Professional Paper SJ2000-PP1

APPROXIMATION OF RELATIVE CONTRIBUTIONS OF VARIOUS ENTITIES TO THE OVERALL DRAWDOWN IN THE UPPER FLORIDAN AQUIFER OF THE POTATO-GROWING REGION IN ST. JOHNS AND PUTNAM COUNTIES, FLORIDA

by

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St. Johns River Water Management District
Palatka, Florida

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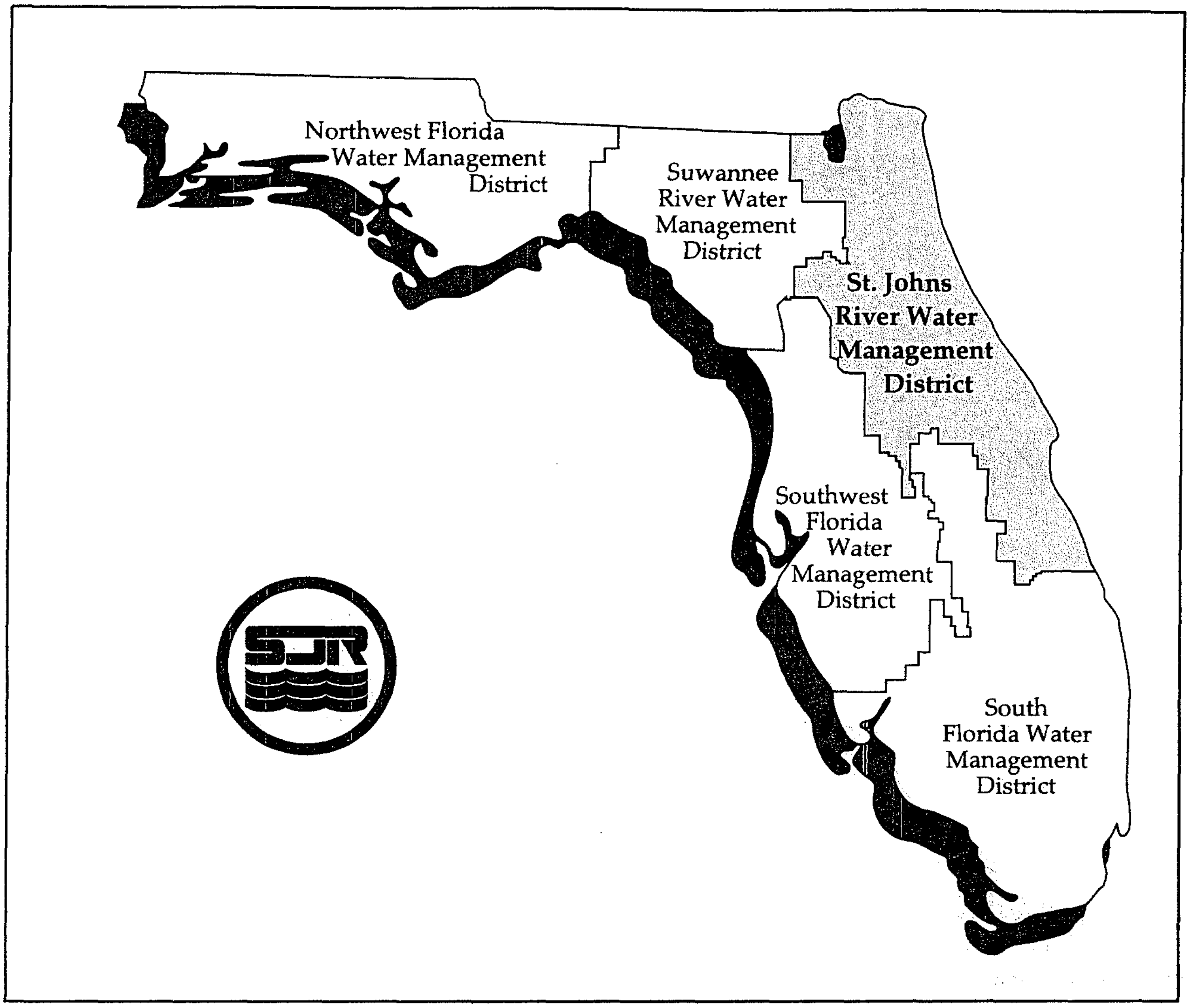

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ABSTRACT

The Floridan aquifer system is the primary source of potable water in east Putnam and southwest St. Johns counties. Major uses of water from the Floridan aquifer system in this area include paper and electricity production, potato irrigation, and domestic self-supply. During the potato irrigation season, which occurs annually from March 1 through May 31, the area experiences the temporary disablement of domestic self-supply wells due to temporary, large drawdowns in the potentiometric surface of the Upper Floridan aquifer. In this study, an analytical groundwater flow model (Motz 1978) was used to estimate the relative contributions of various water users to drawdowns in the potentiometric surface of the Upper Floridan aquifer of east Putnam and southwest St. Johns counties during the potato irrigation season. The water users included in the analysis were the Georgia-Pacific Corporation paper mill in Putnam County, the Seminole Electric Cooperative power plant in Putnam County, and the potato farms of Putnam, St. Johns, and Flagler counties.

The analytical groundwater flow model employed in the study was that of Motz (1978). It represents a steady-state, coupled aquifer system consisting of an underlying semiconfined aquifer from which water is withdrawn by a fully penetrating well, an overlying unconfined aquifer, and an intervening semiconfining unit. The aquifer system is represented as homogeneous and isotropic. The drawdown in the unconfined aquifer occurs as a result of induced leakage across the semiconfining unit. In this study, the semiconfined aquifer of the Motz (1978) model corresponds to the Upper Floridan aquifer, the semiconfining unit corresponds to the intermediate semiconfining unit, and the unconfined aquifer corresponds to the surficial aquifer system. The portion of the Floridan aquifer system that lies below the Upper Floridan aquifer is not represented in this study. A FORTRAN implementation of the Motz (1978) model that enables the determination of cumulative drawdowns due to withdrawals from more than one well was used.

The estimated average withdrawal rate from the Upper Floridan aquifer per potato irrigation well was determined to be approximately 178,000 gallons per day (gpd) during the potato irrigation season. Given a total of 726 such wells within the study area, the total average withdrawal rate of all potato irrigation wells was estimated to be approximately 129 million gallons per day (mgd) during the potato irrigation season. The estimated average daily withdrawal rate from the Upper Floridan aquifer for the wells operated by Georgia-Pacific Corporation was determined to be approximately 13 mgd from March through May, 1997. The estimated average daily withdrawal rate from the Upper Floridan aquifer for the two wells operated by Seminole Electric Cooperative was determined to be approximately 480,000 gpd in 1997.

The transmissivity estimate used to represent the permeability of the Upper Floridan aquifer in the model was 60,000 square feet per day (ft^2/d). The leakance estimate used to represent the vertical permeability of the intermediate semiconfining unit was 1.0×10^{-4} per day. The transmissivity estimate used to represent the permeability of the surficial aquifer system was 1,000 ft^2/d. The estimate of the evapotranspiration reduction coefficient used in the model was 2.66×10^{-4} per day.

The simulated drawdowns in the potentiometric surface of the Upper Floridan aquifer due to potato irrigation range up to approximately 27 feet (ft). The affected area includes most of St. Johns County, northeast Putnam County, southeast Clay County, and northwest Flagler County. The simulated drawdowns in the potentiometric surface of the Upper Floridan aquifer due to withdrawals by Georgia-Pacific Corporation range up to approximately 9 ft. The affected area includes northern Putnam and southern Clay counties. The simulated drawdown in the potentiometric surface of the Upper Floridan aquifer due to withdrawals made by Seminole Electric Cooperative range up to approximately 0.5 ft. The affected area includes northeast Putnam County only.

Primarily, the results of the study indicate that drawdowns in the potentiometric surface of the Upper Floridan aquifer due to withdrawals for potato irrigation are the greatest component of the overall drawdown from March through May. The drawdowns due to the withdrawals made by Georgia-Pacific Corporation are significant, but are considerably smaller. The drawdowns due to withdrawals made by Seminole Electric Cooperative are insignificant as compared to the drawdowns attributable to the other two subjects of the study.

INTRODUCTION

The Floridan aquifer system is the primary source of potable water in the area of east Putnam and southwest St. Johns counties (Figure 1). Major uses of water from the Floridan aquifer system in this area include potato irrigation, paper and electricity production, and domestic self-supply. The area experiences temporary disablement of domestic self-supply wells due to temporary, large drawdowns in the potentiometric surface of the Upper Floridan aquifer from March 1 through May 31. The 1998 Water Supply Assessment of the St. Johns River Water Management District (SJRWMD) identifies the need for strategies to protect existing legal uses of groundwater in the area (Vergara 1998). Estimating the relative contributions of various major water users to the overall drawdown in the potentiometric surface of the Upper Floridan aquifer was an important step to this end. The analysis of the drawdowns was performed through the use of a groundwater flow model, and this report documents its application.

OBJECTIVE

The present study provides an approximation of the relative contributions of various major water users to observed seasonal declines in the potentiometric surface of the Floridan aquifer. These occur annually from March through May (92 days) in east Putnam and southwest St. Johns counties.

METHOD

The application of the Motz (1978) analytical groundwater flow model was the method of evaluation for this study. The Motz model that was used to perform regional-scale steady-state drawdown calculations was selected for the following reasons:

1. It adequately represents the Floridan aquifer system of the study area.

Figure 1. Study area

2. Time for conducting the study was limited. Application of an analytical model has fewer requirements for data input and requires less time.

