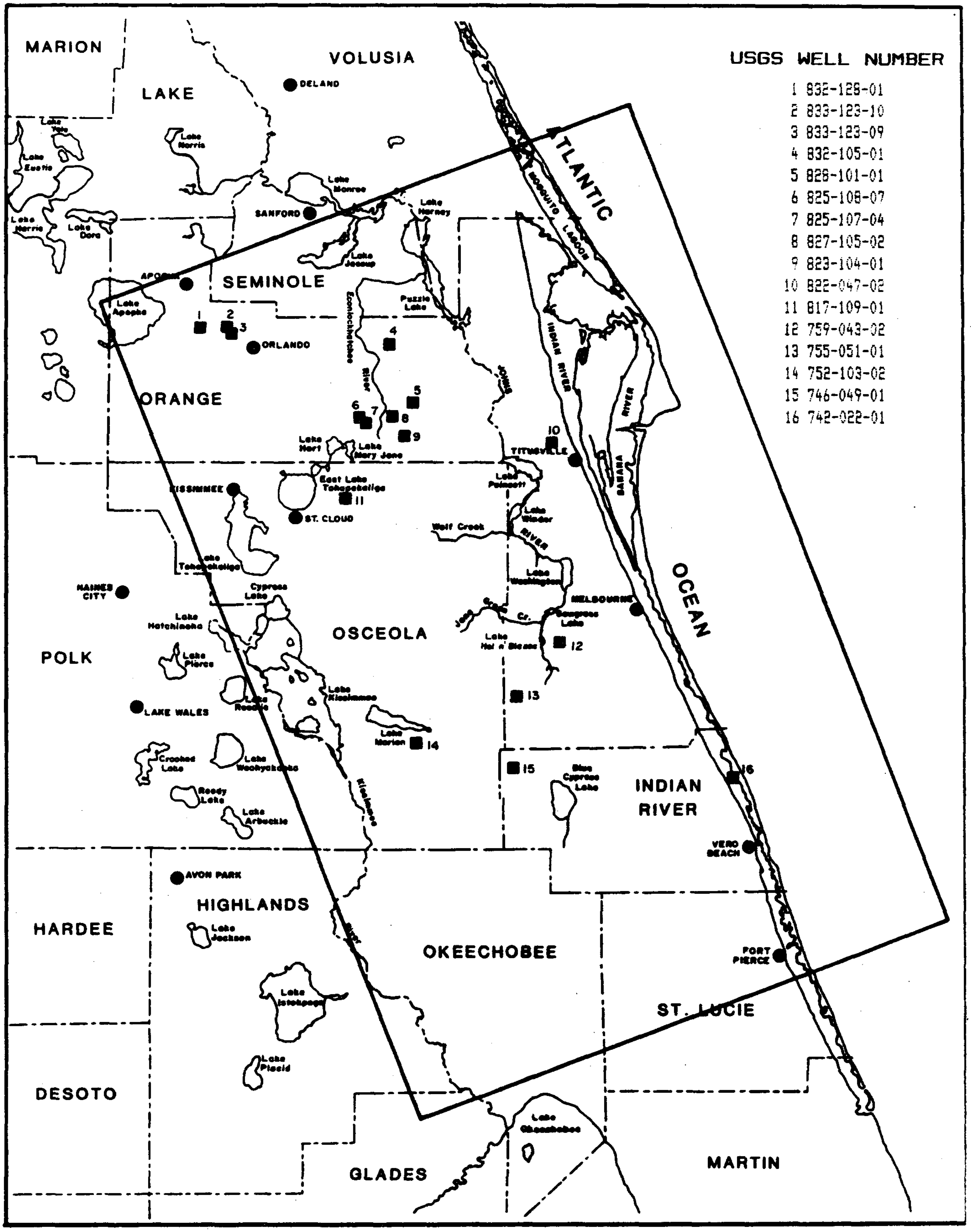


Figure 21: Location of Floridan Aquifer Observation Wells in the BIOS Area

the results appear to vary with the amount of agricultural activity in the vicinity of the well and the viability of the agricultural withdrawal scenario used in this study. For example, the best results were achieved at the five observation wells located at or near the Cocoa wellfield (Figure 22 and 23). Approximately 17 mgd of ground water was withdrawn at the wellfield in 1980 while agricultural withdrawals in this vicinity are relatively low. Because the quantity of withdrawals in the area is well documented, results should be quite good. Some uncertainty is introduced by not knowing the exact distribution of the 17 mgd among the many supply wells. (In this study, total monthly withdrawals were distributed based on percentages of total wellfield-pumping capacity in each finite-difference block.) Several of the hydrographs also indicate that withdrawals are not constant over the course of a month, but rather are greater during the first half and than during the second half.

Relatively good results were also achieved at locations where, while agricultural withdrawals may be substantial, it can be assumed that the majority of water was withdrawn from groundwater sources. Examples of these wells are given in Figure 24. Note also that the shape of the hydrographs at these locations are very similar; water levels declined fairly uniformly between February and July and then showed a mild recovery into October.

The quality of the results decreases to varying degrees in Indian River County and nearby surrounding areas (Figure 25). For example, results are quite poor at 742-022-01. The

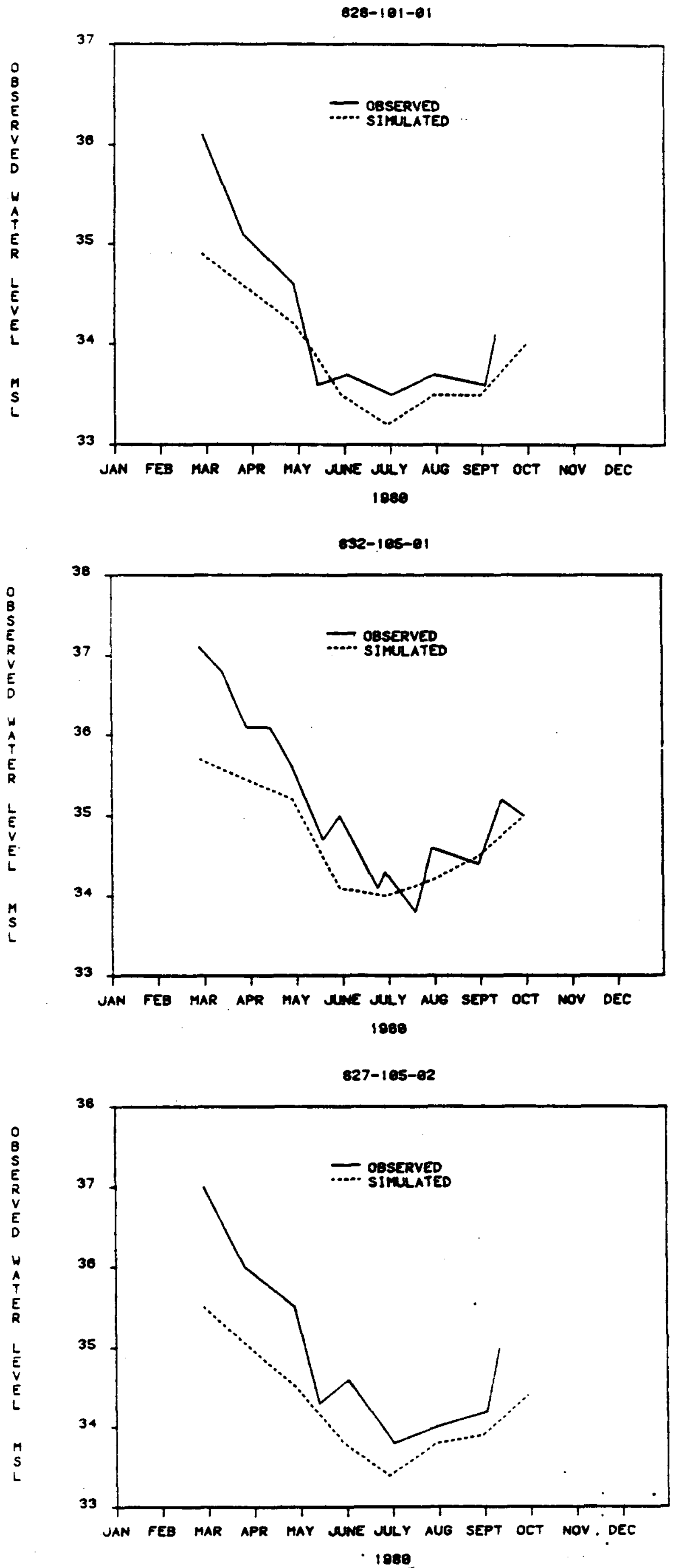
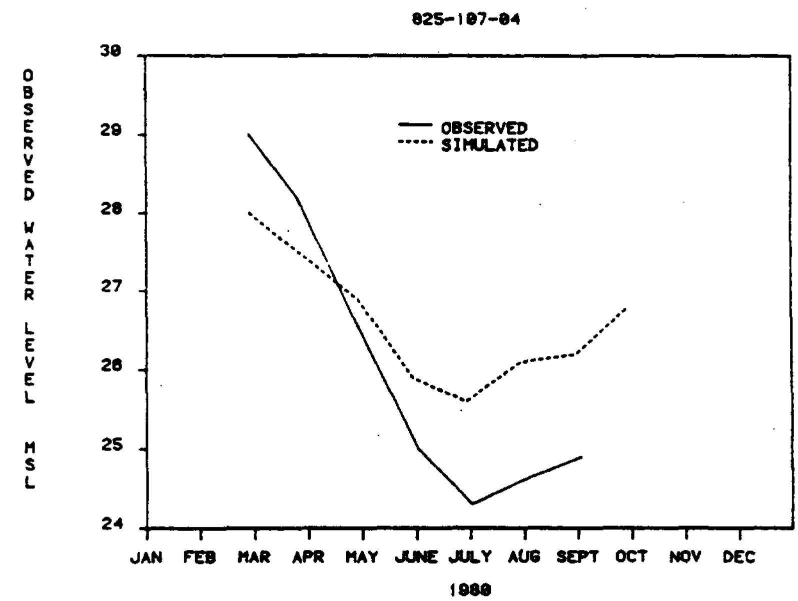