3. The ability to represent the effects of multiple wells was important. A FORTRAN implementation of the model enabled superposition of the effects of numerous wells throughout an area. Thus, the effects of withdrawals from hundreds of wells in the study area combine to form the overall drawdown in the potentiometric surface of the Upper Floridan aquifer.

In applying the Motz (1978) model, rates of groundwater withdrawals were averaged over the 92-day period of interest to estimate drawdowns in the potentiometric surface of the Upper Floridan aquifer that are averaged over the same time period.

MODEL CONFIGURATION AND IMPLEMENTATION

Model Layering

Motz (1978) derived an analytical model for a steady-state, coupled aquifer system consisting of an underlying semiconfined aquifer from which water is withdrawn by a fully penetrating well, an overlying unconfined aquifer, and an intervening semiconfining unit (Figure 2). The aquifer system is represented as homogeneous and isotropic. The drawdown in the unconfined aquifer occurs as a result of induced leakage across the semiconfining unit. This drawdown is assumed to be small relative to the saturated thickness of the unconfined aquifer, thus enabling the use of transmissivity in the specification of its permeability. The decline in the rate of evapotranspiration (ET) from the unconfined aquifer is approximated as varying linearly with the decline in its water level. The coefficient of proportionality in this relationship is referred to as the ET reduction coefficient (Motz 1978).

In this study, the semiconfined aquifer of the Motz (1978) model corresponds to the Upper Floridan aquifer, the semiconfining unit corresponds to the intermediate semiconfining unit, and the unconfined aquifer corresponds to the surficial aquifer system (Figure 3 and Table 1). Determination of the drawdown in the elevation of the water table of the surficial aquifer system was not an objective. However, because the simulated drawdown in the surficial aquifer system influences the calculation of drawdown in the potentiometric surface of the Floridan aquifer system, an attempt was made to use realistic hydraulic parameters in the representation of the surficial aquifer system.

The semiconfined aquifer of the Motz (1978) model is idealized as being underlain by impermeable material. Therefore, the portion of the Floridan aquifer system that lies below the Upper Floridan aquifer is not represented in the model (Figure 3).

Model Grid

The SJRWMD FORTRAN implementation of the Motz (1978) model uses the principle of superposition to enable calculation of cumulative drawdowns due to the effects of withdrawals from multiple wells. The program uses a grid of rows and columns to effect the spatial distribution of the cumulative drawdown throughout a region of interest. The numbers of rows and columns of the grid are specified by the user, as is the distance between adjacent rows and columns. The program determines the cumulative drawdown at the intersection of each of the rows and columns. The location of the grid on the surface of the earth is indicated by the

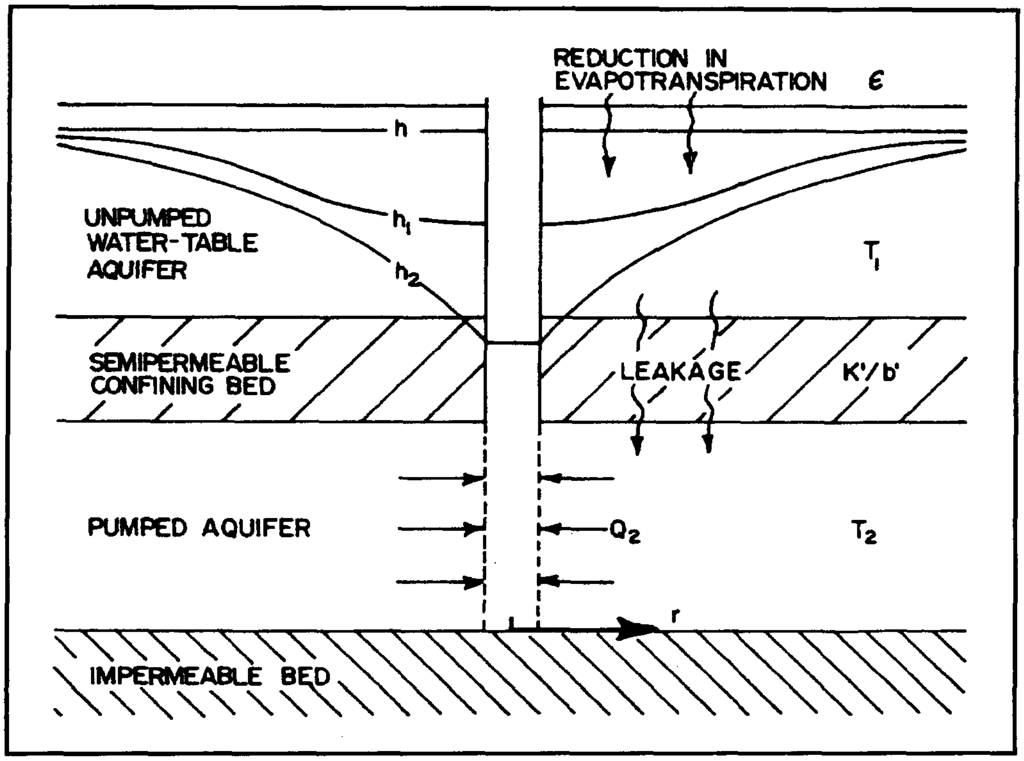

Figure 2. Generalized aquifer system of Motz (1978) model

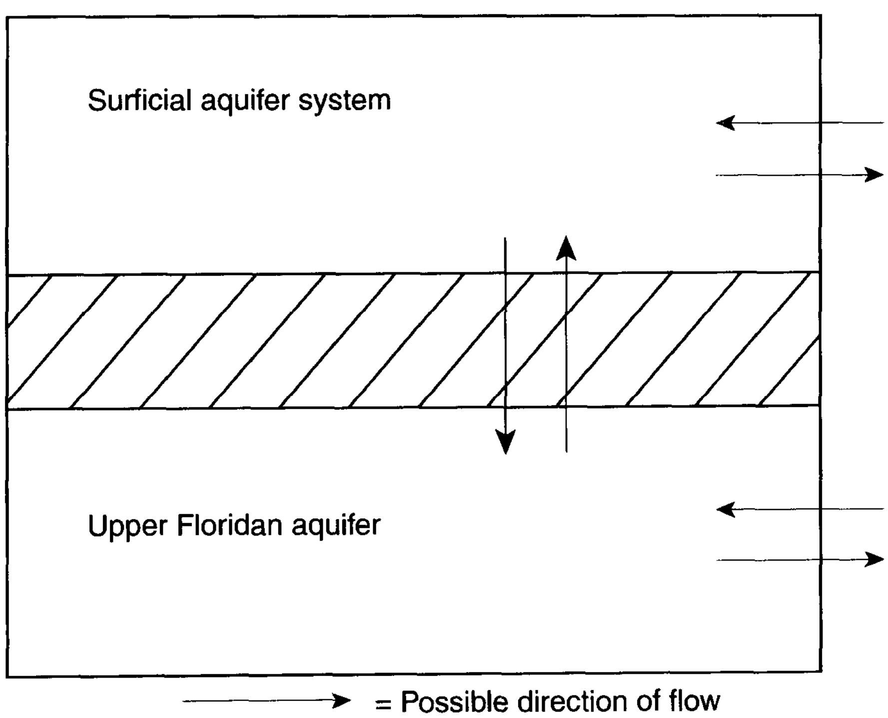

Figure 3. Generalized representation of the Floridan aquifer system in study

Table 1. Summary of groundwater systems within the study area

<table>
<tr><th>Geologic Epoch</th><th>Geologic Unit</th><th colspan="2">Hydrologic Unit</th><th>Description</th></tr>
<tr><td>Pleistocene and Recent</td><td>Pleistocene and Recent deposits</td><td colspan="2" rowspan="2">Surficial aquifer system</td><td rowspan="2">Consists of sand, clayey sand, shell, and thin limestone beds, and is divided into an upper, water table zone and a lower, shallow-rock zone, which are separated by a semiconfining unit. Thickness of the surficial aquifer system ranges approximately from 20 to 150 feet</td></tr>
<tr><td rowspan="2">Pliocene</td><td rowspan="2">Pliocene deposits</td></tr>
<tr><td colspan="2" rowspan="2">Upper confining unit, including the intermediate aquifer system</td><td rowspan="2">Upper confining unit consists of clay, marl, and discontinuous beds of sand, shell, dolomite, and limestone (aquifers of intermediate aquifer system). Confines intermediate aquifer system and underlying Floridan aquifer system. Thickness ranges approximately from 150 to 450 feet. Aquifers of intermediate aquifer system are up to 40 feet thick</td></tr>
<tr><td>Middle Miocene</td><td>Hawthorn Group</td></tr>
<tr><td>Late Eocene</td><td>Ocala Limestone</td><td rowspan="2">Upper Floridan aquifer</td><td rowspan="8">FLORIDAN AQUIFER SYSTEM</td><td rowspan="2">Consists primarily of limestone. Thickness ranges approximately from 300 to 700 feet</td></tr>
<tr><td rowspan="3">Middle Eocene</td><td rowspan="3">Avon Park Formation</td></tr>
<tr><td>Middle semi-confining unit</td><td>Consists primarily of limestone and dolomite. Thickness ranges approximately from 50 to 300 feet</td></tr>
<tr><td rowspan="2">Lower Floridan aquifer</td><td rowspan="2">Consists primarily of limestone and dolomite. Thickness ranges approximately from 400 to 1,000 feet</td></tr>
<tr><td rowspan="3">Early Eocene</td><td rowspan="3">Oldsmar Formation</td></tr>
<tr><td>Lower semi-confining unit</td><td>Consists primarily of limestone and dolomite. Thickness ranges approximately from 100 to 200 feet</td></tr>
<tr><td rowspan="2">Fernandina permeable zone</td><td rowspan="2">Consists primarily of limestone and dolomite. Thickness ranges approximately from 170 to 1,000 feet</td></tr>
<tr><td rowspan="2">Paleocene</td><td rowspan="2">Cedar Keys Formation</td></tr>
<tr><td colspan="2">Lower confining unit</td><td>Consists of low-permeability anhydrite beds. Thickness is unknown</td></tr>
</table>

Source: Bermes et al. 1963; Clark et al. 1964; Leve 1966; Fairchild 1972; Scott 1983; Miller 1986; Clarke et al. 1990 specification of the cartesian coordinates of its lower left corner. Well locations may be specified at any point within the grid according to the same cartesian coordinate system.