Figure 22: Hydrographs of Selected Wells Near the Cocoa Wellfield



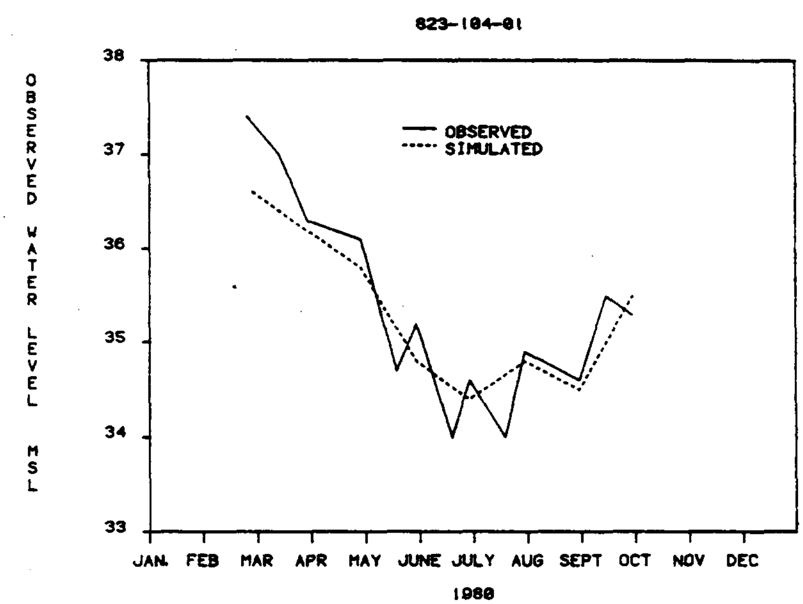


Figure 23: Hydrographs of Selected Wells Near the Cocoa Wellfield

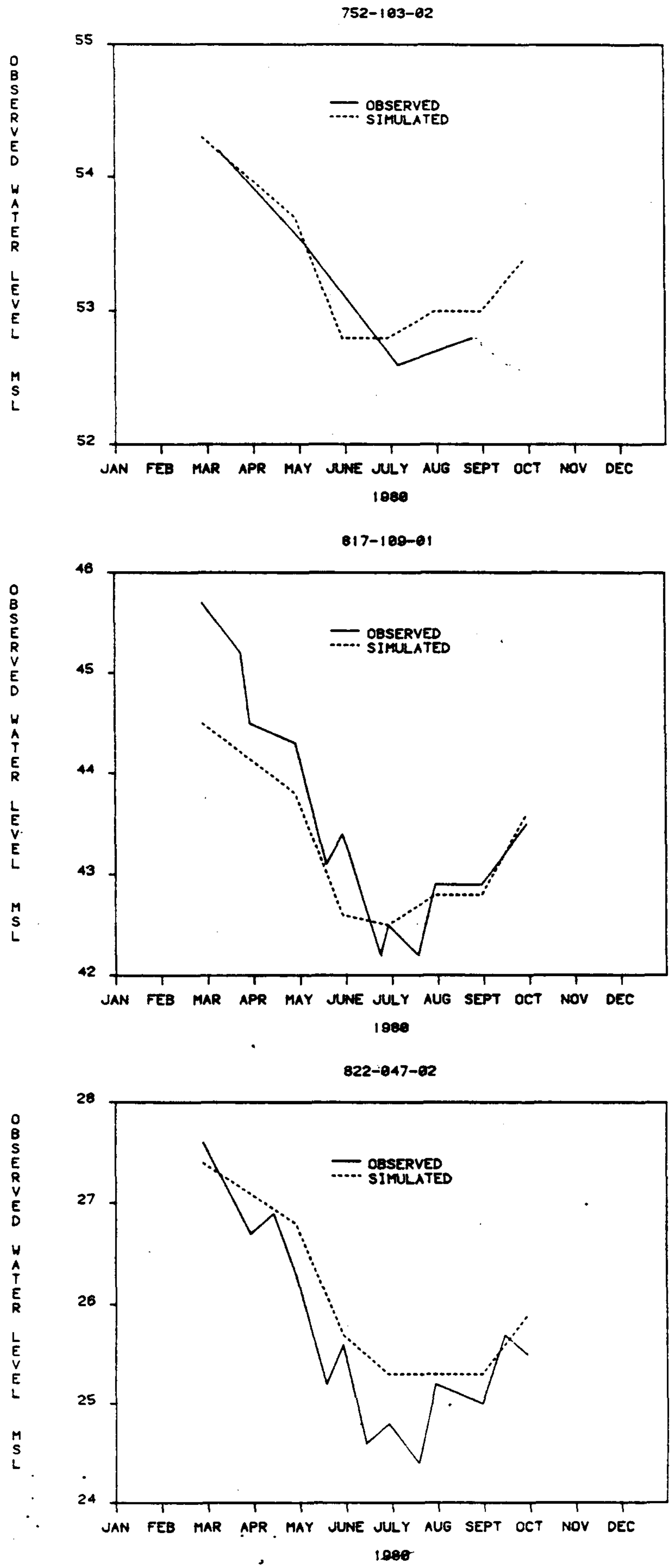


Figure 24: Hydrographs of Selected Wells in Areas of Agricultural Withdrawals

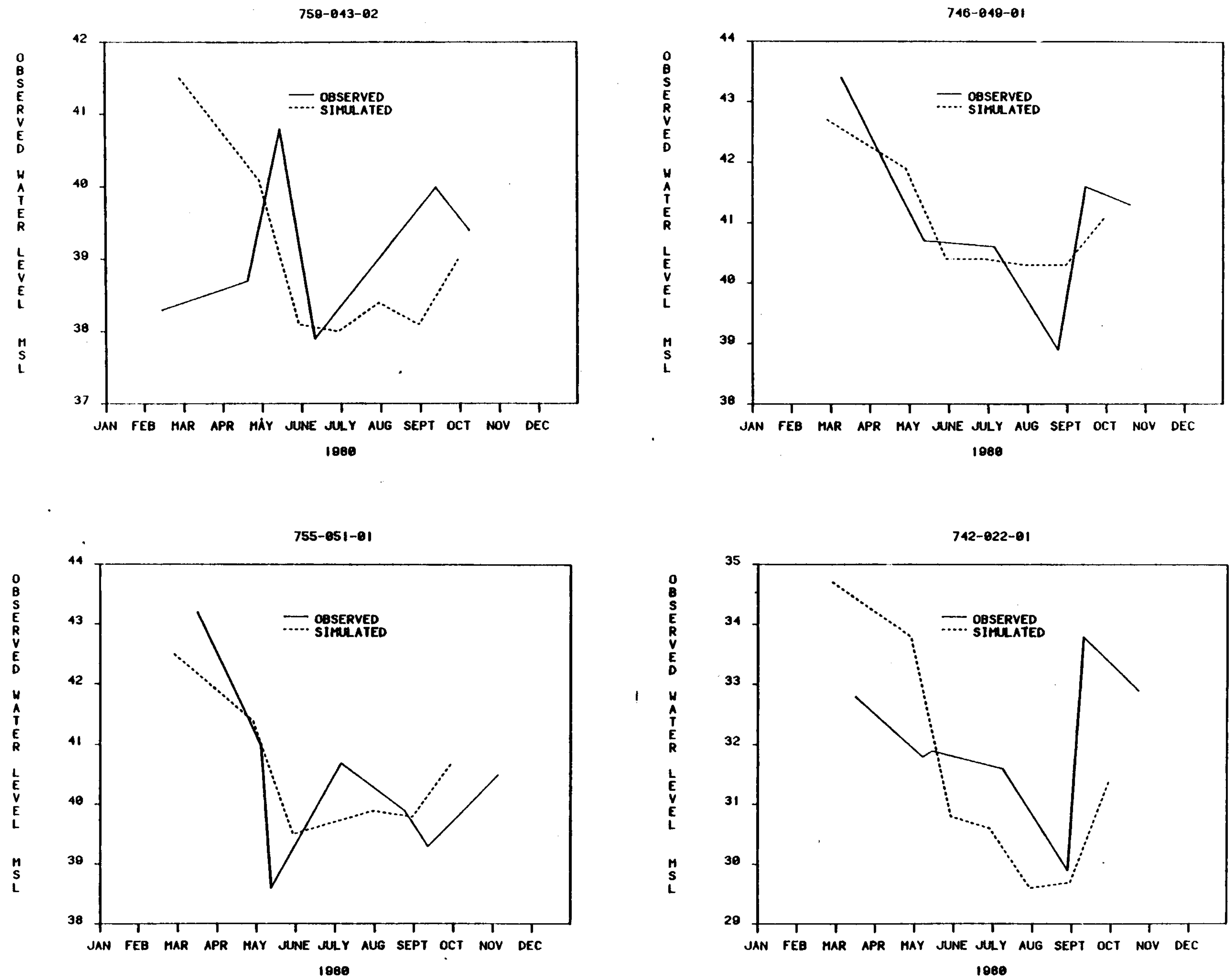
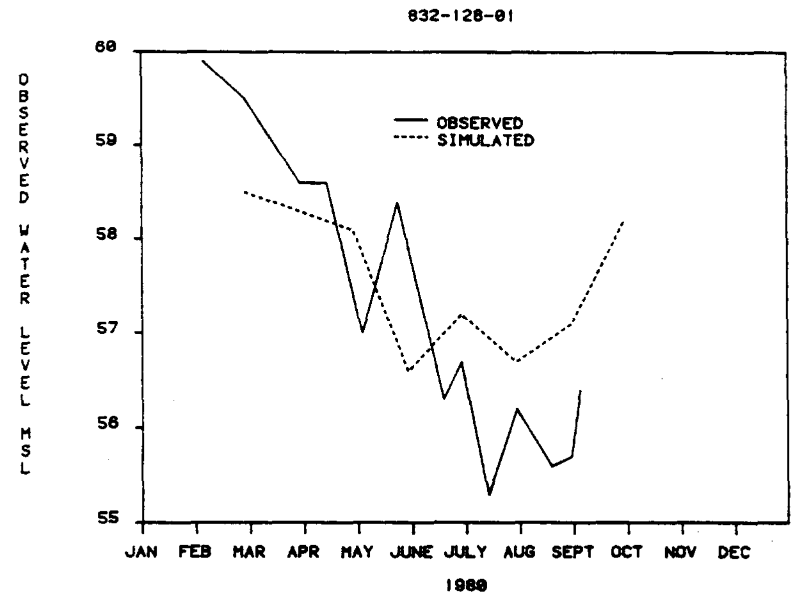


Figure 25: Hydrographs of Selected Wells in Southern Brevard and Indian River Counties

hydrograph at this and the other sites in this region are different from those previously described. Most notable is the large water-level declines that occur in July and August. (Data is insufficient to confirm or deny this response at 759-043-002). This type of hydrograph is consistent with the alternative agricultural pumping scheme previously mentioned that included heavy ground-water pumping during these months.

Poor to moderate results are achieved in the Orlando area in the northwest portion of the study area (Figure 26). Simulated drawdowns were considerably less than those observed. These results suggest that the estimated annual agricultural withdrawals per acre of crop (8 inches) may be low in this area. Public supply withdrawals are a potentially important factor in this area as well. Approximately 57 mgd was withdrawn from the Floridan aquifer in this region by the Orlando Utilities Commission and the Orange County Sewer and Water Department. While total monthly withdrawals for each utility were known, only average daily withdrawals were known for each of the individual water treatment plants. Monthly withdrawals at each plant were estimated by assigning each site that percentage of the monthly total accounted for by the site's average daily withdrawal. Consequently, while the total withdrawals simulated for the utilities are correct, monthly variations between sites are not. The proximity of the two observation wells to model boundaries is also a potential factor in the poor results.



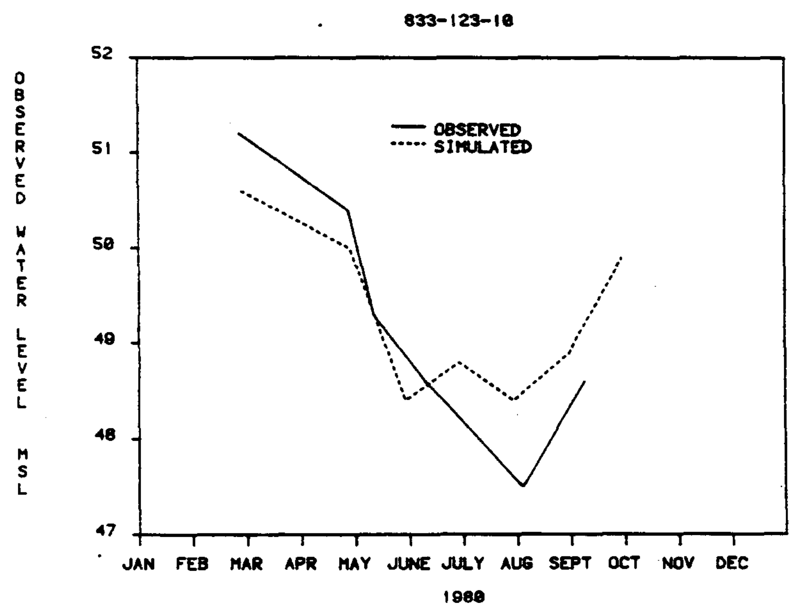


Figure 26: Hydrographs of Selected Wells in the Orlando Area

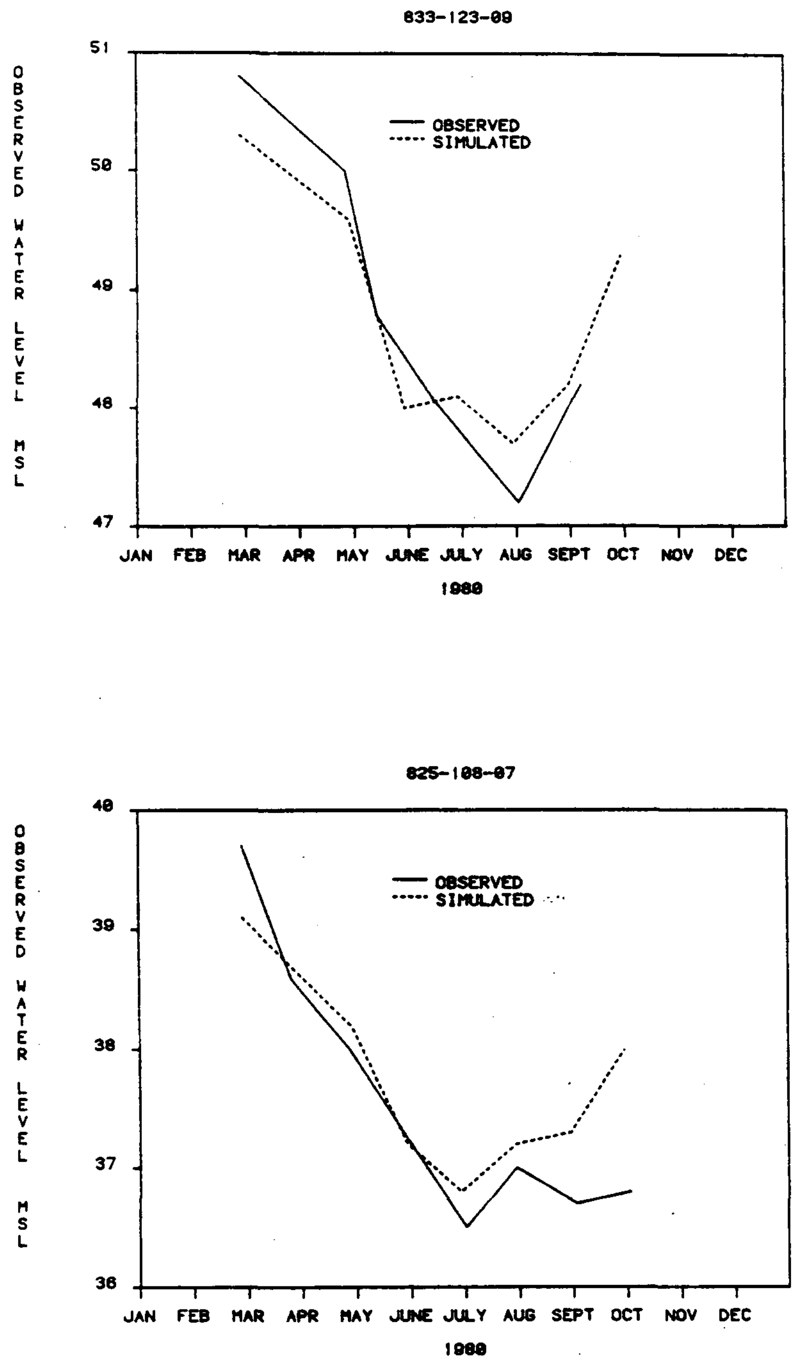


Figure 27: Hydrographs of Two Lower Permeable Zone Observation Wells

Hydrographs were also available for two wells open in the lower permeable zone (Figure 27). Good results were obtained for both the well in the Cocoa wellfield 825-108-07 and the one in the Orlando area 833-123-09. Considering the limited amount of data available on the hydrogeology of the lower zone, these results are very satisfactory.

WATER BUDGET

A water budget has been calculated for the Floridan aquifer system based on the simulated results of the September 1979 pumping period. This budget is presented in Table 5. It is important to bear in mind that the estimated flows are influenced by the accuracy of the simulated ground-water levels and consequently should not be considered absolute.

The Floridan aquifer system is considered to have been under steady-state conditions in September 1979. The upper permeable zone is recharged at an approximate rate of 728 cubic feet per second (CfS). This recharge is balanced by an equivalent rate of discharge. The majority of recharge (41%) enters the aquifer as leakage from the overlying surficial aquifer system. Slightly less (34%) enters as lateral cross-boundary flow, while approximately 18% comes as upward leakage from the lower permeable zone. The remaining 7% is supplied by recharge wells in the Orlando area. Figure 28 presents the lateral boundary flows simulated by the model for the upper permeable zone.

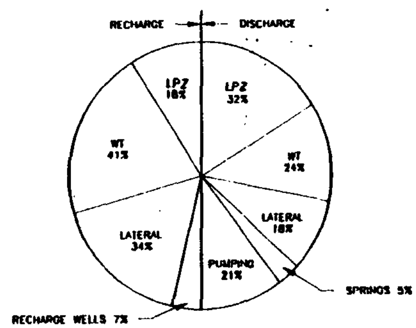
Discharge from the upper permeable zone is dominated by downard leakage to the lower permeable zone (32%), the vast majority of which occurs in the Orlando area. Another 63% of discharge is relatively equally distributed between upward leakage to the surficial aquifer (24%), pumping (21%), and lateral cross-boundary outflow (18%). The remaining 5% of total discharge occurs as discharge from springs.

Layer	RECHARGE: from layer above (ft³/s)	(in/yr)	from layer below (ft³/s)	(in/yr)	lateral (ft³/s)	(in/yr)	pumping (ft³/s)	(in/yr)	DISCHARGE: to layer below (ft³/s)	(in/yr)	to layer above (ft³/s)	(in/yr)	lateral (ft³/s)	(in/yr)	springflow (ft³/s)	(in/yr)	pumping (ft³/s)	(in/yr)
3 (surficial aquifer)	1/ -	-	174	0.39	2/ -	-	1/-	-	301	0.67	1/ -	-	2/ -	-	-	-	0	0
2 (upper permeable zone)	301	0.67	129	0.29	247	0.55	51	0.11	233	0.52	174	0.39	132	0.29	39	0.09	150	0.33
1 (lower permeable zone)	233	0.52	3/ -	-	35	0.08	0	0	3/ -	-	129	0.29	55	0.12	-	-	84	0.19

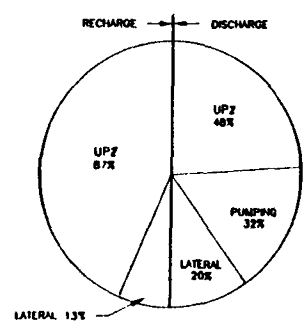
1 Layer 3 is uppermost layer (surficial aquifer) and is simulated as a constant-head source-sink layer.

2 No-flow lateral boundary conditions.

3 No recharge from below because base of layer 1 is simulated as impermeable.



UPPER PERMEABLE ZONE



LOWER PERMEABLE ZONE

Table 5. Summary of ground-water flow computed by model, September 1979

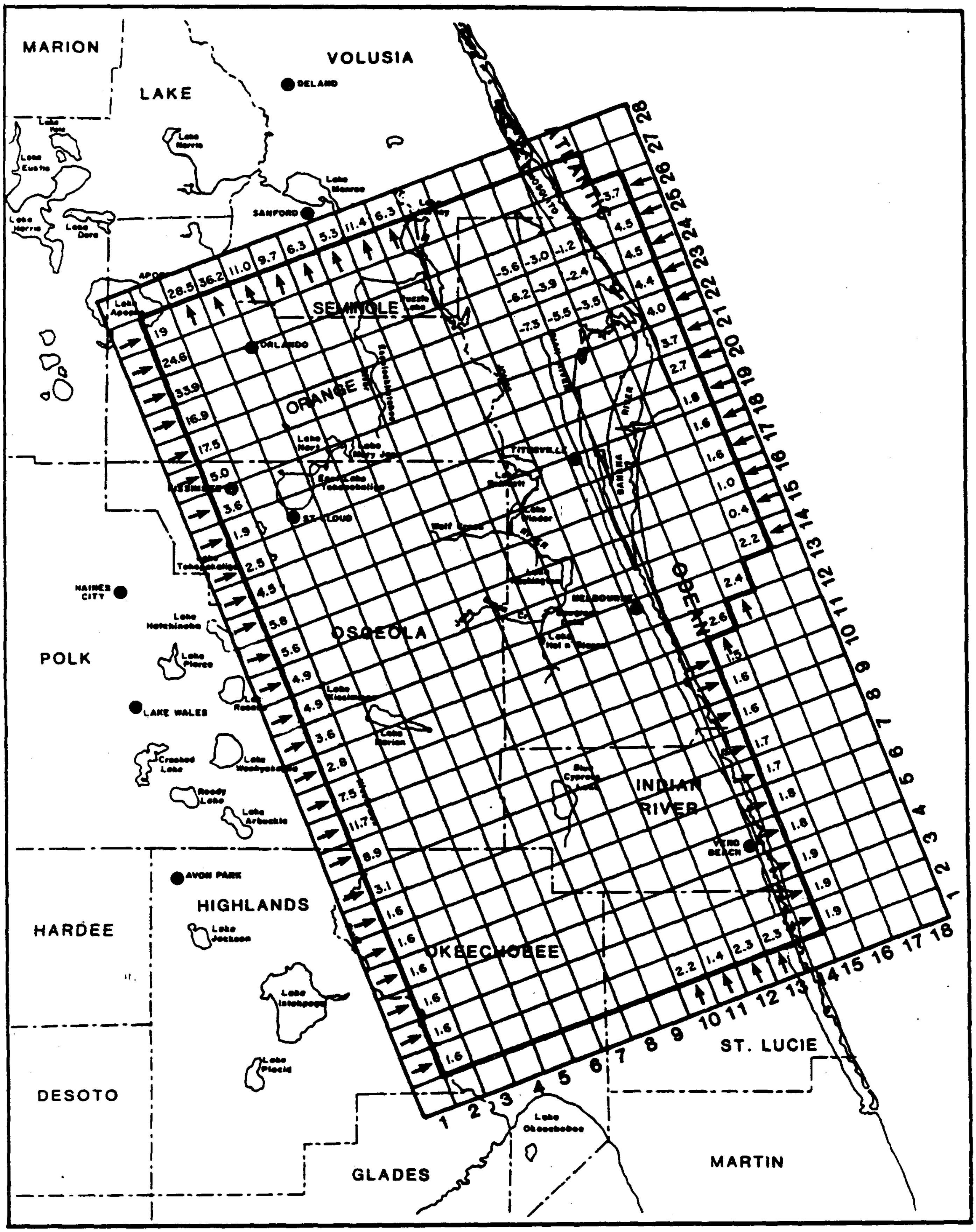


Figure 28: Lateral Flow Into and Out of Upper Permeable Zone As Simulated by the Model

The lower permeable zone is recharged by downard leakage from the upper permeable zone (87%), as well as by lateral inflow from the constant head boundary along the west (13%). Approximately half of this volume (48%) is returned to the upper zone through upward leakage. Discharges from public supply wells in the Orlando area account for another 32% of the total flow from the lower zone. The remaining 20% is lost as lateral outflow from the aquifer.

A significant uncertainty with regard to the water budget is the volume of water exchanged between the upper and lower permeable zones. This exchange is somewhat sensitive to the leakance value assigned to the "TK-layer" separating the two zones. For example, when this value is decreased by an order of magnitude, recharge to the upper permeable zone from all sources is decreased by approximately 18% (130 cfs). However, while this decrease is accounted for relatively equitably between declines in recharge from the lower permeable zone, surficial aquifer, and lateral inflow (41%, 35%, 24%, respectively), 93% of the associated 18% decrease in discharge is accounted for by a decrease in the volume of water moving from the upper zone to the lower zone. Consequently, very little change in water level occurs in the upper zone. However, it is apparent that the overall water budget for the Floridan aquifer system could be improved if data on the transmissive properties of the intervening confining layer were available.

SENSITIVITY ANALYSIS

Developing a ground-water model requires the estimation of values for numerous hydrologic parameters at regular intervals throughout the study area. These values are never known with certainty. Successful calibration and verification of a model suggests some degree of accuracy in the values used. However, by assessing the response of the model to changes in parameter values throughout the model area, some further measure of the reasonableness of the estimated values can be made. This assessment is referred to as a sensitivity analysis. In this analysis the value of each parameter is varied throughout the model by some constant factor while all other parameters are maintained at their original values. The amount of variation for a particular parameter reflects a potential range of error in the value of that parameter. Such sensitivity analysis was conducted for both steady state and transient conditions.

The sensitivity of the BIOS model under steady-state conditions (September 1979) is presented in Figures 29 and 30. Two cross-sections are used for illustrative purposes, one oriented along a line of flow (column 13), the other roughly perpendicular to flow (row 10). Table 6 lists all the parameters that were varied in this analysis and the amount by which they were varied. Only the results caused by increasing parameter values in the upper permeable zone (layer 2) are presented, however. In general, decreasing the values by the same amount resulted in changes of equal, but opposite degree. Changing the

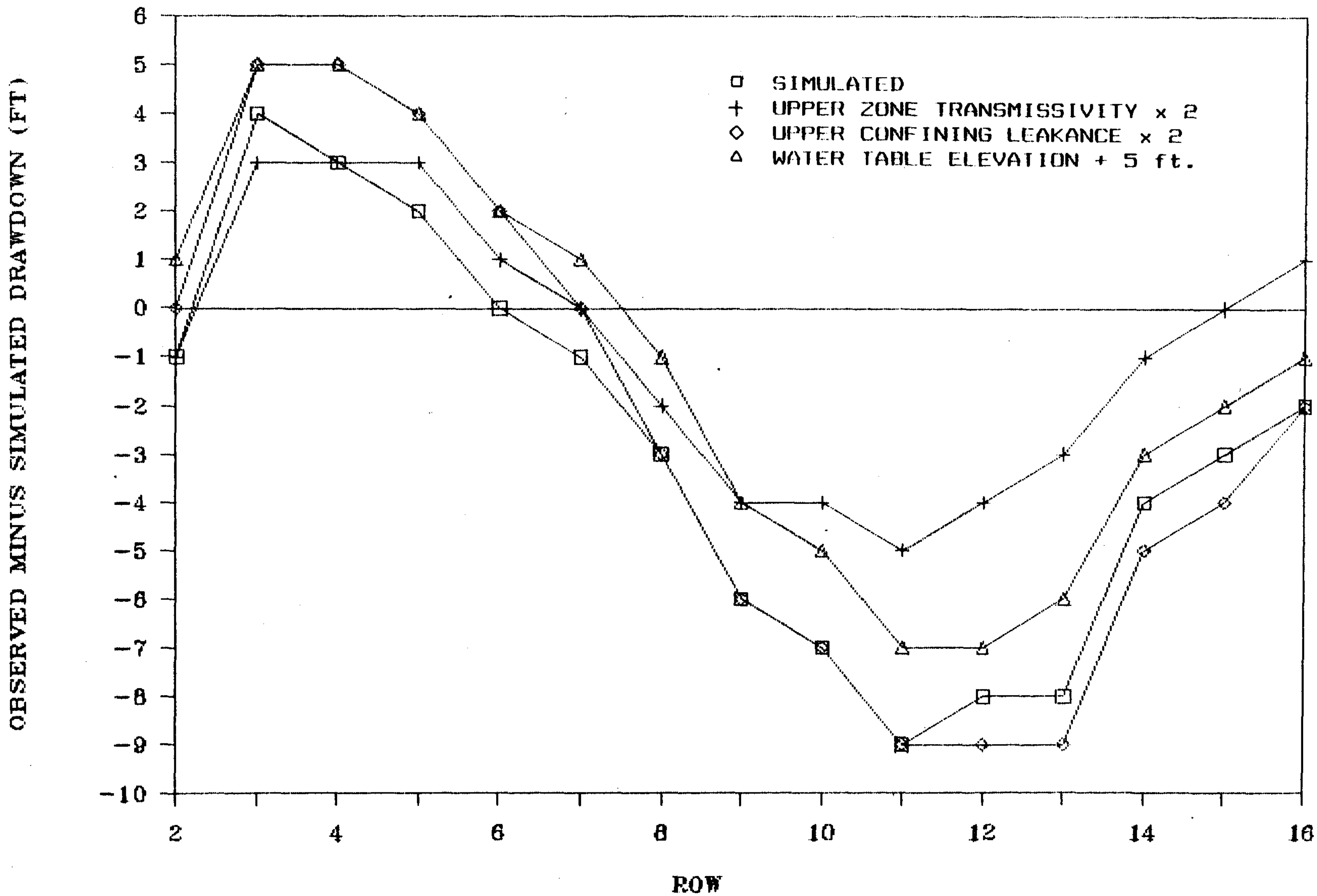


Figure 29: Response of Water Levels in the Upper Permeable Zone to Changes in Selected Parameters, Steady-State Conditions, Column 13

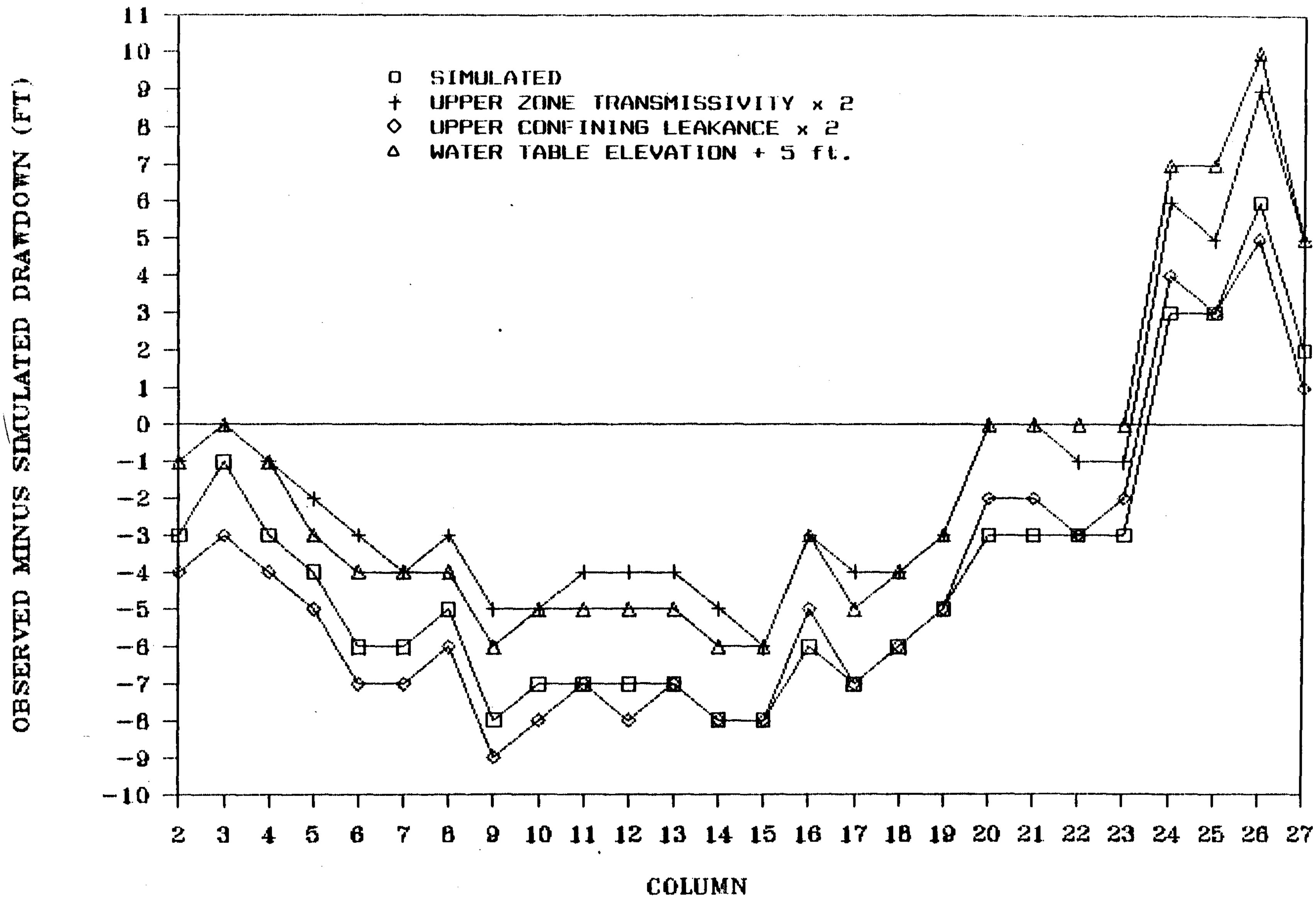


Figure 30: Response of Water Levels in the Upper Permeable Zone to Changes in Selected Parameters, Steady-State Conditions, Row 10