In this model, the grid consists of 145 rows by 145 columns. The distance between adjacent rows and columns of the grid is approximately 2,500 feet (ft), and the cartesian coordinate system is the Universal Transverse Mercator (UTM) coordinate system.

Well and Water Use Representation

Potato irrigation. The locations and average rate of withdrawal of wells used for potato irrigation were obtained from Singleton (pers. com. 1998). A total of 726 potato irrigation wells were included in the study (Figure 4 and Appendix A). The location information on these wells was obtained from global positioning system (GPS) surveys conducted by SJRWMD. Withdrawal rate information on individual wells was not available. Instead, an estimate of the amount of water extracted by a typical well on an average day for purposes of potato irrigation was applied uniformly to all potato irrigation wells included in the study. This estimate is 390,000 gallons per day (gpd) per well. It was based on information obtained from the SJRWMD Benchmark Farms Project (Singleton 1996, pers. com. 1998).

Although potato irrigation occurs primarily from March 1 to May 31, a typical farmer does not irrigate on every one of those 92 days. Based on information obtained from the Benchmark Farms Project, irrigation for potatoes is applied approximately 42 days on average (Singleton, pers. com. 1998). The estimate of 390,000 gpd per well is the amount of water withdrawn *on a typical day of irrigation*. Of greater interest is the average rate of withdrawal per well as averaged over the entire potato irrigation season. This *seasonal-average* rate of withdrawal was needed to compute the drawdown due to withdrawals for purposes of potato irrigation as averaged over the entire potato irrigation season.

To obtain the seasonal-average rate of withdrawal per well, the estimate of 390,000 gpd per well was multiplied by 42 days. The result, 16.38 million gallons, is the total volume of groundwater withdrawn by a typical well in a typical growing season. This amount was then divided by 92 days, the length of the growing season. The result is the seasonal-average rate of withdrawal per well, which is approximately 178,043 gpd. Thus, the amount of 178,043 gpd was used to represent the withdrawal rate of each of the potato irrigation wells represented in the model. The total seasonal-average rate of withdrawal from all potato irrigation wells represented in the model is approximately 129 million gallons per day (mgd).

Information concerning the depths of potato irrigation wells was not available. However, most agricultural wells in the study area do not penetrate the Lower Floridan aquifer due to the high mineral content of the water contained therein. Therefore, in absence of better information, all potato irrigation wells were assumed to tap the Upper Floridan aquifer only.

Paper production. Paper production within the study area occurs at the Georgia-Pacific Corporation paper mill in Palatka (Figures 1 and 4). Monthly well-by-well estimates of groundwater withdrawals from the Floridan aquifer system for use at the Georgia-Pacific Corporation paper mill in the years 1996 and 1997 were available at the time of the study. These estimates were

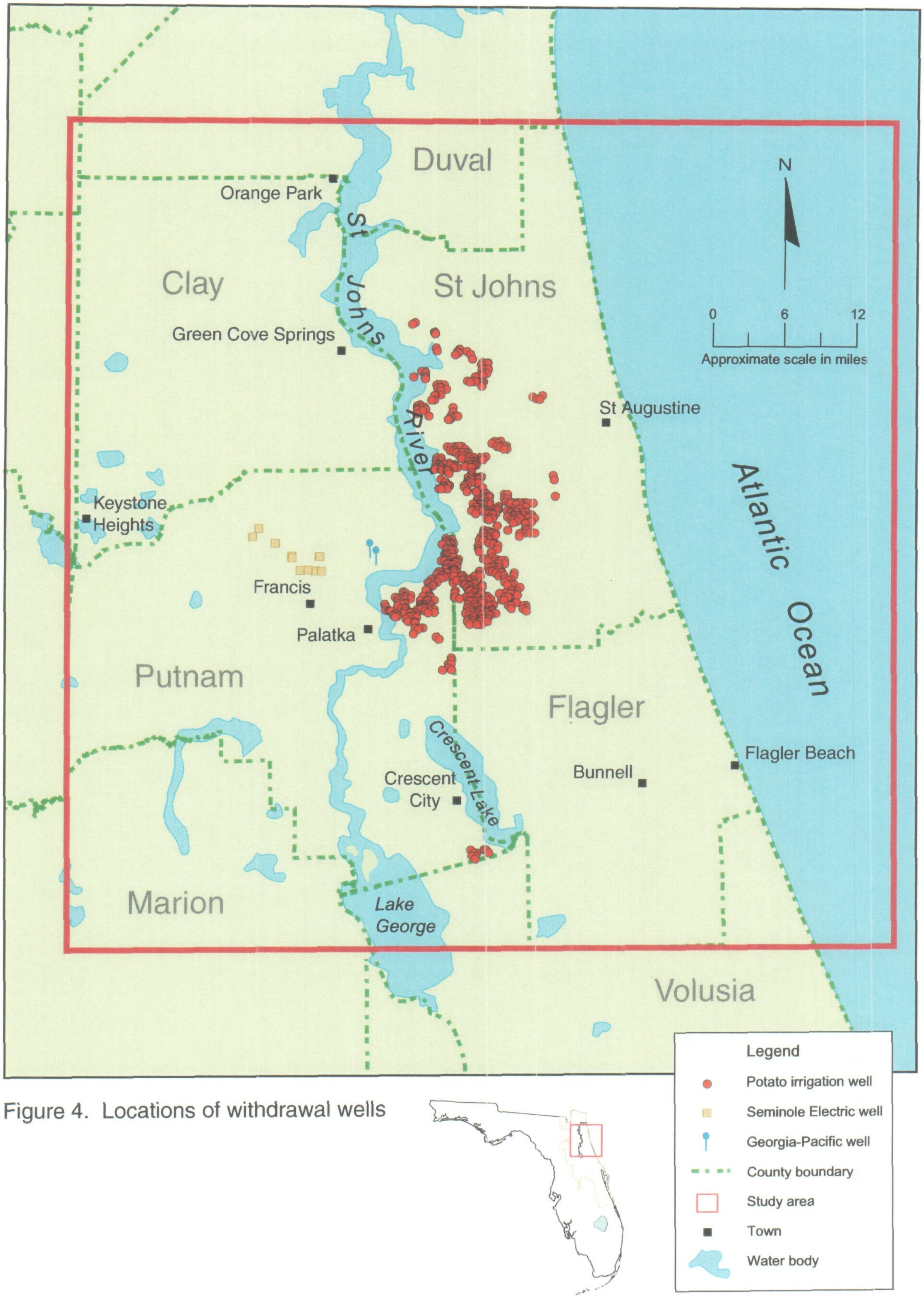

Figure 4. Locations of withdrawal wells

based on data submitted to SJRWMD by Georgia-Pacific Corporation as a condition of the Georgia-Pacific Corporation consumptive use permit (CUP). Of the two sets of data, the 1997 data set resulted in a larger seasonal-average rate of withdrawal (7.3 mgd versus 22.1 mgd). To help ensure conservative drawdown estimates, the larger of the two withdrawal rate estimates was used in the study (Table 1).

Based on hydrogeologic information in Miller (1986), several wells operated by Georgia-Pacific Corporation were determined to penetrate the Lower Floridan aquifer (Table 2). These dual-aquifer wells are open to and, consequently, obtain water from both the Upper and Lower Floridan aquifers. The model, however, does not represent the portion of the Floridan aquifer system beneath the Upper Floridan aquifer. Accordingly, in these cases, only the estimated portion of the withdrawal obtained from the Upper Floridan aquifer was included in the model.

Table 2. Information on Georgia-Pacific Corporation wells in the model

Well Name	Casing Diameter (inches)	Casing Depth (feet)	Total Depth (feet)	Land-Surface Elevation (feet NGVD)	Seasonal-Average Withdrawal Rate in 1996 (gpd)	Seasonal-Average Withdrawal Rate in 1997 (gpd)	Latitude	Longitude
G	12	179	600	11	123,391.30	239,391.30	294256	814257
H	12	178	600	20	0.00	0.00	294359	814242
I	12	174	700	12	0.00	0.00	294359	814237
J	12	198	1,000	25	315.22	1,888,771.74	294401	814456
K	20	206	580	25	0.00	0.00	294352	814455
L	20	178	895	15	655,967.39	2,478,402.17	294300	814414
M	20	183	1,203	16	224,728.26	0.00	294301	814335
N	20	177	975	5	0.00	0.00	294255	814228
O	20	163	1,000	68	3,766,086.96	3,982,065.22	294455	814617
P	20	144	1,404	90	2,563,858.70	6,818,500.00	294559	814740
Q	20	171	1,000	78	0.00	6,649,782.61	294523	814809

Note: gpd = gallons per day
NGVD = National Geodetic Vertical Datum

The actual breakdown in withdrawal rates for wells which penetrate both the Upper and Lower Floridan aquifers is unknown. In the present study, the respective withdrawal rates were assumed to be proportional to the respective amounts of open hole of such wells in the Upper and Lower Floridan aquifers. Therefore, the total rate of withdrawal by Georgia-Pacific Corporation as represented in the model was reduced from approximately 22.1 mgd to approximately 13.1 mgd. Thus, 13.1 mgd is the estimated seasonal-average rate of withdrawal from the Upper Floridan aquifer of the Georgia-Pacific Corporation wells as represented in the model (Figure 4 and Table 2). The locations of the Georgia-Pacific Corporation wells were obtained from the SJRWMD CUP database in the form of latitude/longitude coordinates.