Table 6: Parameters Varied in Sensitivity Analysis

Parameter	Variation Factor	
transmissivity	x2.0	x0.5
leakance	x2.0	x0.5
water-table elevation	+5 ft	- 5 ft
storage coefficient	x1.2	x0.8
agricultural withdrawals	x1.5	-
boundary conditions		
o upper permeable zone	constant-head along west	
o lower permeable zone	no-flow along west	

same parameter values for the lower permeable zone caused changes similar to those of the upper zone, but of lesser degree.

The model is most sensitive to the transmissivity of the upper permeable zone. Doubling transmissivity increased water levels between one to four feet; the greatest increases occur in the eastern portion of the study area. Increasing the elevation of the water table caused a two to three foot increase in the potentiometric surface throughout the entire modeled area. The effects of doubling the leakance of the upper confining layer vary between recharge and discharge areas. Water levels increased on the order of one foot in recharge areas while declining approximately that much in discharge areas. This response is explained by the fact that in areas of recharge, more water can enter the upper permeable zone from the surficial aquifer while such a change promotes greater losses of water from this zone in discharge areas.

The effects of parameter variations on transient simulations are presented in Figures 31 and 32. Comparisons are for simulated drawdowns between September 1979 and May 1980. As expected, the model is less sensitive to changes under these conditions thanunder steady-state conditions. The greatest change is observed with the increasing of agricultural withdrawals by a factor of 1.5. Declines in head are of course dependent on the amount of agricultural withdrawal originally estimated at a particular node. Declines of two to three feet are seen throughout much of row 10 which passes through some of

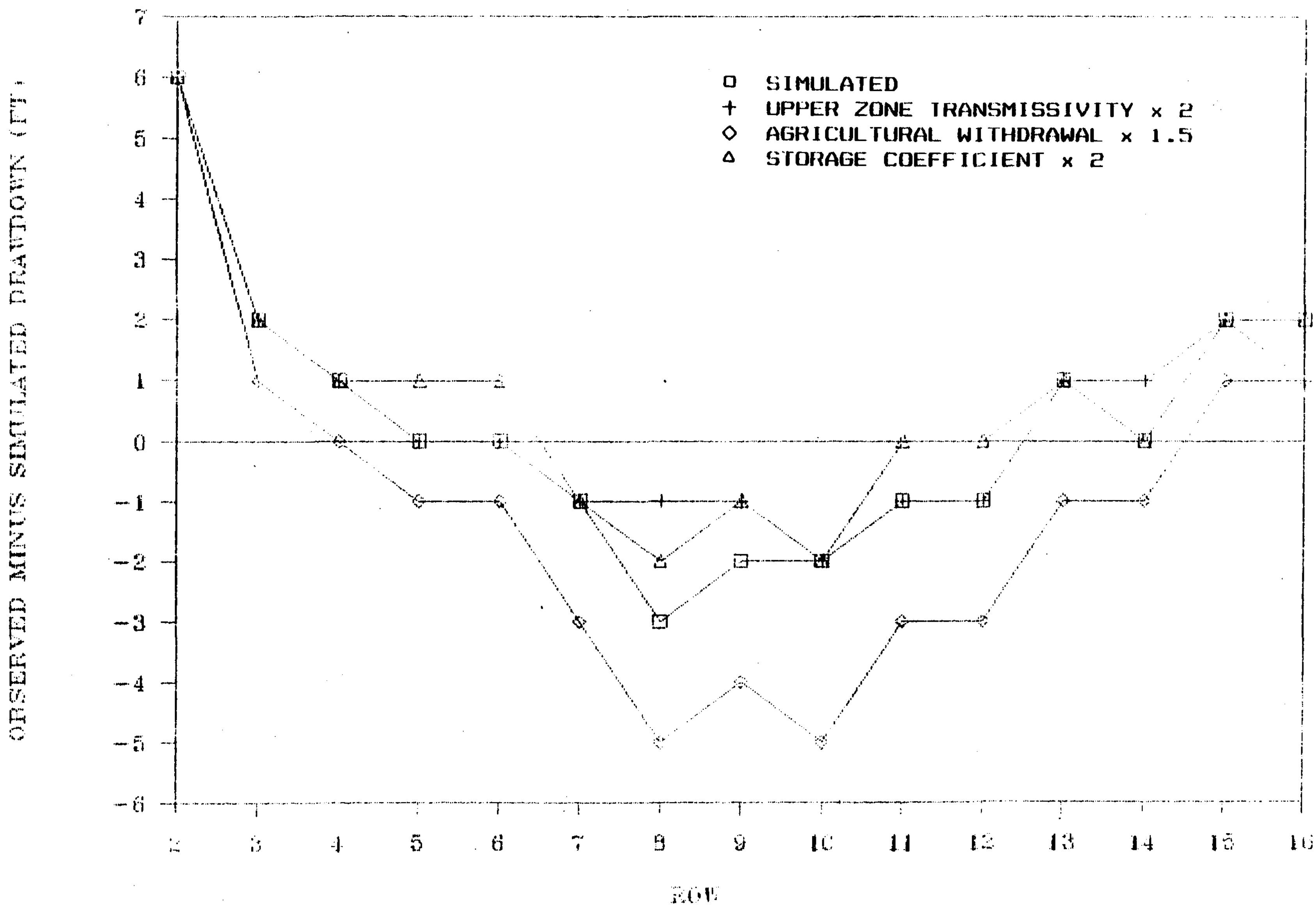


Figure 31: Response of Water Levels in the Upper Permeable Zone to Changes in Selected Parameters, Transient Conditions, Column 13

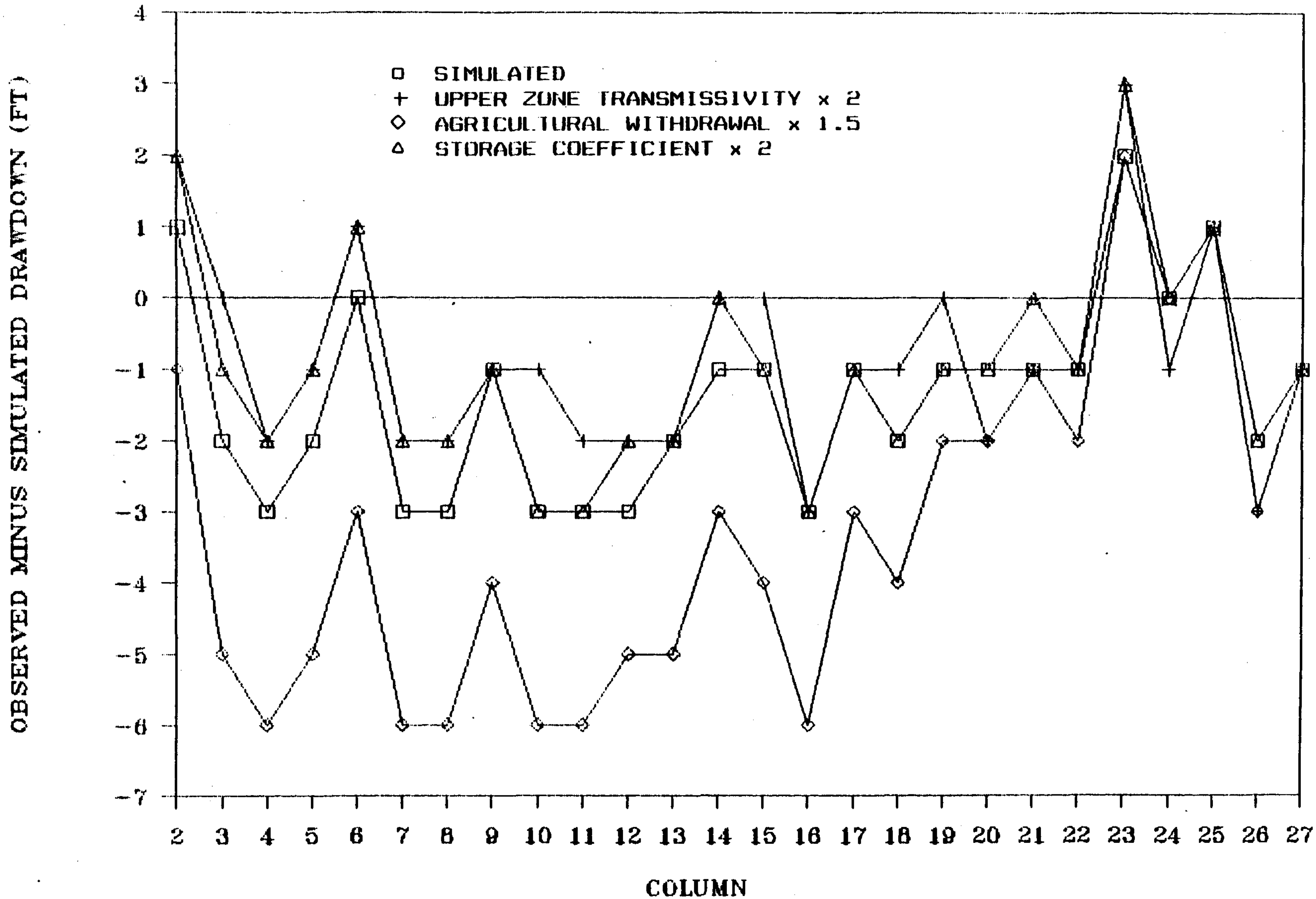


Figure 32: Response of Water Levels in the Upper Permeable Zone to Changes in Selected Parameters, Transient Conditions, Row 10

the largest agricultural areas. The model is not as sensitive to changes in other parameters. Doubling layer-two transmissivity caused water-level increases of approximately one foot while doubling leakance and storage coefficient resulted in slightly lower increases.

SOURCES OF ERROR AND UNCERTAINTY

There are several sources of error and uncertainty in the model presented in this report. These affect both the acceptable range of deviations between simulated and observed conditions and the overall validity of the model. Consequently, it is important to describe each source of error and uncertainty and its particular effect on the model.

The principal sources of error and uncertainty in this model, in order or importance, are:

1. agricultural water use estimates
2. lack of consideration of confining layer storage
3. finite difference block size
4. constant water table elevation

Each will be discussed individually in the following section.

In accounting for agricultural withdrawals of ground water, an average annual application rate per acre of citrus and pasture is estimated for each county. This annual rate is subsequently subdivided into shorter term rates. The use of average rates introduces error into the simulation since both annual and monthly rates can vary significantly within a county. For example, annual applications of water for citrus at seventeen farms in Polk County ranged from 0.01 inches to 10.98 inches with a mean of 5.9 inches and standard deviation of 3.5. Annual rates at 32 farms throughout west central Florida ranged up to 19.45 inches with a mean of 6.2 inches and standard deviation of 5.7 (Duerr and Trommer, 1982). Consequently, even using a reliable average application rate, errors of several feet in simulated water levels can be expected.

Uncertainty in model results is also introduced by the inability to define with any certainty the variation between the use of surface and ground water for agricultural purposes in Indian River and St. Lucie counties. Hydrographs in these areas suggest that the schedule used in this study may not be valid, although simulated results are relatively good.

Given the size of the area being modeled, a lack of data concerning confining-layer properties, and the excessive storage and computational time that would result from its inclusion, storage in the upper and lower confining layers was not considered. This is not a problem for steady-state analyses in which storage can be ignored. However, it may be an important factor for analysis of transient conditions, particularly in areas with confining beds in excess of 100 feet. Based on very preliminary analysis, it appears that incorporating storage in the upper confining layer into the model might reduce simulated drawdowns between September 1979 and May 1980 by one to four feet. Such a response would generally improve the simulated results in the southern portion of the study area.

The finite difference grid utilized in this study consists of 4-mile by 4-mile square grid blocks. Blocks of this size were needed to allow coverage of such a large area while keeping the computation and storage requirements reasonable. All hydrogeologic parameters are considered constant within each block (so-called "effective parameters") and all withdrawals are simulated as a single withdrawal from the center of the block. The water level computed in a block is an average level for the entire block area. The need for these simplifications and the use of such large blocks may introduce some errors in the simulations.