Electricity production. Seminole Electric Cooperative is a major electricity producer in the study area; its power plant is located in Putnam County near Palatka (Figures 1 and 4). Seminole Electric Cooperative uses two wells, a north well and a south well, to withdraw water from the Floridan aquifer system for steam generation (Figure 4 and Table 3). The locations of the wells were determined from a GPS survey (Shiver, pers. com. 1998). In 1997, the total volume of water withdrawn from the north well was 133,131,090 gallons, and the total volume of water withdrawn from the south well was 42,248,000 gallons (Shiver, pers. com. 1998). Dividing these estimates by 365 days yields estimates of average-day rates of withdrawal from these two wells. The estimate for the north well is 364,743 gpd, and the estimate for the south well is 115,748 gpd. These estimates were used as approximations of the seasonal-average daily rates of withdrawal from the two wells at Seminole Electric Cooperative.

Table 3. Information on Seminole Electric Cooperative wells in the model

Well Name	Latitude	Longitude	Average 1997 Withdrawal Rate
North	294434	813828	364,742.72
South	294405	813801	115,747.95

Source: T. Eller, SJRWMD, pers. com. 1998

Model Hydraulic Parameters

Upper Floridan aquifer. The transmissivity estimate used to represent the permeability of the Upper Floridan aquifer in the model is 60,000 square feet per day (ft^2/d). This estimate is based on an average value of hydraulic conductivity (130 ft/d) as determined by Bentley (1977) and the approximate thickness of the Upper Floridan aquifer near Palatka (450 ft) as interpolated from maps in Miller (1986). The report by Bentley is a summary and analysis of the results of a number of aquifer performance tests conducted on the Floridan aquifer system within and near the present study area.

Intermediate semiconfining unit. Initially, the estimate of the leakance of the intermediate semiconfining unit was based on an estimate of the vertical hydraulic conductivity of the intermediate semiconfining unit (1×10^{-3} ft/d) (Brown 1984) and an estimate of its thickness near Palatka (125 ft) (Miller 1986). Rounded to the nearest order of magnitude, the resulting leakance estimate was 1×10^{-5} per day.

The value of 1×10^{-5} per day, in combination with the stated transmissivity estimate and other parameters necessary to represent the surficial aquifer system, resulted in a maximum simulated drawdown due to withdrawals for potato irrigation of approximately 90 ft. Hydrographs of water levels at four observation wells in the area indicate that declines in water levels, as averaged over the 92 days, ranged from approximately 6 to 19 ft in 1994 and 1995 (Appendix B). Maximum drawdowns at the same four wells ranged from approximately 9 to 40 ft in 1994 and 1995 (Appendix B, Figure B4).

Trial and error was introduced as a means of improving the leakance estimate. In this process, the leakance was varied, while all other model hydraulic parameters (which had been predetermined) were constant. The leakance was thus increased to a value of 1×10^{-4} per day, which, in combination with the stated transmissivity estimate and other parameters necessary to represent the surficial aquifer system, resulted in a maximum drawdown of approximately 27 ft. This result seemed reasonable in light of available information (Appendix B), so the leakance of the intermediate semiconfining unit was estimated to be 1×10^{-4} per day.

Bentley (1977) stated that the leakance estimates resulting from his study might be too high. Therefore, Bentley (1977) was not used to estimate the leakance of the intermediate semiconfining unit. However, the leakance estimate of this study is only slightly lower than the low end of the leakance range stated in Bentley (1977), which was 2×10^{-4} per day.

Surficial aquifer system. The transmissivity of the surficial aquifer system was estimated to be 1,000 ft^2/day. This estimate is considered to be a generalized, average value. It is based on permeability and transmissivity estimates cited in previous groundwater publications (e.g., Brown 1984, Causey and Phelps 1978, and Franks 1980).

The estimate of the ET reduction coefficient used in the study (2.66×10^{-4} per day) was based on information in Tibbals (1990). Estimates of the ET reduction coefficient are not widely available. Therefore, it too must be considered a generalized, average value.

SIMULATION RESULTS

Drawdowns Due to Potato Irrigation

The simulated drawdowns in the potentiometric surface of the Upper Floridan aquifer due to potato irrigation range up to approximately 27 ft. The affected area includes most of St. Johns County, northeast Putnam County, southeast Clay County, and northwest Flagler County (Figure 5). The greatest drawdowns are in areas where wells used to withdraw water from the Upper Floridan aquifer for potato irrigation are most densely clustered. These areas are southwest St. Johns and east Putnam counties (Figures 4 and 5), where drawdowns range from approximately 4 to 27 ft (Figure 5).

Drawdowns Due to Paper Production

The simulated drawdowns in the potentiometric surface of the Upper Floridan aquifer due to withdrawals made by Georgia-Pacific Corporation range up to approximately 9 ft. The affected area includes northern Putnam and southern Clay counties (Figure 6).

Drawdowns Due to Electricity Production

The simulated drawdowns in the potentiometric surface of the Upper Floridan aquifer due to withdrawals made by Seminole Electric Cooperative range up to approximately 0.5 ft. The affected area includes northeast Putnam County only (Figure 7).

POTENTIAL DISCREPANCIES BETWEEN THE MODEL AND THE FLORIDAN AND SURFICIAL AQUIFER SYSTEMS

The Motz model was applied to provide an approximation of the relative, average effects of the withdrawals made by the three major water users in the area. While the Motz (1978) model is adequate to meet this objective, it is not perfectly applicable. An analytical groundwater flow model is actually a solution of the groundwater flow equation. Due to the mathematical complexity of the equation, analytical solutions of it are possible only for relatively simplistic, idealized aquifer systems. These are rarely, if ever, matched perfectly by actual aquifer systems. Thus, the objective in applying an analytical solution is not to match an actual aquifer system perfectly but, rather, to match it adequately.

In the present application of the Motz (1978) model, four discrepancies are apparent:

1. The assumption of steady state
2. The assumption of hydraulic-parameter homogeneity

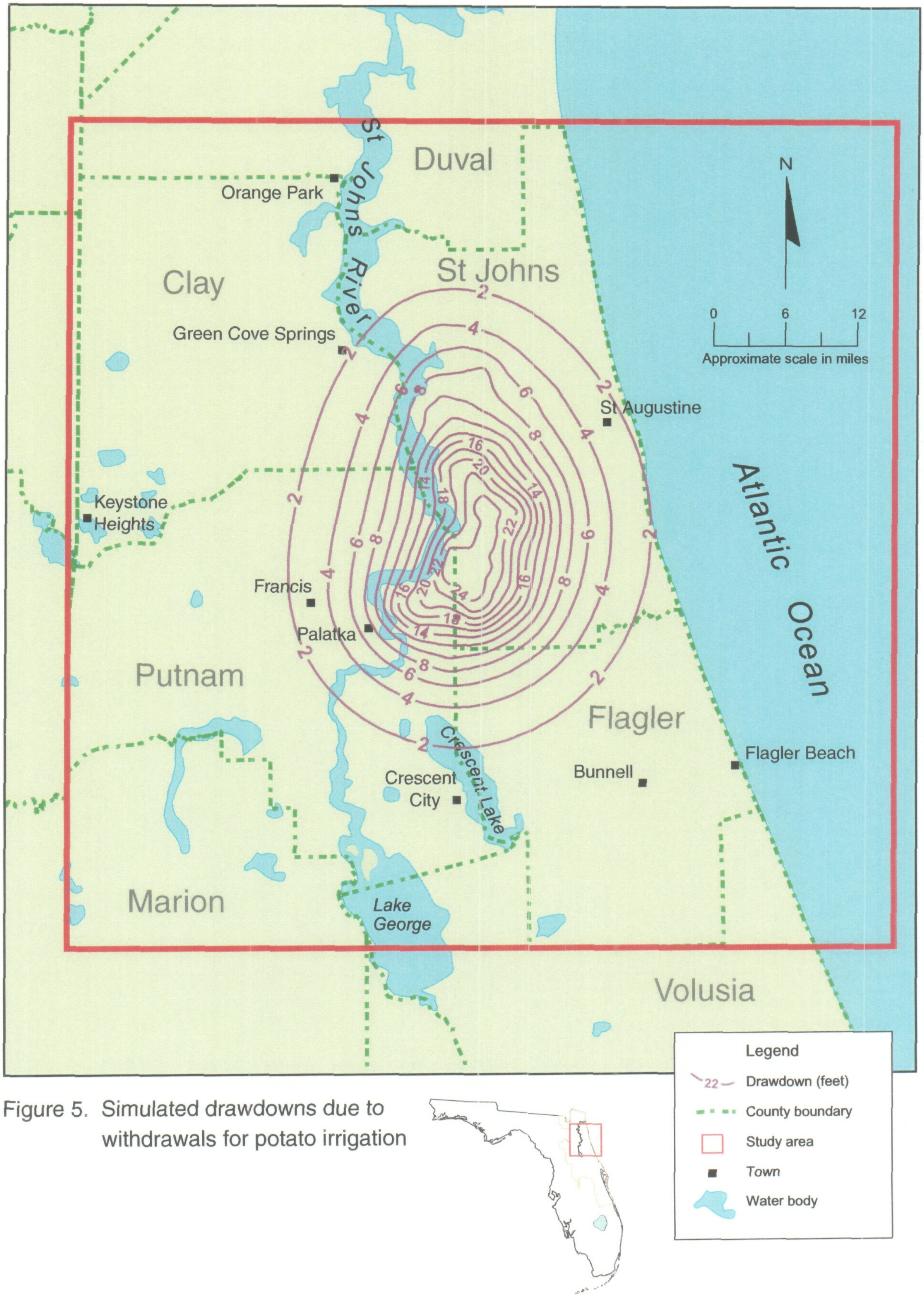

Figure 5. Simulated drawdowns due to withdrawals for potato irrigation

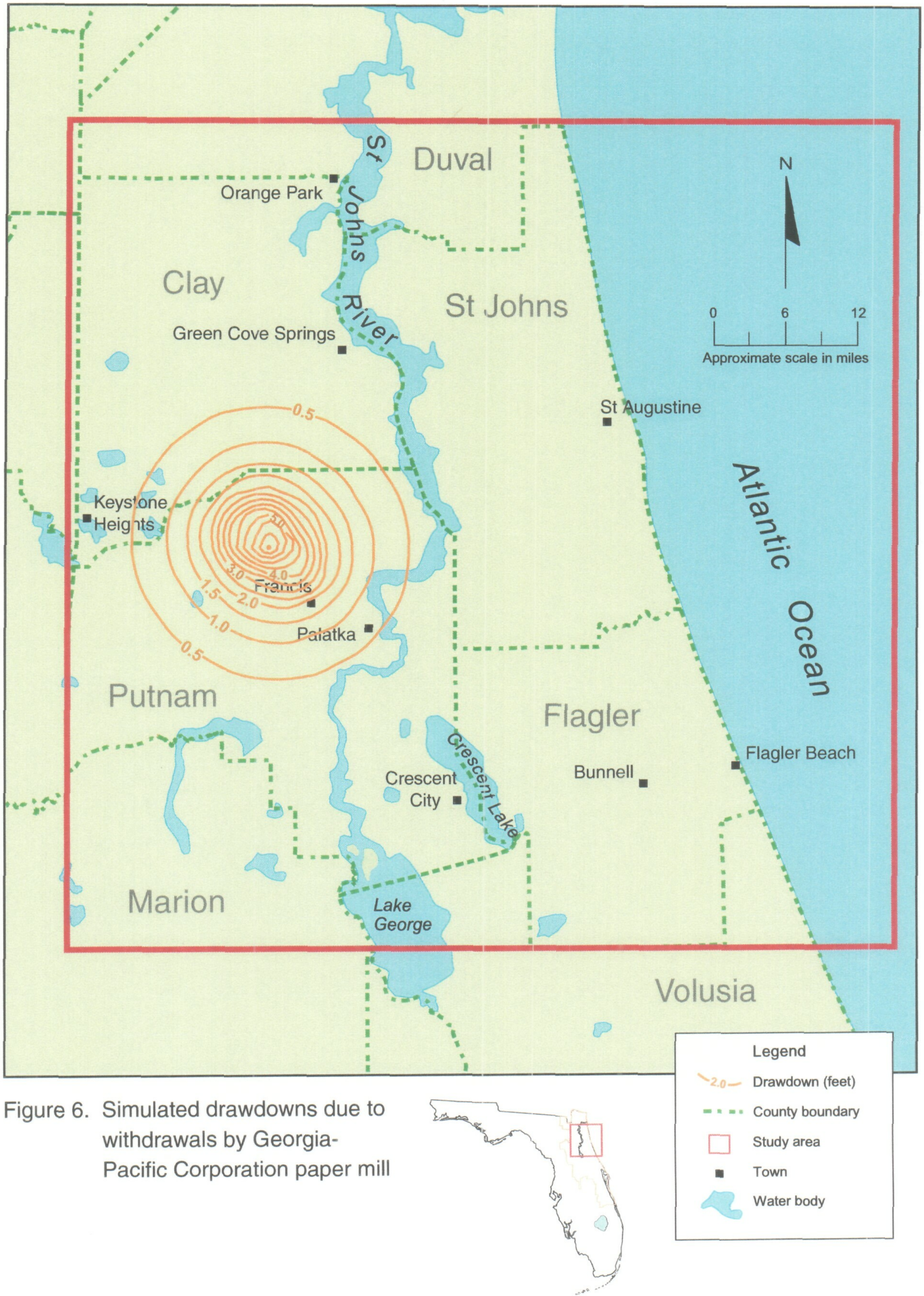

Figure 6. Simulated drawdowns due to withdrawals by Georgia-Pacific Corporation paper mill

Figure 7. Simulated drawdowns due to withdrawals by Seminole Electric Cooperative

3. The representation of the middle semiconfining unit as completely impermeable
4. The assumption of nontransient rates of well withdrawals

A discussion of each of these discrepancies follows and a justification is offered for allowing the discrepancy in this analysis.

Assumption of Steady State

In the present application of the Motz (1978) model, both the Upper Floridan aquifer and the surficial aquifer system are assumed to be in steady state. Potatoes are irrigated in the study area primarily from March through May for 92 days (Singleton, pers. com. 1998). If 92 days were insufficient for the re-attainment of steady state in the Floridan aquifer system in the study area, then the simulated drawdowns due to withdrawals for potato irrigation determined using the Motz model would not have time to be realized fully. Therefore, application of the Motz model would result in overestimation of the drawdowns in such a case.

Transient MODFLOW model. A MODFLOW model was used to determine the amount of time needed for the Upper Floridan aquifer to re-attain steady state. This model is a numerical, transient version of the Motz (1978) model and consists of three model layers. The uppermost model layer does not represent an actual aquifer but is used to effect the reduction in the rate of ET that occurs as the water table of the surficial aquifer system is drawn down.

- All head values in the uppermost layer are designated as constant, and the specified value of these heads is 0 ft.
- The middle model layer represents the surficial aquifer system, although it is designated as confined. This is allowable as long as the simulated drawdown in the surficial aquifer system is small relative to its saturated thickness.
- The lowermost model layer represents the Upper Floridan aquifer.

The VCONT value assigned to the uppermost model layer is the ET reduction coefficient of the surficial aquifer system. As water levels decline in a given grid cell of the middle model layer, flow into that grid cell from the one above it in the uppermost model layer increases in the form of vertical leakage. This additional inflow, which represents the reduction in the rate of ET in the grid cell of the middle model layer, is linearly proportional to the decline in head in the middle model layer. The coefficient of proportionality in this relationship is the product of the specified ET coefficient and the grid-cell area. This handling of ET reduction is hydraulically equivalent to that of the Motz (1978) model.

The aquifer system represented by the MODFLOW model is assumed to be homogeneous and isotropic, also consistent with the analytical model. The permeabilities of the surficial aquifer system and the Upper Floridan aquifer are each represented with separate, uniform values of transmissivity (1,000 and 60,000 ft^2/d, respectively). The storage properties of the surficial aquifer system and the Upper Floridan aquifer are each represented with a uniform value of specific yield and storativity, respectively (0.2 and 0.0008, respectively). The leakance of the intermediate semiconfining unit (1.0×10^{-4} per day) is represented with a uniform VCONT value assigned to the middle model layer. The storage properties of the intermediate semiconfining unit are neglected. This specific-yield estimate is based on Franks (1980) and Brown (1984), and this storativity estimate is based on Bentley (1977).

The lateral boundaries of the model consist of general-head boundary (GHB) conditions, the MODFLOW implementation of the head-dependent flux boundary. GHB conditions are prescribed for every grid cell within an outermost row or column of the model grid in the middle and lowermost model layers. The source heads of the GHB conditions are specified as 0 ft, in accordance with the assumption of no change in hydraulic head at points at which source heads are specified. The following formula was used to determine conductances of the GHB conditions:

$$C = \frac{TW}{L} \tag{1}$$

where

C = conductance
T = transmissivity
W = the width of the cross-sectional area normal to the direction of flow
L = the length of the flow path

This transmissivity is that assigned to the grid cell to which the GHB condition is prescribed. The width of the cross-sectional area is the width of the grid cell to which the GHB condition is prescribed. The length of the flow path is the distance between the point at which the GHB-condition source head is specified and the center of the grid cell to which the GHB condition is prescribed.

The model grid consists of 101 rows by 101 columns. The widths of the rows and columns are specified uniformly as 5,000 ft. A single production well is prescribed to the lowermost model layer at row 51, column 51. The specified rate of withdrawal of the well is 5 mgd.

MODFLOW model results. Because the specific yield of the surficial aquifer system is typically much greater than the storativity of the Upper Floridan aquifer, the re-attainment of steady state in the surficial aquifer system can require a long time. In a previous evaluation of a District-required permit activity conducted by the author, transient simulations of the surficial aquifer system in the area of Green Cove Springs (see Figure 1) indicated that the time required for re-attainment of steady state in the surficial aquifer system is years rather than days. The application of the Motz (1978) model in the present analysis, however, implies that steady state in both the Upper Floridan aquifer and the surficial aquifer system is re-attainable within 92 days.