The ability to define an effective parameter is influenced by the true variability of the parameter within the discretized area. A true effective parameter for hydraulic conductivity (k) cannot be defined if the maximum block length is more than twice the integral scale of the natural log (ln) of hydraulic conductivity (Gelhar, 1976). The integral scale represents the average distance over which ln k is correlated in space. It is uncertain whether this rule is violated with the chosen block size. However, Delhomme (1979) has shown that an integral scale of 6 to 12 miles is possible for limestone aquifers.

The proximity of a well to the model node that represents it will influence the accuracy with which the stress imposed by that well can be simulated. In this model, a withdrawal is represented as occurring in the center of the block that the withdrawal is located in. The resultant drawdown is the average for the entire block area. Consequently, the further the actual withdrawal location from the block center, the less accurate the simulated drawdown for that block and surrounding blocks will be. With a four-mile by four-mile block, the simulated withdrawal location could be as much as 2.8 miles from the actual location of the withdrawal.

The final source of error in the model is the representation of the water table as being of a constant elevation. In reality the water table fluctuates seasonally from one to four feet in most places. Assuming that the fixed water table represents a seasonal average level, a total fluctuation of four-feet would result in a possible true level of two-feet above or below the average level used in this study. The sensitivity analysis showed that a uniform change in water-table elevation of five feet changed steady-state water levels by two to three feet in the upper permeable zone. Consequently, even under steady-state conditions an error of two-feet is unlikely to result in an error of more than a few tenths of a foot in the calculated Floridan aquifer water level.

CONCLUSIONS

The goal of this project was to develop a numerical model of the Floridan aquifer system in Brevard, Indian River, Orange, Osceola, and Seminole (BIOS) counties. The model should be capable of accurately simulating the response of the aquifer system to stresses over both the short and long tern. Ultimately, this goal was only partially met.

The model developed during this study is capable of providing relatively accurate representations of the ground-water system in the BIOS area under steady-state conditions. Simulations of both the predevelopment and September 1979 potentiometric surfaces are reasonable. These simulations are largely unaffected by the two greatest sources of uncertainty in this modeling process: agricultural withdrawal estimates and confining-layer storage. The particular scenarios considered allowed both of these factors to be ignored. The results are affected by uncertainty over the amount of water withdrawn for heat pump and lawn irrigation use. Reliable estimates of daily use would improve the accuracy of the simulations by eliminating the remaining uncertainty.

The ability of the model to simulate transient (short term) responses of the aquifer system cannot be determined until two important factors are better understood. These factors are the effects of storage in the confining layers and agricultural withdrawals of ground water in Indian River and St. Lucie counties. Only confining-layer storage can be evaluated without the collection of additional data. However, given the size of the area covered in the BIOS model, explicit inclusion of the confining layers is not practical. A portion of the model, perhaps a sub-basin, would have to be separated out to conduct the simulations necessary to determine if confining-layer storage is an important factor.

While no definitive statements are possible, certain general conclusions can be made about the use of ground water for agricultural purposes. Initial estimates of agricultural water use for citrus ranged from 20 inches/acre/year in Brevard County to 32 inches/acre/year in Indian River County. Water use for improved pasture was estimated as high as 56 inches/acre/year (Marella, 1982). Even taking into account confining-layer storage, these estimates appear to be, on the average, excessively high. This conclusion is supported by the Benchmark Farms study conducted by the Southwest Florida Water Management District (Duerr and Trommer, 1982). The values used in the present study, 8-12 inches/acre/year for citrus and 6 inches/acre/year for improved pasture, appear to be more realistic estimates. The St. Johns River Water Management District is conducting a study similar to that of the SWFWMD. The data collected during the course of the study will greatly improve the District's future agricultural water use estimates.

RECOMMENDATIONS

1. The average annual application rates estimated for various crops using the modified Blaney-Criddle method appear to be unrealistically high. These estimates need to be reassessed using the data on water use collected as part of the Benchmark Farms program and revised as appropriate.
2. Considerable uncertainty exists concerning the variability between surface and ground-water use for agricultural purposes in Indian River County. This uncertainty needs to be addressed through the acquisition of data on sources of water in this area as part of the Benchmark Farms program.
3. The two principal confining layers -- clays of the Hawthorn Formation and the low porosity zone of the Avon Park Limestone -- play important roles in the hydrology of the Floridan aquifer system in the BIOS area. Very little data is available on the hydrologic properties of these units. Consideration should be given to performing tests designed to evaluate the hydrologic properties of each of these.
4. Future modeling of the Floridan aquifer system should:
    a. encompass areas smaller than that considered in this report to allow sufficient accuracy in defining withdrawal sites and consideration of all pertinent hydrogeologic factors; and
    b. determine the need to include explicit representations of the upper and lower confining layers in the model.

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APPENDIX A

Description of Methodology Used to Revise Estimates of Combined Heat Pump and Lawn Irrigation Well Withdrawals

Water use heat pumps are a common means of air conditioning in Brevard County. This is due in part to the fact that in much of the county the Floridan aquifer is under flowing artesian conditions. Consequently, heat pump wells completed in the Floridan often do not require pumps. It has been estimated that heat pumps, together with lawn irrigation systems, used 141.51 mgd of water from the Floridan aquifer in 1980 (Marella, 1982). Doubts about the accuracy of this figure have been raised based on the results of tests conducted using a numerical ground-water model of an area that includes all of Brevard County. Subsequently, it was decided that the water use figures needed to be reexamined and revised where necessary. It is the purpose of this memo to outline the results of this study.

The original 141.51 mgd estimate for water use by heat pumps and for lawn irrigation was developed in the following manner. As part of a larger study (Post, Buckley, Schuh and Jernigan, 1979), an inventory was made of all wells in Brevard County. Each well was classified as to its primary use and according to the particular aquifer system it utilized, whether shallow or Floridan. The inventory was completed in 1977. In 1981, Jim Frazee prepared a map based on the inventory that presented the combined number of heat pump and lawn irrigation wells completed in the Floridan aquifer in the county. The wells were totalled for areas defined by each minute of latitude and longitude. Total water use by these wells was estimated using the following assumptions:

1. All wells in areas where artesian pressure was sufficient to cause flow at the required rate were uncontrolled and flowed 24 hours a day at a rate of 11,520 gpd.

2. Wells in areas of insufficient pressure were assumed to have pumps and to be controlled at 4,580 gpd.

The 141.51 mgd value is the sum of estimated water use by 9,711 uncontrolled wells and 6464 controlled wells.

Re-examination of the data suggests that 141.51 mgd is an excessive and unrealistic estimate. In addition to the model tests, this is suggested by the following:

1. Many of the 16,175 wells are used for lawn irrigation. The majority of lawn irrigation wells probably are controlled and many probably require pumps to be effective in irrigation systems (R. Marella, W.R. Timmons, personal communications).

2. The daily water use estimates for controlled and uncontrolled wells are based on heat pump demand, not lawn irrigation demand.

3. Not all heat pump wells in flowing artesian areas are allowed to flow continuously.

These factors were all taken into account in revising the water use estimates.

In 1985, a revised value of 59 MGD was calculated. This value was based on certain revised assumptions about the number of wells that had controlled discharges. This value was also deemed unrealistic due in large part to its ignoring of the large number of lawn irrigation wells included in the inventory.

The first step in developing a more realistic estimate was to distinquish between heat pump wells and lawn irrigation wells. Maps showing the concentration of each type of well per square mile were available, (Post, Buckley, Schuh, and Jernigan 1979). These maps were used in conjunction with the map prepared by Frazee to estimate the number of each type of well in each square minute block. This was done by:

1) identifying the concentration of each type of well in the block;

2) where possible, classifying as heat pump wells the maximum number associated with the specified concentration and classifying the remainder as lawn irrigation wells; and

3) for blocks where concentration of both types of wells is the same, assigning half of the wells to each well category.

Through this process, its was estimated that of 16,492 total wells, 12,327 were lawn irrigation wells and 4,165 were heat pump wells.

The second and final task is to estimate an average daily withdrawal for each of the two types of water uses. The rates estimated are based on hydrologic conditions in 1980 and are considered valid for that year only. The approach taken for each use will be presented separately.

It is estimated that the average rate of withdrawal of water from the Floridan aquifer by heat pumps in Brevard County in 1980 was 22.75 MGD. This rate is based on the following assumptions:

1) Heat pump wells that have controlled discharges, either due to the presence of a control valve or a pump, are assumed to withdraw an average of 2,663 gpd. This value is based on an estimated 4.9 hours of operation per day for a 3-ton unit that requires a delivery rate of 9 gpm (J. Frazee, personal communication).

2) Heat pump wells that are allowed to flow freely 24 hours a day are assumed to withdraw 12,960 gpd. This is the volume for a 3-ton unit using 9 gpm.

3) Wells located in areas identified as having insufficient artesian pressure are assumed to utilize pumps and to withdraw at a rate of 2,663 gpd.

4) Elsewhere, it is assumed that 50% of the heat pump wells have control valves and utilize 2,663 gpd; the other 50% utilize 12,960 gpd.

5) There were 3,033 heat pump wells with controlled discharges (8.08 mgd) and 1,132 with uncontrolled discharges (14.67 mgd).

Lawn irrigation withdrawals are highly seasonal and consequently an average annual rate (4.59 MGD) has little meaning. Rather, seasonal averages in 1980 of 13.72 mgd, 5.47 mgd, and 0.00 mgd were estimated for April-May, June through October, and November through March, respectively. These rates are based on the following assumptions:

1) There were 12,327 lawn irrigation wells utilizing water from the Floridan aquifer in Brevard County and all had controlled discharges.

2) Each well supplied 40 inches of water per year for an area equal to 0.125 acres.

3) Half of the total water used (20 inches @ 1,113 gpd) was applied in April and May; the other half was applied from June through October (20 inches @ 444 gpd).

In summary, it was originally estimated that heat pump and lawn irrigation wells were withdrawing 141.51 mgd of water from the Floridan aquifer in Brevard County in 1980. This estimate appears to be excessive. Re-examination of the data suggests that the average withdrawal by heat pumps in 1980 was 22.75 mgd and that lawn irrigation withdrawals ranged from 13.72 mgd in April and May to none between November and March.

APPENDIX B

DIFFERENCE BETWEEN SIMULATED AND OBSERVED POTENTIOMETRIC SURFACE (FT) - PREDEVELOPMENT
(+ = EXCESSIVE DRAWDOWN SIMULATED, - = INSUFFICIENT DRAWDOWN SIMULATED)

ROW	COLUMN 2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
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
2.	-1.1	-0.7	-0.5	-0.3	-0.2	-0.2	-0.2	-0.5	-0.7	0.8	-0.6	-0.3	0.0	0.8	0.8	0.6	0.9	0.1	-0.9	-0.9	1.4	1.9	2.0	1.5	-0.5	-1.3
3.	-0.9	-0.3	-1.0	-0.9	-0.9	-0.6	-0.1	-0.3	-0.2	0.3	-0.8	-0.6	-1.2	-0.9	-0.9	-1.1	-0.6	-1.4	-1.4	-2.5	-3.7	-1.8	0.1	0.3	-0.1	0.8
4.	0.5	0.2	-0.4	-0.3	-0.1	0.3	0.0	-0.2	-0.2	-0.1	-1.0	-0.8	-1.7	-1.6	-1.7	-1.8	-1.1	-1.6	-1.3	-1.5	-2.0	-2.3	-2.1	-0.1	-0.7	0.4
5.	-0.2	0.5	0.0	-0.6	-1.1	-0.6	-0.9	-1.0	-1.1	-1.1	-1.0	-0.9	-0.8	-0.8	-1.9	-0.9	-1.2	-1.5	-0.9	-1.5	-0.4	-0.3	-0.8	1.9	-0.7	0.3
6.	0.1	0.0	-0.3	-0.7	-1.1	-1.4	-1.7	-1.8	-1.9	-1.9	-1.8	-1.7	-1.6	-1.5	-1.5	-1.6	-0.8	-0.9	-0.1	-0.3	0.3	0.8	0.5	0.3	-1.2	0.6
7.	1.9	1.8	0.7	0.4	0.2	-0.1	-0.3	-0.5	-0.5	-0.5	-0.5	-0.3	-0.1	0.0	0.1	0.1	1.0	1.1	1.2	2.2	2.2	2.2	1.1	1.2	-1.0	-1.2
8.	1.7	1.7	1.5	1.4	1.2	1.0	0.9	0.8	0.7	0.8	0.9	1.1	1.3	1.6	0.9	1.1	1.2	1.4	1.7	2.0	2.4	2.7	2.2	1.7	1.3	-2.6
9.	1.4	1.3	1.2	1.1	0.9	0.8	0.7	0.7	0.7	0.8	0.9	1.2	1.6	1.0	1.5	1.1	0.6	1.2	1.8	3.4	4.2	3.9	4.7	3.7	-0.8	-1.7
10.	0.8	0.8	0.7	0.6	0.5	0.4	0.4	0.4	0.5	0.6	0.8	1.2	1.6	1.2	2.0	0.9	0.9	1.9	3.1	4.2	5.4	6.5	5.8	3.8	-1.8	-1.3
11.	1.0	1.0	1.0	1.0	1.0	0.9	1.0	1.0	1.2	1.4	1.7	2.1	2.6	2.3	2.3	2.6	2.1	1.8	3.4	5.0	3.8	5.0	4.7	0.1	-2.7	-2.2
12.	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.6	0.9	1.3	1.8	2.3	3.2	3.5	3.1	2.1	3.4	4.0	4.9	2.8	2.3	1.4	0.6	-2.5	-2.3
13.	0.2	0.3	0.3	0.4	0.4	0.5	0.6	0.8	1.0	1.2	1.6	2.1	2.8	2.8	3.4	3.4	1.9	2.9	3.9	2.6	1.4	-1.3	-0.9	-1.3	-3.1	-1.3
14.	0.3	0.3	0.4	0.4	0.5	0.6	0.7	0.9	1.1	1.4	1.5	2.1	2.9	3.3	2.0	2.3	2.0	3.3	3.5	2.1	-0.8	-0.9	0.4	0.6	-0.3	-0.4
15.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	1.8	1.8	2.3	2.2	2.5	3.2	3.4	1.0	1.6	-1.1	-0.7	-0.3	0.1	-0.1	-0.1
16.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	1.5	1.0	0.9	1.2	0.9	1.0	1.4	0.8	-0.2	-1.7	-1.1	-0.2	0.3	0.4
17.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	1.4	1.3	1.6	3.2	1.2	1.6	0.7	-0.4	-1.0	-0.4	-0.3	0.4	0.0
18.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