The results of the MODFLOW simulation show that if the leakance of the intermediate semiconfining unit is relatively high, the long time required to re-attain steady state in the surficial aquifer system can translate into a long time to re-attain steady state in the Upper Floridan aquifer also (Figures 8 and 9). In the early stages of the MODFLOW simulation (i.e., within the first 99 days), the Upper Floridan aquifer appears to be approaching its steady-state drawdown, because its drawdown-versus-time curve appears to be leveling off (Figure 8). The surficial aquifer system, however, is clearly not approaching its steady-state drawdown, because its drawdown-versus-time curve is obviously still rising at what appears to be a constant rate (Figure 8). When viewed over a much longer time, the Upper Floridan aquifer is seen to have attained only approximately 85% of its steady-state drawdown within the first 99 days (Figure 9). Approximately 8.5 more years are required for the Upper Floridan aquifer to attain the remaining 15% and, in fact, both the Upper Floridan aquifer and the surficial aquifer system re-attain

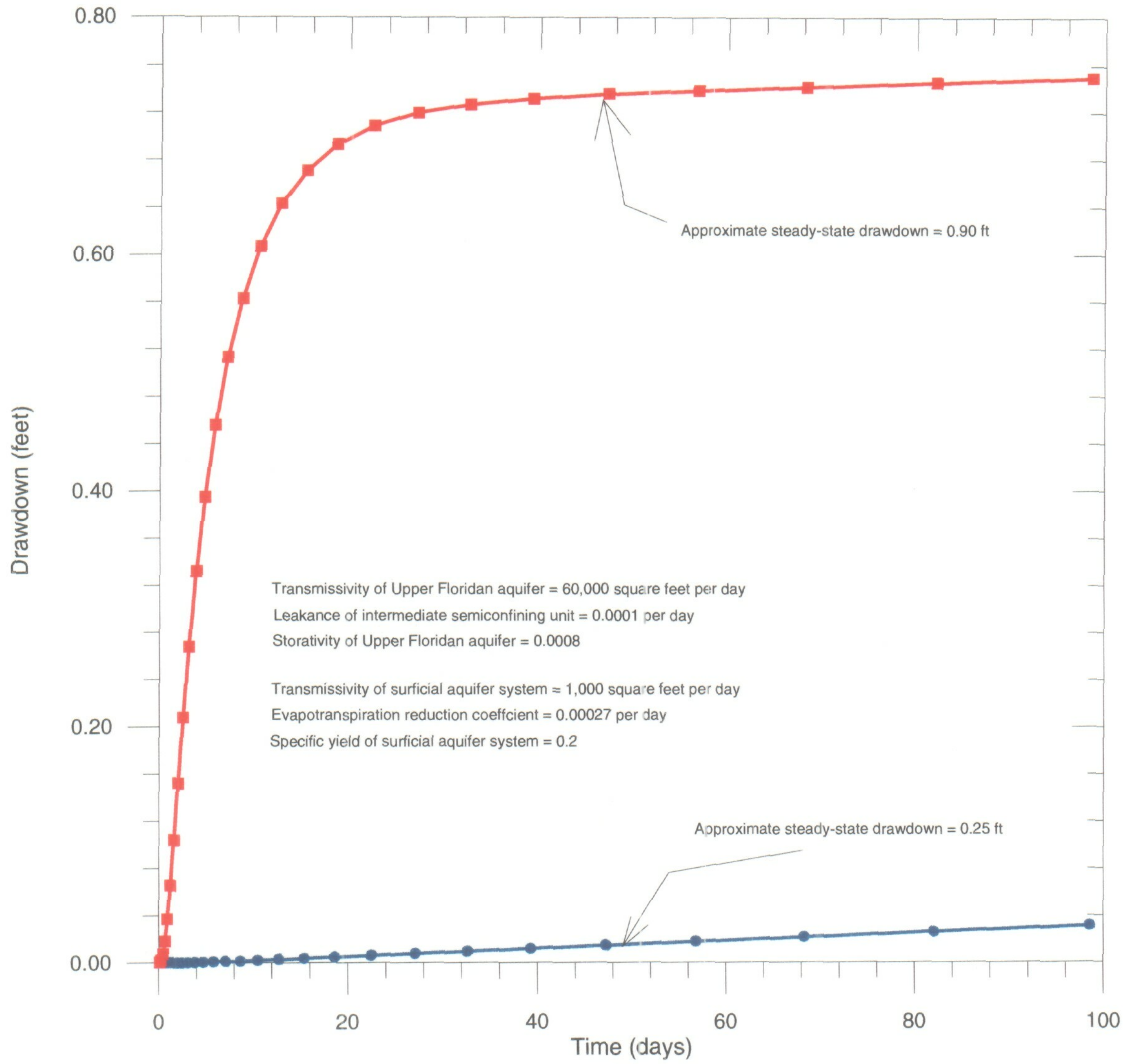

Figure 8. Drawdown in the Upper Floridan aquifer (red) and the surficial aquifer system (blue) as a function of time at 25,000 feet from well during 100 days

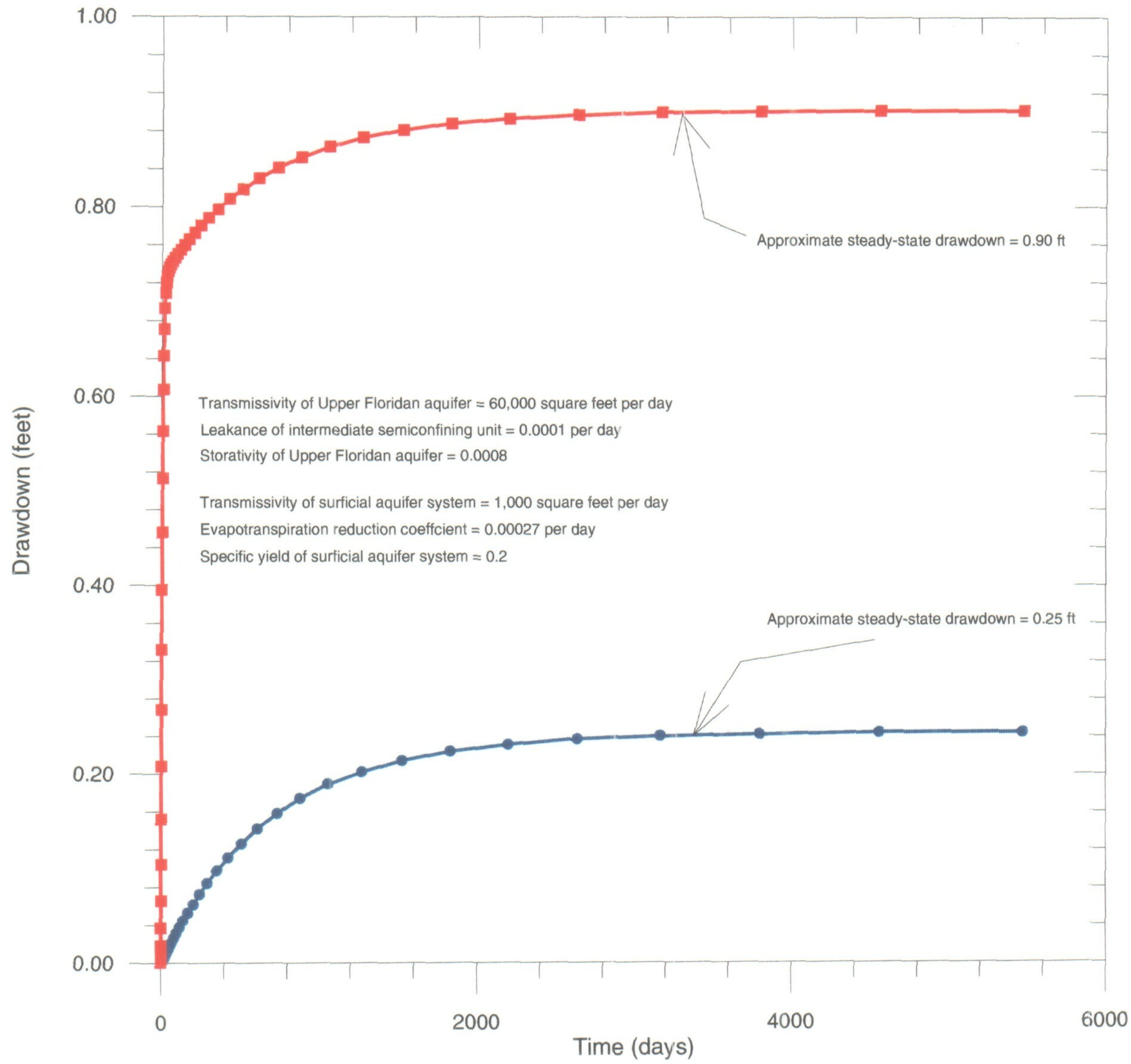

Figure 9. Drawdown in the Upper Floridan aquifer (red) and the surficial aquifer system (blue) as a function of time at 25,000 feet from well during 6,000 days

steady state at the same time (Figure 9). The additional time required to re-attain steady state in the Upper Floridan aquifer is due to the high leakance of the intermediate semiconfining unit. The high leakance allows for a high degree of interaction between the surficial aquifer system and the Upper Floridan aquifer. As a result, the Upper Floridan aquifer is unable to re-attain steady state until the surficial aquifer system does, because changes in water levels in the surficial aquifer system result in corresponding changes in water levels in the Upper Floridan aquifer.