DIFFERENCE BETWEEN SIMULATED AND OBSERVED POTENTIOMETRIC SURFACE (FT) - SEPTEMBER 1979
(+ = EXCESSIVE DRAWDOWN SIMULATED, - = INSUFFICIENT DRAWDOWN SIMULATED)

ROW	COLUMN 2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.0	0.0	0.0	0.0	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.	-1.3	-1.5	-2.0	-1.5	-2.0	-1.0	-1.0	-0.6	-3.4	-2.7	-4.5	-1.4	-0.3	-0.4	-0.9	-1.2	-0.9	-0.8	-0.9	-0.7	-1.9	-2.2	-4.6	-3.0	-1.5	0.0
3.	-0.5	-0.7	-1.4	-1.6	-3.0	-3.4	-4.4	-3.9	-3.0	-4.6	-4.1	-4.9	-3.7	-2.1	-2.3	-1.6	-1.8	-2.9	-2.9	-3.7	-4.0	-1.6	-8.7	-5.8	-1.4	2.4
4.	-1.6	-0.8	0.5	-0.5	-2.5	-3.4	-4.0	-3.2	-2.8	-4.3	-4.1	-4.3	-4.7	-4.1	-2.4	-1.5	-2.5	-2.5	-2.2	-2.8	-2.8	-4.2	-6.2	-8.5	-3.6	-3.4
5.	-2.7	1.0	1.5	-1.1	-1.8	-1.3	-2.7	-2.8	-2.6	-2.4	-5.3	-3.4	-3.6	-3.8	-3.0	-2.0	-1.1	-2.0	-1.8	-1.7	-2.1	-1.8	0.0	-3.0	-4.9	-2.2
6.	0.3	2.2	0.9	0.5	0.2	-0.1	-0.3	-1.3	-1.2	-1.1	-1.0	-0.9	-0.9	-1.0	-1.2	-1.3	-1.3	-1.1	-0.7	-0.1	0.1	-3.8	-0.2	-0.1	-1.0	-1.0
7.	1.7	1.7	2.7	1.5	1.4	1.3	1.2	0.3	1.4	0.6	0.7	0.9	1.0	-0.0	-0.0	1.0	-0.1	0.2	-0.1	0.4	-0.2	-3.5	-1.5	-1.3	-2.6	-0.2
8.	2.2	3.3	4.4	3.4	3.5	3.6	2.7	2.9	3.1	2.4	2.6	2.9	3.1	3.2	3.3	2.4	1.3	1.6	2.2	1.3	-2.6	-1.0	-0.6	-2.5	-3.1	-7.1
9.	2.5	1.7	1.9	3.2	4.3	4.6	3.9	6.2	5.6	5.0	5.4	5.8	6.1	6.4	4.6	2.8	5.0	3.4	2.8	2.5	2.1	2.1	-2.0	-1.0	-5.9	-4.1
10.	2.2	0.9	2.3	3.7	5.1	5.5	4.9	7.4	7.0	6.6	7.1	6.8	8.2	8.5	5.8	7.1	6.6	5.2	2.8	2.5	3.2	2.8	-3.8	-3.6	-6.7	-2.1
11.	0.3	1.0	2.6	4.1	1.7	4.2	3.8	5.5	7.3	8.2	8.0	8.9	9.7	10.0	10.1	11.6	8.3	4.2	3.8	0.7	0.7	-1.8	-2.8	-3.0	-4.3	-1.9
12.	1.2	1.1	1.8	2.6	2.2	2.8	4.6	6.4	7.4	9.5	9.6	8.9	8.4	10.9	10.6	9.0	6.8	3.8	2.0	-2.4	-2.5	-0.7	-2.3	-3.4	-3.9	-1.7
13.	2.3	1.2	1.0	1.0	1.6	0.3	4.1	5.3	7.5	8.5	9.5	8.3	8.2	8.1	6.8	4.3	3.3	0.3	-1.5	-0.6	1.1	0.6	0.6	-5.2	-6.1	-1.4
14.	1.8	1.3	0.0	0.8	1.5	0.3	3.2	4.4	7.2	7.1	5.7	4.8	5.0	5.0	4.0	4.0	1.8	1.6	-0.1	-1.0	2.0	2.2	1.1	0.0	-3.0	-4.1
15.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	3.4	4.4	3.4	4.5	2.8	3.0	1.4	1.3	1.3	2.5	3.3	3.3	2.4	-1.8	-2.6
16.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	2.9	3.9	4.0	3.0	3.2	3.6	4.2	5.0	2.9	3.5	3.7	3.4	1.3	2.3
17.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	2.5	4.3	3.1	2.1	3.3	3.6	3.8	4.2	2.7	2.8	2.8	1.8	0.0
18.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

DIFFERENCE BETWEEN SIMULATED AND OBSERVED POTENTIOMETRIC SURFACE (FT) - MAY 1980
(+ = EXCESSIVE DRAWDOWN SIMULATED, - = INSUFFICIENT DRAWDOWN SIMULATED)

ROW \ COLUMN	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
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
2.	-0.6	-1.6	-2.6	-4.5	-4.5	-5.6	-5.7	-6.7	-4.7	-3.8	-0.8	-5.8	-5.8	-5.8	-5.8	-4.8	-4.7	-3.7	-1.8	-0.5	0.8	-0.3	-0.9	-0.4	-0.1	-0.7
3.	-2.1	-2.0	-1.8	-2.7	-2.6	-2.9	-3.1	-4.1	-4.2	-1.2	-2.2	-2.2	-4.2	-5.2	-5.1	-4.0	-3.8	-3.6	-1.6	-0.6	1.4	-0.4	2.1	0.4	-3.4	-2.1
4.	0.6	-0.3	-1.9	-1.7	-0.6	-0.2	-0.4	-1.5	-2.4	-0.6	-0.6	-0.6	-0.6	-1.5	-3.4	-4.2	-3.0	-2.9	-2.1	-2.1	-1.0	2.4	2.2	1.3	-2.9	0.5
5.	2.2	-0.8	-1.6	0.7	0.6	-0.7	0.2	0.3	-0.5	0.1	2.0	0.0	0.1	1.3	-0.6	-1.4	-2.2	-2.4	-1.6	-0.7	0.5	1.8	0.6	0.7	2.5	-0.9
6.	0.6	-1.4	-0.3	0.8	0.8	-0.3	-0.4	0.7	0.8	0.7	0.7	-0.3	-0.1	1.2	0.5	0.7	-0.6	-1.1	-0.5	0.4	-1.3	0.7	0.0	0.2	2.3	2.8
7.	0.1	0.1	-0.8	1.3	1.3	0.2	1.2	1.3	0.5	1.4	1.4	0.6	0.7	3.2	2.9	1.8	1.7	0.4	1.8	1.5	0.9	-0.5	-0.5	0.6	0.1	0.4
8.	-0.2	-1.2	-2.2	0.9	1.2	-0.1	1.9	1.0	2.7	3.5	2.0	2.1	2.3	3.0	3.7	3.7	2.0	1.5	0.9	0.3	2.3	-1.9	-1.8	-0.1	2.1	1.0
9.	-1.4	0.7	1.7	1.8	2.1	0.8	2.5	-0.5	1.7	2.5	1.3	1.6	1.6	2.6	4.0	4.2	1.0	1.1	1.5	0.1	-0.1	-3.2	-1.3	-1.5	-0.5	0.1
10.	-1.2	1.2	2.7	1.8	-0.1	2.9	2.3	1.2	2.6	2.8	2.3	2.1	0.1	0.6	3.4	0.9	1.2	0.7	1.2	0.8	0.6	-2.5	0.3	-0.9	3.0	0.7
11.	0.2	1.7	2.9	2.2	4.6	1.5	2.3	-0.3	4.9	2.5	2.3	0.7	0.5	0.4	-0.8	-2.1	0.5	1.4	-2.1	-0.5	-1.7	-0.8	-1.0	-0.1	1.7	-0.4
12.	-1.0	2.0	4.8	3.6	4.4	2.9	2.3	0.0	2.2	1.7	0.8	0.3	0.8	-1.4	-0.7	0.1	1.9	-1.0	-1.4	0.2	-1.1	-3.2	-0.1	1.8	0.6	-2.4
13.	-2.7	0.1	2.9	4.1	4.2	4.7	2.7	1.5	-0.2	1.0	-0.7	-1.2	-4.8	-5.1	-2.3	-0.6	1.2	-0.7	-0.4	0.0	-4.2	-2.4	-1.9	0.3	-1.1	-3.4
14.	-1.9	-0.5	3.0	3.2	3.3	5.4	3.1	2.1	-0.7	1.4	0.6	-1.0	-3.4	-4.7	-3.0	-1.2	0.6	-1.1	-0.7	-0.3	-0.5	1.4	-0.5	-1.4	-1.2	-2.1
15.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.4	-2.7	-5.9	-4.2	-4.3	-1.5	-0.5	0.5	0.6	2.5	1.4	1.3	0.3	-1.6	-0.6	-1.5
16.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-2.2	-3.3	-3.5	-2.6	-2.7	-1.7	-1.7	-0.7	-1.7	1.2	0.2	-0.8	-2.8	0.3	-1.7
17.	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	-3.7	-4.7	-2.8	-0.8	-1.8	-0.8	-0.8	-0.9	1.1	0.1	0.1	-0.9	0.0
18.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

DIFFERENCE BETWEEN SIMULATED AND OBSERVED POTENTIOMETRIC SURFACE (FT) - SEPTEMBER 1980
(+ = EXCESSIVE DRAWDOWN SIMULATED, - = INSUFFICIENT DRAWDOWN SIMULATED)

	COLUMN																									
ROW	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
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
2.	-1.0	0.0	1.0	2.9	2.9	4.0	4.0	5.0	3.0	2.0	-1.0	4.0	4.0	4.0	4.0	3.0	2.9	1.9	0.0	-1.1	-2.2	-1.2	-0.6	-1.0	-1.4	-0.9
3.	1.1	1.0	0.9	1.7	1.6	1.9	2.0	3.1	3.1	0.1	1.1	1.1	3.0	4.0	3.9	2.8	2.7	2.6	0.8	-0.1	-2.1	-0.1	-2.5	-0.9	-1.3	0.9
4.	-0.8	0.1	1.7	1.5	0.4	-0.1	0.1	1.1	2.1	0.1	0.1	0.1	0.0	0.9	2.8	3.6	2.5	2.5	1.8	1.9	1.0	-2.0	-1.7	-0.8	-1.3	-1.4
5.	-1.6	1.4	2.2	-0.1	-0.1	1.3	0.3	0.2	0.8	0.1	0.2	0.1	-0.1	-1.3	0.5	1.3	2.2	2.4	1.7	1.0	0.1	-0.5	0.6	0.5	-1.9	0.9
6.	0.8	2.8	1.7	0.6	0.6	1.6	1.6	0.5	0.3	0.3	0.2	1.0	0.7	-0.7	0.0	-0.3	1.0	1.4	0.8	0.1	2.0	0.1	0.7	0.5	-1.9	-2.8
7.	2.1	2.1	3.0	1.0	0.9	2.0	0.9	0.7	0.4	0.3	0.2	0.8	0.5	-2.1	-1.9	-0.9	-0.9	0.2	-1.2	-0.8	-2.2	1.0	0.7	-0.7	-0.4	-1.0
8.	3.1	4.2	5.2	2.2	1.9	3.1	1.1	1.8	0.0	-1.1	0.1	-0.2	-0.6	-1.6	-2.4	-2.6	-1.0	-0.7	-0.2	0.2	-1.8	2.0	1.7	-0.5	-2.8	-1.8
9.	4.9	3.0	2.2	2.2	2.0	3.2	1.3	4.1	1.6	0.5	1.4	0.7	0.5	-0.8	-2.5	-2.9	0.0	-0.3	-0.9	0.3	0.2	3.0	0.9	0.7	-0.5	-1.5
10.	5.0	3.2	1.9	3.1	5.0	2.0	2.3	3.2	1.4	0.7	0.8	1.5	2.2	1.3	-1.7	0.5	-0.2	0.1	-0.7	-0.6	-0.7	2.2	-1.0	-0.1	-4.2	-2.2
11.	4.1	3.3	2.4	3.4	1.1	4.1	3.0	5.3	-0.4	1.4	1.1	2.2	2.0	1.7	2.6	3.5	0.5	-0.7	2.5	0.5	1.4	0.2	0.0	-1.1	-3.1	-1.1
12.	5.5	3.3	1.1	2.5	1.9	3.4	3.6	5.4	2.7	2.4	2.7	2.6	1.7	3.5	2.4	1.3	-1.0	1.6	1.5	-0.6	0.3	2.1	-1.2	-3.3	-2.2	0.8
13.	7.5	5.4	3.0	2.0	2.0	1.6	3.2	3.9	5.0	3.3	4.1	4.0	7.1	7.0	3.9	1.7	-0.5	1.0	0.2	-0.6	3.2	1.0	0.3	-1.9	-0.5	1.7
14.	7.0	6.0	2.9	2.9	2.9	0.8	2.8	3.3	5.4	2.5	2.3	3.3	5.3	6.3	4.1	1.9	-0.2	1.1	0.3	-0.6	-0.7	-2.9	-1.1	-0.3	-0.4	0.5
15.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	4.1	7.1	5.1	5.0	1.8	0.5	-0.8	-1.3	-3.5	-2.6	-2.8	-1.9	0.0	-1.1	-0.1
16.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	3.8	3.7	2.6	2.4	1.2	1.0	-0.3	0.5	-2.6	-1.8	-0.8	1.1	-2.0	0.0
17.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	3.2	4.1	2.0	-0.2	0.7	-0.5	-0.6	-0.7	-2.8	-1.9	-1.9	-0.9	0.0
18.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

DIFFERENCE BETWEEN SIMULATED AND OBSERVED POTENTIOMETRIC SURFACE (FT) - SEPTEMBER 1980
(+ = EXCESSIVE DRAWDOWN SIMULATED, - = INSUFFICIENT DRAWDOWN SIMULATED)

ROW \ COLUMN	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
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
2.	-1.0	0.0	0.9	2.9	2.9	3.9	4.0	5.0	3.0	2.0	-1.0	4.0	4.0	4.0	3.9	2.9	2.9	1.9	-0.1	-1.2	-2.3	-1.2	-0.6	-1.1	-1.4	-1.0
3.	1.0	0.9	0.8	1.6	1.5	1.8	2.0	3.0	3.0	0.0	1.0	1.0	2.9	3.9	3.8	2.7	2.6	2.5	0.7	-0.3	-2.2	-0.3	-2.6	-1.0	-1.4	0.9
4.	-0.9	0.0	1.5	1.3	0.2	-0.2	0.0	1.0	1.9	0.0	0.0	-0.1	-0.2	0.7	2.6	3.4	2.2	2.3	1.5	1.7	0.8	-2.3	-1.9	-1.0	-1.4	-1.4
5.	-1.8	1.2	2.0	-0.4	-0.3	1.0	0.1	0.0	0.6	-0.1	0.0	-0.2	-0.4	-1.6	0.2	1.0	1.9	2.1	1.4	0.7	-0.2	-0.8	0.3	0.3	-2.1	0.8
6.	0.5	2.5	1.4	0.3	0.3	1.3	1.3	0.2	0.0	0.0	-0.1	0.7	0.4	-1.0	-0.4	-0.7	0.6	1.1	0.5	-0.3	1.7	-0.2	0.5	0.3	-2.0	-2.9
7.	1.7	1.7	2.7	0.6	0.5	1.6	0.5	0.3	0.0	-0.1	-0.2	0.4	0.1	-2.5	-2.4	-1.4	-1.4	-0.2	-1.5	-1.2	-2.5	0.7	0.5	-0.9	-0.5	-1.1
8.	2.7	3.7	4.8	1.7	1.5	2.7	0.6	1.4	-0.4	-1.5	-0.3	-0.7	-1.0	-2.0	-2.9	-3.1	-1.5	-1.1	-0.6	-0.1	-2.1	1.8	1.5	-0.6	-2.9	-2.0
9.	4.4	2.5	1.7	1.7	1.4	2.7	0.7	3.5	1.1	0.0	0.9	0.3	0.0	-1.3	-3.0	-3.3	-0.4	-0.7	-1.3	0.0	0.0	2.8	0.7	0.6	-0.7	-1.6
10.	4.5	2.6	1.3	2.4	4.3	1.3	1.6	2.5	0.8	0.2	0.3	1.1	1.7	0.9	-2.1	0.1	-0.6	-0.3	-1.0	-0.9	-0.9	2.0	-1.1	-0.3	-4.3	-2.3
11.	3.5	2.6	1.7	2.6	0.3	3.3	2.3	4.6	-1.0	0.9	0.6	1.7	1.5	1.3	2.1	3.1	0.1	-1.0	2.2	0.2	1.2	0.1	-0.1	-1.2	-3.2	-1.2
12.	4.9	2.6	0.3	1.7	1.0	2.5	2.8	4.7	2.1	1.9	2.2	2.2	1.3	3.1	2.0	0.9	-1.3	1.3	1.3	-0.7	0.2	2.0	-1.3	-3.4	-2.3	0.8
13.	6.8	4.7	2.2	1.2	1.1	0.7	2.4	3.2	4.4	2.8	3.7	3.6	6.8	6.7	3.5	1.4	-0.8	0.7	0.0	-0.8	3.1	0.9	0.3	-1.9	-0.6	1.6
14.	6.4	5.3	2.1	2.1	2.0	-0.1	2.0	2.6	4.9	2.0	2.0	3.0	5.0	6.0	3.9	1.7	-0.4	0.9	0.1	-0.7	-0.8	-3.0	-1.2	-0.3	-0.5	0.4
15.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	4.0	7.0	4.9	4.8	1.6	0.4	-1.0	-1.4	-3.6	-2.7	-2.9	-2.0	-0.1	-1.1	-0.2
16.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7	3.7	3.6	2.5	2.3	1.1	0.9	-0.4	0.5	-2.7	-1.8	-0.9	1.0	-2.0	-0.1
17.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	3.1	4.0	1.9	-0.2	0.6	-0.5	-0.7	-0.8	-2.8	-1.9	-1.9	-1.0	0.0
18.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

APPENDIX C

DAILY NONAGRICULTURAL WITHDRAWALS FROM THE UPPER FLORIDAN (MGD)

NODE	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEPT	OCT	NOV	DEC
2.21	2.58	2.46	2.68	2.63	3.07	3.11	2.89	3.36	2.86	3.06	3.10	2.88
2.24	0.29	0.31	0.59	0.61	0.88	0.61	0.29	0.29	0.30	0.59	0.61	0.59
2.25	0.09	0.09	0.10	0.12	0.12	0.14	0.13	0.12	0.12	0.13	0.11	0.10
2.26	1.00	1.30	1.10	1.10	1.10	1.60	2.20	2.20	1.00	1.20	1.60	1.30
2.26	0.81	0.83	1.07	1.47	1.53	1.87	1.62	1.23	1.26	1.56	1.14	0.95
2.26	0.02	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.02	0.02
2.26	2.93	2.86	2.06	2.81	4.20	3.13	0.31	0.44	0.86	0.59	0.40	2.70
2.26	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
3.23	0.25	0.25	0.29	0.33	0.34	0.38	0.37	0.34	0.34	0.35	0.30	0.29
3.25	0.27	0.27	0.32	0.37	0.37	0.42	0.41	0.37	0.37	0.39	0.33	0.31
3.25	0.09	0.10	0.18	0.19	0.27	0.19	0.09	0.09	0.09	0.18	0.19	0.18
3.26	0.20	0.20	0.24	0.27	0.28	0.31	0.30	0.27	0.27	0.29	0.25	0.23
3.26	0.09	0.10	0.18	0.19	0.27	0.19	0.09	0.09	0.09	0.18	0.19	0.18
3.27	0.08	0.08	0.09	0.11	0.11	0.12	0.12	0.11	0.11	0.11	0.10	0.09
4.20	1.10	1.05	1.14	1.11	1.31	1.32	1.23	1.42	1.21	1.30	1.31	1.22
4.23	0.05	0.05	0.06	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.07	0.06
4.23	0.04	0.04	0.05	0.05	0.05	0.07	0.06	0.07	0.06	0.07	0.06	0.05
4.23	0.16	0.17	0.16	0.17	0.19	0.20	0.19	0.19	0.20	0.19	0.20	0.16
4.23	0.05	0.05	0.09	0.10	0.14	0.10	0.05	0.05	0.05	0.09	0.10	0.09
4.24	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.02
4.24	2.58	2.79	2.61	2.70	2.61	2.70	2.61	1.29	1.33	1.29	2.70	2.61
4.25	0.31	0.33	0.62	0.64	0.93	0.64	0.31	0.31	0.32	0.62	0.64	0.62
4.26	1.00	1.02	1.19	1.36	1.39	1.54	1.52	1.38	1.37	1.44	1.24	1.17
4.26	0.32	0.34	0.64	0.66	0.96	0.66	0.32	0.32	0.33	0.64	0.66	0.64
4.27	0.28	0.30	0.34	0.36	0.40	0.43	0.44	0.44	0.40	0.40	0.33	0.33
4.27	1.08	1.14	1.26	1.34	1.50	1.66	1.68	1.54	1.47	1.70	1.30	1.19
4.27	0.21	0.21	0.22	0.28	0.32	0.31	0.40	0.38	0.39	0.41	0.31	0.27
5.24	1.33	1.36	1.58	1.81	1.85	2.05	2.02	1.84	1.82	1.91	1.64	1.56
5.24	0.02	0.02	0.03	0.03	0.03	0.04	0.03	0.04	0.03	0.04	0.03	0.03
5.24	0.35	0.37	0.70	0.72	1.04	0.72	0.35	0.35	0.36	0.70	0.72	0.70
5.26	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
5.26	1.72	1.68	2.01	2.29	2.26	2.59	2.49	2.53	2.41	2.51	2.09	2.01
5.26	1.30	1.28	1.51	1.68	2.05	2.38	2.21	1.98	1.95	2.24	1.60	1.50
5.26	0.17	0.18	0.34	0.35	0.50	0.35	0.17	0.17	0.17	0.34	0.35	0.34
5.27	0.74	0.76	0.84	0.97	1.03	1.17	1.07	0.97	0.97	1.10	0.90	0.84
5.27	3.25	3.41	3.77	4.03	4.49	4.98	5.05	4.61	4.41	5.16	3.91	3.57
5.27	0.46	0.49	0.54	0.62	0.67	0.83	0.74	0.62	0.62	0.77	0.55	0.51
5.27	1.00	0.89	1.11	1.32	1.39	1.73	1.76	1.43	1.46	1.72	1.21	1.13
5.27	0.19	0.20	0.38	0.39	0.56	0.39	0.19	0.19	0.19	0.38	0.39	0.38
6.24	0.11	0.11	0.13	0.15	0.16	0.17	0.17	0.16	0.15	0.16	0.14	0.13
6.24	0.09	0.10	0.19	0.19	0.28	0.19	0.09	0.09	0.10	0.19	0.19	0.19
6.25	0.13	0.13	0.15	0.16	0.19	0.19	0.17	0.16	0.15	0.13	0.13	0.12
6.25	0.17	0.17	0.20	0.21	0.20	0.25	0.24	0.27	0.22	0.27	0.23	0.18
6.25	0.29	0.30	0.35	0.40	0.41	0.45	0.45	0.40	0.40	0.42	0.36	0.34
6.25	0.08	0.09	0.16	0.17	0.24	0.17	0.08	0.08	0.08	0.16	0.17	0.16
6.26	0.64	0.65	0.68	0.83	1.07	1.10	1.10	1.07	0.80	1.19	1.13	0.64
6.26	0.41	0.42	0.44	0.56	0.65	0.62	0.79	0.76	0.78	0.81	0.62	0.53
6.26	0.73	0.76	0.91	0.96	1.06	1.24	1.21	1.01	1.03	1.14	0.92	0.84
6.26	0.09	0.10	0.19	0.20	0.29	0.20	0.09	0.09	0.10	0.19	0.20	0.19
6.27	0.08	0.08	0.09	0.10	0.11	0.14	0.12	0.10	0.10	0.13	0.09	0.09
6.27	0.72	0.76	0.88	1.01	1.05	1.03	0.98	0.91	0.99	1.07	0.85	0.76
6.27	2.20	2.29	2.73	2.86	3.17	3.71	3.62	3.01	3.09	3.43	2.77	2.53
6.27	0.64	0.59	0.58	0.77	0.81	0.83	0.90	0.84	0.87	0.77	0.83	0.71
6.27	0.16	0.17	0.32	0.33	0.48	0.33	0.16	0.16	0.16	0.32	0.33	0.32
7.21	2.84	2.78	3.27	3.32	3.24	3.46	3.45	3.68	3.27	3.23	3.02	2.73

7.22	8.22	8.04	9.45	9.58	9.36	10.00	9.96	10.62	9.43	9.33	8.71	7.87
7.24	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
7.25	0.32	0.33	0.39	0.44	0.45	0.50	0.50	0.45	0.45	0.47	0.40	0.38
7.25	0.31	0.33	0.61	0.63	0.91	0.63	0.31	0.31	0.31	0.61	0.63	0.61
7.26	0.08	0.08	0.09	0.10	0.11	0.14	0.12	0.10	0.10	0.13	0.09	0.09
7.26	0.19	0.21	0.39	0.40	0.58	0.40	0.19	0.19	0.20	0.39	0.40	0.39
8.21	0.63	0.62	0.73	0.74	0.72	0.77	0.77	0.82	0.73	0.72	0.67	0.61
8.22	4.11	4.02	4.72	4.79	4.68	5.00	4.98	5.31	4.72	4.66	4.36	3.94
8.24	0.06	0.07	0.13	0.13	0.19	0.13	0.06	0.06	0.07	0.13	0.13	0.13
8.26	0.28	0.23	0.19	0.39	0.35	0.40	0.27	0.32	0.28	0.24	0.31	0.27
9.23	0.24	0.26	0.48	0.49	0.72	0.49	0.24	0.24	0.25	0.48	0.49	0.48
9.25	0.08	0.08	0.09	0.10	0.11	0.14	0.12	0.10	0.10	0.13	0.09	0.09
12.02	0.40	0.52	0.47	0.57	0.42	0.00	0.00	0.00	0.00	0.28	0.24	0.44
13.02	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40
13.05	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
13.05	0.13	0.11	0.15	0.16	0.19	0.22	0.17	0.19	0.15	0.15	0.13	0.16
13.07	0.23	0.25	0.47	0.48	0.70	0.48	0.23	0.23	0.24	0.47	0.48	0.47
13.24	0.18	0.17	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
13.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13.24	0.31	0.22	0.20	0.21	0.26	0.40	0.35	0.34	0.34	0.35	0.37	0.37
TOTAL	54.08	54.56	62.64	67.39	74.16	75.50	68.39	65.88	61.64	68.59	62.83	60.26

TOTAL WITHDRAWALS FOR NONAGRICULTURAL USED FROM THE LOWER FLORIDAN AQUIFER (MGD)