While potato irrigation is confined for the most part to the 92-day period of March to May (Singleton, pers. com. 1998), the withdrawals made by Georgia-Pacific Corporation and Seminole Electric Cooperative are spread more evenly over the year. Thus, water levels in the surficial aquifer system near the Georgia-Pacific Corporation and Seminole Electric Cooperative wells approximate long-term steady state better than the water levels of the surficial aquifer system in the potato-growing region. As a result, simulated drawdowns due to withdrawals for potato irrigation may be overestimated relative to those due to Georgia-Pacific Corporation and Seminole Electric Cooperative. The MODFLOW application indicates that this overestimation is probably only about 15%, which will not change the conclusions of the study.

Assumption of Hydraulic-Parameter Homogeneity

Like other analytical models, the Motz (1978) model represents the aquifer system as homogeneous and isotropic. In reality, the hydraulic parameters of the Floridan aquifer system vary spatially throughout the study area, as indicated by aquifer testing (Bentley 1977). To deal with the inability of the Motz model to represent the spatial variation in hydraulic parameters, this study estimated average, regionally representative values of the various hydraulic parameters. The assigned parameters, at least with respect to the Upper Floridan aquifer, are probably most representative of conditions in northeast Putnam and southwest St. Johns counties.

Assumption of Impermeability of the Middle Semiconfining Unit

The use of the Motz (1978) model implies that the middle semiconfining unit is impermeable within the study area (Table 1). While this is probably not the case in most of the study area, the leakance of the middle semiconfining unit could be low enough to approximate impermeability over large areas. Little is known regarding the hydraulic properties of the middle semiconfining unit.

Assumption of Nontransient Rates of Well Withdrawals

The rates of withdrawal of the three major water users in the area were represented as constant over time. In reality, of course, the rates vary. The withdrawal rates used in this study represent likely average rates of withdrawal from March through May of any given year. These average rates of withdrawal were used to determine average drawdowns over the 92-day potato irrigation period.

While represented rates of withdrawal cannot be varied temporally in the Motz (1978) model, the calculated drawdowns can be extrapolated easily to other rates of withdrawal. A linear relationship exists between the rate of withdrawal from a well in a semiconfined aquifer such as the Upper Floridan aquifer and the resulting drawdown in the potentiometric surface at any given point in the aquifer (Bear 1979). Thus, for example, if the withdrawal rate assigned to each of the Georgia-Pacific Corporation wells represented in the study were doubled, then the simulated drawdown at any given location in the model domain due to these withdrawals would be doubled also.

The simulated drawdown due to withdrawals from the Upper Floridan aquifer made by Georgia-Pacific Corporation is approximately 0.5 ft along the east bank of the St. Johns River near Palatka (Figure 6). Doubling the Georgia-Pacific Corporation withdrawal rate as represented in the model application would increase the estimated drawdown at this location to about 1 ft.

CONCLUSIONS AND RECOMMENDATIONS

This study indicates that drawdowns in the potentiometric surface of the Upper Floridan aquifer due to withdrawals for potato irrigation are the greatest component of the annual overall drawdown from March through May. The drawdowns due to the withdrawals made by Georgia-Pacific Corporation are significant but are considerably smaller. The drawdowns due to withdrawals made by Seminole Electric Cooperative are insignificant as compared to the drawdowns attributable to the other two subjects of the study.

This study is intended to provide a first-order approximation of the relative effects of the withdrawals made by the three major water users in the area. Application of the U.S. Geological Survey MODFLOW code (McDonald and Harbaugh 1988; Harbaugh and McDonald 1996) would result in a more rigorous evaluation. Specifically, a MODFLOW model of the study area could possess the following qualities, which are necessary to address aspects of the problem that cannot be addressed using analytical models such as the Motz (1978) model:

1. The ability to represent the variation of drawdowns with time in both the Upper Floridan aquifer and the surficial aquifer system
2. The ability to represent the Lower Floridan aquifer
3. The ability to represent the spatial variation in the hydraulic parameters of the Floridan and surficial aquifer systems to the extent that such variations are known

The possession of these qualities is beyond the scope of the Motz (1978) model. Such a model could be developed fairly quickly in the guise of a regional drawdown model if calibration requirements were eased. However, a full-scale calibration of a groundwater flow model would be useful, along with aquifer testing, for improving the knowledge of the spatial variation in the hydraulic parameters of the Floridan and surficial aquifer systems.

Additional data are needed to improve the results of whatever type of model is used to evaluate the study area. These data include the following:

1. Areawide, reliable information concerning the hydraulic parameters of the Lower Floridan aquifer, the middle semiconfining unit, and the other hydrogeologic units represented in the model applications of the study
2. Flow-log information on dual-aquifer wells to delineate more accurately the percentage of groundwater derived from the Upper versus the Lower Floridan aquifer in such wells

3. Information to delineate the top and bottom elevations of the hydrogeologic units that comprise the Floridan and surficial aquifer systems (Table 1). Fewer data were available to Miller (1986) on the study area than on other areas, particularly on the Lower Floridan aquifer, so an update of the Miller study for this area, with emphasis on the Lower Floridan aquifer, would be beneficial

Finally, notwithstanding the aforementioned discrepancies between the model application and the actual Floridan and surficial aquifer systems, the results of this study align with common sense. The simulated drawdowns due to withdrawals for potato irrigation are greater than the drawdowns due to withdrawals by Georgia-Pacific Corporation because the magnitudes of the withdrawals for potato irrigation are approximately 10 times greater on average. This factor is overwhelming even in the face of the stated discrepancies.

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Appendix A. Location of the 726 potato irrigation wells in the study

Well Coordinates		Estimated Well Withdrawal Rate (gpd)
UTM *x*	UTM *y*	
448,186.38	3,291,846.75	178043.58
449,007.72	3,291,718.00	178,043.58
448,422.75	3,291,578.00	178,043.58
448,422.75	3,291,578.00	178,043.58
448,281.41	3,291,423.50	178,043.58
448,767.59	3,291,361.00	178,043.58
448,134.84	3,291,252.00	178,043.58
449,171.00	3,291,217.25	178,043.58
448,864.28	3,291,180.50	178,043.58
448,784.12	3,291,084.25	178,043.58
448,451.00	3,291,065.25	178,043.58
447,709.25	3,291,026.00	178,043.58
448,556.41	3,290,731.00	178,043.58
448,295.03	3,290,547.25	178,043.58
449,025.50	3,290,488.00	178,043.58
448,919.97	3,290,478.50	178,043.58
448,654.06	3,290,421.50	178,043.58
449,230.22	3,290,315.75	178,043.58
448,224.47	3,290,284.50	178,043.58
448,879.25	3,290,266.75	178,043.58
448,300.50	3,289,892.00	178,043.58
448,870.81	3,289,825.00	178,043.58
447,989.44	3,289,712.25	178,043.58
448,202.38	3,289,674.00	178,043.58
448,403.03	3,289,604.00	178,043.58
448,429.59	3,289,330.00	178,043.58
449,178.38	3,2,89,323.25	178,043.58
448,274.41	3,289,090.50	178,043.58
448,351.59	3,288,926.50	178,043.58
448,619.12	3,288,877.00	178,043.58
447,551.97	3,288,858.75	178,043.58
447,952.78	3,288,842.00	178,043.58
449,052.44	3,288,625.25	178,043.58
448,519.59	3,288,614.00	178,043.58
448,524.66	3,288,428.00	178,043.58
448,232.00	3,288,425.25	178,043.58
448,843.91	3,288,407.50	178,043.58
448,447.75	3,288,378.75	178,043.58
449,059.94	3,288,070.25	178,043.58
448,652.94	3,288,034.00	178,043.58
448,652.09	3,287,815.00	178,043.58
448,077.75	3,287,681.50	178,043.58
448,868.72	3,287,550.75	178,043.58
447,510.78	3,287,417.50	178,043.58

Well Coordinates		Estimated Well Withdrawal Rate (gpd)
UTM *x*	UTM *y*	
447,195.44	3,287,413.75	178,043.58
447,374.19	3,287,374.50	178,043.58
448,847.09	3,287,372.00	178,043.58
448,843.25	3,287,234.00	178,043.58
448,321.38	3,287,225.00	178,043.58
447,534.09	3,287,096.50	178,043.58
447,538.47	3,287,095.25	178,043.58
446,966.38	3,287,073.50	178,043.58
447,919.91	3,286,922.50	178,043.58
447,621.84	3,286,888.00	178,043.58
448,843.16	3,286,755.00	178,043.58
447,942.03	3,286,661.25	178,043.58
447,191.56	3,286,591.25	178,043.58
447,237.44	3,286,586.25	178,043.58
447,495.25	3,286,519.25	178,043.58
446,295.97	3,286,435.00	178,043.58
446,330.38	3,286,142.25	178,043.58
445,798.69	3,286,003.00	178,043.58
449,154.22	3,285,976.50	178,043.58
446,998.78	3,285,975.75	178,043.58
449,196.28	3,285,931.75	178,043.58
446,038.53	3,285,893.75	178,043.58
446,510.53	3,285,745.25	178,043.58
446,373.66	3,285,563.00	178,043.58
445,949.31	3,285,284.00	178,043.58
445,710.56	3,285,109.25	178,043.58
445,545.09	3,285,000.75	178,043.58
442,477.59	3,284,765.00	178,043.58
442,733.12	3,284,596.25	178,043.58
442,460.78	3,284,408.75	178,043.58
445,997.56	3,284,330.00	178,043.58
443,491.16	3,284,242.50	178,043.58
442,823.53	3,284,183.25	178,043.58
445,122.94	3,284,173.50	178,043.58
446,007.72	3,284,133.50	178,043.58
442,594.53	3,284,116.50	178,043.58
441,458.31	3,283,988.75	178,043.58
442,691.91	3,283,983.25	178,043.58
446,206.22	3,283,977.25	178,043.58
441,801.41	3,283,859.25	178,043.58
442,292.66	3,283,811.00	178,043.58
443,444.62	3,283,797.00	178,043.58
442,617.72	3,283,721.50	178,043.58
446,010.12	3,283,629.00	178,043.58
444,781.97	3,283,605.50	178,043.58
446,627.28	3,283,602.00	178,043.58