NODE	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
3.24	2.45	2.44	2.77	2.96	3.02	3.36	3.54	3.44	3.17	3.37	2.90	2.68
3.25	3.99	3.99	4.52	4.83	4.93	5.49	5.78	5.62	5.17	5.50	4.73	4.37
3.26	7.86	7.86	8.89	9.51	9.70	10.80	11.40	11.10	10.20	10.80	9.31	8.60
4.25	7.19	7.18	8.13	8.69	8.87	9.88	10.40	10.10	9.30	9.89	8.51	7.86
4.27	0.40	0.41	0.47	0.54	0.55	0.62	0.61	0.55	0.55	0.57	0.49	0.47
5.24	5.08	5.08	5.75	6.15	6.27	6.99	7.36	7.15	6.58	7.00	6.02	5.56
5.25	14.40	14.40	16.30	7.42	17.80	19.80	20.80	20.30	18.60	19.80	17.10	15.80
5.25	1.72	1.68	2.01	2.29	2.26	2.59	2.49	2.53	2.41	2.51	2.09	2.01
5.26	1.72	1.68	2.01	2.29	2.26	2.59	2.49	2.53	2.41	2.51	2.09	2.01
5.27	0.26	0.32	0.28	0.32	0.30	0.34	0.37	0.35	0.39	0.35	0.31	0.26
5.27	4.34	4.29	4.53	4.52	4.12	2.98	2.85	3.53	3.35	3.35	3.65	3.72
6.24	0.82	0.84	0.98	1.12	1.15	1.27	1.26	1.14	1.13	1.18	1.02	0.97
6.25	1.72	1.68	2.01	2.29	2.26	2.59	2.49	2.53	2.41	2.51	2.09	2.01
6.26	1.72	1.68	2.01	2.29	2.26	2.59	2.49	2.53	2.41	2.51	2.09	2.01
TOTAL	53.67	53.53	60.66	55.22	65.75	71.89	74.33	73.40	68.08	71.85	62.40	58.33

TOTAL AGRICULTURAL WITHDRAWALS (MGD)

NODE	S-F	M-A	MAY	JUN	JUL	AUG	SEPT
2.22	0.23	0.21	0.63	0.13	0.55	0.36	0.06
2.24	0.13	0.12	0.35	0.25	0.19	0.12	0.04
2.25	1.02	0.94	2.84	0.59	2.15	1.91	0.29
2.26	0.89	0.82	2.47	0.51	2.13	1.40	0.25
2.27	0.49	0.46	1.37	0.28	1.03	0.92	0.14
3.05	0.05	0.11	0.18	0.10	0.00	0.07	0.00
3.06	0.18	0.39	0.62	0.35	0.00	0.23	0.00
3.18	0.01	0.02	0.05	0.01	0.04	0.04	0.00
3.19	0.30	0.28	0.84	0.61	0.46	0.30	0.09
3.20	0.04	0.04	0.11	0.02	0.08	0.07	0.01
3.21	0.07	0.08	0.22	0.05	0.15	0.10	0.02
3.25	0.02	0.02	0.05	0.04	0.03	0.02	0.00
3.26	0.79	0.73	2.22	0.46	1.68	1.49	0.23
3.27	0.56	0.52	1.59	0.33	1.20	1.06	0.16
4.04	0.38	0.86	1.37	0.77	0.00	0.50	0.00
4.05	0.30	0.68	1.09	0.61	0.00	0.40	0.00
4.06	0.60	1.32	2.12	1.20	0.00	0.77	0.00
4.18	0.22	0.20	0.61	0.44	0.34	0.22	0.06
4.19	0.19	0.18	0.53	0.11	0.40	0.35	0.06
4.21	0.06	0.06	0.16	0.12	0.09	0.06	0.02
4.24	0.12	0.11	0.32	0.23	0.18	0.12	0.04
4.25	0.02	0.02	0.05	0.01	0.05	0.03	0.00
4.26	0.36	0.34	1.01	0.21	0.76	0.68	0.11
4.27	1.56	1.40	4.36	0.90	3.75	2.48	0.45
5.02	0.16	0.16	0.43	0.33	0.25	0.16	0.05
5.03	0.07	0.07	0.19	0.14	0.11	0.07	0.02
5.04	0.05	0.03	0.08	0.06	0.04	0.03	0.01
5.05	0.32	0.71	1.14	0.64	0.00	0.41	0.00
5.06	0.18	0.39	0.62	0.35	0.00	0.23	0.00
5.09	0.08	0.18	0.28	0.16	0.00	0.10	0.00
5.10	0.52	1.15	1.85	1.04	0.00	0.67	0.00
5.14	0.04	0.08	0.13	0.07	0.00	0.05	0.00
5.18	0.31	0.29	0.88	0.64	0.48	0.32	0.09
5.19	0.31	0.30	0.89	0.18	0.67	0.59	0.09
5.20	0.19	0.18	0.52	0.38	0.29	0.19	0.09
5.22	0.18	0.18	0.51	0.37	0.28	0.19	0.05
5.24	0.28	0.25	0.75	0.55	0.41	0.27	0.08
5.26	0.05	0.04	0.13	0.09	0.07	0.05	0.01
5.27	0.41	0.38	1.15	0.83	0.63	0.41	0.12
6.14	0.05	0.11	0.18	0.10	0.00	0.06	0.00
6.15	0.08	0.19	0.31	0.17	0.00	0.11	0.00
6.22	0.22	0.20	0.60	0.13	0.52	0.35	0.06
6.24	0.05	0.04	0.14	0.10	0.07	0.05	0.02
6.25	0.01	0.01	0.03	0.02	0.02	0.01	0.00
6.26	0.13	0.12	0.35	0.25	0.19	0.12	0.04
7.13	0.14	0.32	0.80	0.00	0.00	0.19	0.00
7.15	0.06	0.13	0.21	0.12	0.00	0.08	0.00
7.17	1.25	2.78	4.45	2.51	0.00	1.62	0.00
7.18	0.54	1.21	1.94	1.09	0.00	0.70	0.00
7.22	0.23	0.21	0.65	0.47	0.36	0.23	0.07
7.25	0.02	0.02	0.05	0.04	0.02	0.02	0.00
7.26	0.65	0.60	1.80	1.30	0.99	0.65	0.19
8.06	0.40	0.39	1.04	0.79	0.61	0.38	0.11
8.10	1.02	1.00	2.68	0.58	2.12	1.84	0.29
8.11	0.47	0.44	1.33	0.96	0.73	0.48	0.14

8.11	0.36	0.35	0.94	0.20	0.84	0.55	0.10
8.13	0.08	0.19	0.47	0.00	0.00	0.11	0.00
8.16	1.64	3.66	5.87	3.31	0.00	2.13	0.00
8.17	1.75	3.91	6.26	3.53	0.00	2.28	0.00
8.18	0.55	1.22	1.95	1.10	0.00	0.71	0.00
8.20	0.19	0.43	0.69	0.39	0.00	0.25	0.00
8.24	0.23	0.21	0.64	0.46	0.35	0.23	0.07
8.26	0.89	0.82	2.48	1.79	1.36	0.90	0.26
8.27	0.85	0.80	2.40	1.74	1.32	0.87	0.25
9.06	0.40	0.39	1.04	0.79	0.61	0.38	0.11
9.13	0.35	0.78	1.95	0.00	0.00	0.45	0.00
9.15	0.89	1.97	3.15	1.78	0.00	1.15	0.00
9.16	1.01	2.24	3.59	2.02	0.00	1.30	0.00
9.17	0.24	0.54	0.86	0.49	0.00	0.31	0.00
9.24	0.05	0.04	0.14	0.10	0.03	0.10	0.09
9.25	0.02	0.02	0.05	0.04	0.03	0.02	0.00
9.26	0.01	0.01	0.03	0.02	0.02	0.01	0.00
9.27	0.11	0.10	0.28	0.21	0.06	0.22	0.19
10.02	0.91	0.91	2.44	1.86	1.42	0.89	0.27
10.03	1.04	1.05	2.79	2.11	1.62	1.02	0.30
10.07	0.26	0.26	0.70	0.53	0.40	0.25	0.08
10.10	0.91	0.84	2.57	1.86	1.40	0.92	0.27
10.15	0.44	0.98	1.58	0.89	0.00	0.57	0.00
11.02	0.59	0.59	1.57	0.34	1.33	1.08	0.17
11.03	0.48	0.48	1.28	0.97	0.74	0.47	0.14
11.05	0.43	0.43	1.13	0.25	0.90	0.78	0.12
11.06	0.92	0.92	2.46	0.53	2.23	1.42	0.27
11.07	1.02	1.01	2.70	2.05	1.57	0.99	0.29
11.08	0.01	0.01	0.02	0.01	0.01	0.01	0.00
11.10	0.54	0.50	1.52	1.10	0.83	0.55	0.16
11.11	0.89	1.96	3.15	1.77	0.00	1.14	0.00
11.12	0.06	0.15	0.23	0.13	0.00	0.08	0.00
11.13	0.01	0.03	0.04	0.02	0.00	0.02	0.00
11.14	0.05	0.09	0.15	0.09	0.00	0.05	0.00
11.19	0.28	0.25	0.76	0.16	0.58	0.51	0.08
11.20	0.02	0.02	0.07	0.05	0.04	0.02	0.01
12.02	0.52	0.51	1.36	1.03	0.79	0.50	0.15
12.03	0.59	0.58	1.54	1.17	0.89	0.56	0.17
12.04	2.63	2.61	6.96	5.27	4.03	2.54	0.75
12.04	0.16	0.16	0.43	0.33	0.25	0.16	0.05
12.05	0.28	0.28	0.74	0.56	0.43	0.27	0.08
12.05	1.39	1.38	3.68	2.79	2.13	1.35	0.40
12.06	1.02	1.00	2.67	0.58	2.38	1.54	0.29
12.07	2.52	2.50	6.67	1.45	5.96	3.85	0.72
12.08	0.91	0.90	2.39	0.52	1.90	1.64	0.26
12.09	0.01	0.02	0.05	0.04	0.03	0.02	0.01
12.10	1.58	1.40	4.40	0.91	3.79	2.50	0.45
12.19	0.23	0.21	0.66	0.47	0.37	0.23	0.07
12.24	0.06	0.06	0.19	0.14	0.10	0.07	0.02
13.04	0.02	0.02	0.05	0.01	0.04	0.03	0.01
13.04	0.20	0.20	0.56	0.12	0.44	0.38	0.06
13.05	0.16	0.16	0.42	0.31	0.24	0.15	0.05
13.06	0.23	0.22	0.59	0.45	0.34	0.22	0.06
13.07	0.90	0.89	2.38	1.80	1.38	0.87	0.26
13.08	0.55	0.55	1.48	0.32	1.16	1.01	0.16
13.09	0.05	0.05	0.13	0.10	0.07	0.05	0.01
13.20	0.47	0.44	1.33	0.95	0.73	0.48	0.14
13.21	0.02	0.02	0.08	0.02	0.05	0.05	0.01
13.24	0.62	0.58	1.75	1.26	0.96	0.63	0.18
13.25	0.79	0.73	2.21	0.46	1.68	1.48	0.23

13.26	0.28	0.25	0.75	0.54	0.41	0.27	0.08
13.27	0.02	0.02	0.06	0.02	0.05	0.05	0.01
14.08	0.38	0.38	1.02	0.22	0.81	0.70	0.11
14.20	0.36	0.34	1.01	0.21	0.87	0.58	0.11
14.26	0.19	0.19	0.58	0.12	0.43	0.38	0.06
14.27	0.26	0.24	0.73	0.53	0.41	0.27	0.08
TOTAL	52.94	67.12	156.09	78.18	74.93	69.90	11.83

HEAT PUMP AND LAWN IRRIGATION WITHDRAWAL RATES (MGD)

NODE	SEPT	OCT-FEB	MAR-AP	MAY	JUN-AUG
	PUMPING PERIOD				
11.14	0.05	0.04	0.05	0.06	0.06
11.15	0.10	0.10	0.10	0.12	0.13
12.10	0.10	0.07	0.09	0.12	0.10
12.11	0.01	0.00	0.01	0.03	0.01
12.12	0.23	0.10	0.25	0.42	0.25
12.13	0.64	0.25	0.70	1.19	0.68
12.14	1.93	1.62	1.76	2.10	2.13
12.15	2.01	1.60	1.87	2.35	2.21
12.16	0.26	0.23	0.23	0.26	0.29
12.17	0.04	0.02	0.02	0.04	0.05
12.18	0.06	0.01	0.06	0.12	0.07
12.19	0.01	0.00	0.01	0.03	0.01
12.22	0.02	0.00	0.01	0.03	0.01
12.23	0.01	0.00	0.01	0.03	0.01
12.24	0.01	0.00	0.01	0.03	0.01
13.09	0.37	0.30	0.33	0.40	0.40
13.10	0.62	0.52	0.56	0.65	0.67
13.11	0.70	0.63	0.62	0.69	0.78
13.12	0.76	0.46	0.77	1.14	0.82
13.13	3.30	2.59	3.07	3.88	3.61
13.14	5.42	4.25	4.18	5.30	6.70
13.15	4.69	3.31	3.56	4.94	5.89
13.16	2.19	1.81	2.01	2.42	2.40
13.17	0.14	0.08	0.07	0.12	0.20
13.18	0.24	0.16	0.10	0.15	0.36
13.22	0.05	0.00	0.06	0.12	0.05
13.23	0.02	0.00	0.03	0.06	0.02
13.24	0.04	0.02	0.02	0.04	0.05
14.16	0.04	0.04	0.03	0.03	0.05
14.17	2.92	2.29	2.30	2.91	3.57
14.18	1.93	1.32	0.83	1.30	2.99
14.19	0.10	0.04	0.06	0.11	0.13
TOTAL	29.01	21.86	23.78	31.19	34.71

PUMPING PERIOD	PERCENT OF AVG HT PMP	LAWN
OCT-FEB	89	0
MAR-APR	30	147
MAY	35	300
JUN-AUG	181	119
SEPT	110	119

AVG HT PMP Q = 22.75 MGD
AVG LAWN Q = 4.59 MGD

NOTE : VARIATIONS IN MONTHLY HEAT-PUMP WITHDRAWALS ONLY APPLY TO HEAT PUMPS WITH CONTROLLED DISCHARGES

DISCHARGES FROM FREE-FLOWING WELLS (MGD)

NODE	Q
8.11	0.02
9.15	0.05
10.11	0.02
10.12	0.10
10.13	0.72
10.15	0.04
10.20	0.14
10.23	0.02
11.11	0.68
11.12	0.20
11.13	0.03
11.14	0.72
11.19	0.75
12.08	0.06
12.11	0.22
12.12	0.24
12.14	0.25
12.18	0.26
12.19	0.35
13.05	0.50
13.06	0.28
13.09	0.36
13.10	1.08
13.11	1.12
13.12	0.36
13.13	0.06
13.15	0.01
13.17	1.14
13.18	1.35
13.19	0.95
13.20	1.13
14.08	0.01
14.09	0.80
14.19	0.03

TOTAL 14.05