Appendix A—*Continued*

Well Coordinates		Estimated Well Withdrawal Rate (gpd)
UTM *x*	UTM *y*	
445,593.16	3,283,575.50	178,043.58
445,782.06	3,283,563.00	178,043.58
441,766.84	3,283,451.75	178,043.58
442,675.81	3,283,324.00	178,043.58
442,273.72	3,283,296.00	178,043.58
446,065.28	3,283,177.00	178,043.58
445,787.06	3,283,162.00	178,043.58
441,878.78	3,283,128.00	178,043.58
442,720.12	3,283,127.25	178,043.58
442,352.41	3,283,075.00	178,043.58
444,824.25	3,283,055.75	178,043.58
445,220.62	3,283,055.50	178,043.58
440,052.22	3,283,049.75	178,043.58
445,244.62	3,283,023.75	178,043.58
444,790.22	3,282,961.50	178,043.58
446,022.66	3,282,877.75	178,043.58
441,793.88	3,282,840.00	178,043.58
445,706.56	3,282,774.00	178,043.58
445,226.62	3,282,763.75	178,043.58
444,996.03	3,282,757.75	178,043.58
444,800.12	3,282,725.25	178,043.58
440,190.41	3,282,671.25	178,043.58
444,823.81	3,282,622.50	178,043.58
442,816.91	3,282,602.75	178,043.58
445,949.62	3,282,557.00	178,043.58
442,360.75	3,282,550.25	178,043.58
445,218.94	3,282,547.00	178,043.58
442,716.03	3,282,490.50	178,043.58
446,626.06	3,282,370.50	178,043.58
444,390.81	3,282,364.50	178,043.58
444,804.69	3,282,337.25	178,043.58
440,130.22	3,282,246.25	178,043.58
446,050.66	3,282,230.75	178,043.58
440,586.94	3,282,227.75	178,043.58
442,771.31	3,282,210.25	178,043.58
440,568.09	3,282,157.25	178,043.58
440,741.38	3,282,154.25	178,043.58
445,423.16	3,282,151.50	178,043.58
440,924.16	3,282,150.50	178,043.58
443,606.22	3,282,027.75	178,043.58
446,635.38	3,282,013.25	178,043.58
445,773.59	3,281,967.75	178,043.58
444,182.34	3,281,944.75	178,043.58
443,207.38	3,281,911.50	178,043.58
442,692.91	3,281,902.75	178,043.58
443,409.03	3,281,898.75	178,043.58

Well Coordinates		Estimated Well Withdrawal Rate (gpd)
UTM *x*	UTM *y*	
441,458.38	3,281,794.75	178,043.58
441,460.69	3,281,792.75	178,043.58
441,462.25	3,281,792.75	178,043.58
444,217.44	3,281,727.00	178,043.58
441,215.59	3,281,612.00	178,043.58
441,200.53	3,281,565.50	178,043.58
443,999.97	3,281,530.75	178,043.58
443,415.03	3,281,518.00	178,043.58
443,637.06	3,281,510.25	178,043.58
441,620.34	3,281,458.75	178,043.58
441,407.62	3,281,375.75	178,043.58
443,214.41	3,281,372.25	178,043.58
444,228.22	3,281,338.75	178,043.58
442,832.09	3,281,106.75	178,043.58
443,154.12	3,280,765.50	178,043.58
444,039.38	3,280,745.75	178,043.58
444,011.47	3,280,709.50	178,043.58
444,029.03	3,280,606.75	178,043.58
445,099.16	3,279,907.50	178,043.58
444,254.31	3,279,901.50	178,043.58
444,036.56	3,279,893.25	178,043.58
444,629.09	3,279,892.00	178,043.58
444,440.22	3,279,696.25	178,043.58
443,857.41	3,279,102.00	178,043.58
446,906.09	3,278,703.00	178,043.58
447,299.41	3,278,348.00	178,043.58
448,913.97	3,275,876.50	178,043.58
448,945.81	3,275,488.75	178,043.58
448,562.62	3,275,069.00	178,043.58
448,942.47	3,275,065.00	178,043.58
448,563.50	3,274,518.00	178,043.58
448,961.72	3,274,247.00	178,043.58
447,788.62	3,274,230.25	178,043.58
453,575.53	3,250,245.00	178,043.58
453,379.38	3,250,208.50	178,043.58
453,693.03	3,250,165.00	178,043.58
451,556.38	3,250,159.00	178,043.58
453,993.53	3,249,841.50	178,043.58
452,358.38	3,249,789.25	178,043.58
451,958.38	3,249,773.00	178,043.58
452255.31	3,249,383.00	178,043.58
451,752.34	3,249,370.25	178,043.58
452,132.72	3,248,986.75	178,043.58
443,901.25	3,320,774.25	178,043.58
443,557.19	3,320,577.25	178,043.58
446,510.28	3,319,500.00	178,043.58
446,595.44	3,319,383.25	178,043.58

Appendix A—*Continued*

Well Coordinates		Estimated Well Withdrawal Rate (gpd)
UTM *x*	UTM *y*	
446,648.84	3,319,286.75	178,043.58
446,745.88	3,317,349.75	178,043.58
446,745.88	3,317,349.75	178,043.58
449,890.16	3,317,215.75	178,043.58
446,890.56	3,316,983.00	178,043.58
449,642.53	3,316,935.75	178,043.58
450,903.59	3,316,902.75	178,043.58
449,719.69	3,316,723.75	178,043.58
451,391.19	3,316,516.25	178,043.58
449,310.53	3,316,456.00	178,043.58
451,614.25	3,315,922.25	178,043.58
453,047.94	3,315,479.25	178,043.58
453,732.94	3,315,410.75	178,043.58
453,689.88	3,315,368.75	178,043.58
452,810.31	3,315,117.25	178,043.58
453,333.50	3,314,660.50	178,043.58
452,891.91	3,314,589.75	178,043.58
453,740.31	3,314,585.00	178,043.58
445,246.12	3,314,256.75	178,043.58
444,804.41	3,314,252.75	178,043.58
453,149.62	3,314,146.50	178,043.58
445,269.16	3,314,052.75	178,043.58
453,527.19	3,314,001.00	178,043.58
452,589.62	3,313,758.00	178,043.58
452,999.53	3,313,735.75	178,043.58
445,270.16	3,313,657.00	178,043.58
451,995.09	3,313,544.50	178,043.58
443,762.88	3,313,541.75	178,043.58
445,281.59	3,313,468.50	178,043.58
445,291.84	3,313,272.25	178,043.58
451,622.62	3,313,032.25	178,043.58
450,955.12	3,312,959.50	178,043.58
453,057.22	3,312,875.75	178,043.58
452,844.53	3,312,873.00	178,043.58
452,535.75	3,312,865.75	178,043.58
452,231.25	3,312,859.75	178,043.58
452,071.97	3,312,856.00	178,043.58
451,317.66	3,312,829.25	178,043.58
446,841.97	3,312,457.50	178,043.58
447,340.00	3,312,455.00	178,043.58
447,831.75	3,312,445.75	178,043.58
452,883.88	3,312,263.25	178,043.58
447,483.56	3,312,059.00	178,043.58
446,954.06	3,312,053.25	178,043.58
447,341.84	3,312,044.75	178,043.58

Well Coordinates		Estimated Well Withdrawal Rate (gpd)
UTM *x*	UTM *y*	
448,131.97	3,311,810.25	178,043.58
447,371.31	3,311,607.25	178,043.58
447,389.91	3,311,063.25	178,043.58
461,038.09	3,311,034.00	178,043.58
446,629.50	3,311,024.25	178,043.58
446,513.75	3,311,020.00	178,043.58
459,713.50	3,310,838.50	178,043.58
460,272.16	3,310,576.50	178,043.58
460,687.69	3,310,550.25	178,043.58
446,594.28	3,310,415.00	178,043.58
446,203.62	3,310,404.00	178,043.58
444,625.03	3,309,791.50	178,043.58
444,288.06	3,309,607.00	178,043.58
445,167.59	3,309,490.00	178,043.58
444,292.62	3,309,395.50	178,043.58
449,050.66	3,309,393.75	178,043.58
444,754.47	3,309,389.75	178,043.58
444,306.56	3,309,181.00	178,043.58
445,376.84	3,309,180.75	178,043.58
444,289.97	3,309,069.25	178,043.58
445,002.19	3,308,992.00	178,043.58
449,013.94	3,308,754.00	178,043.58
444,211.19	3,308,584.50	178,043.58
445,816.84	3,308,291.25	178,043.58
449,099.97	3,308,211.75	178,043.58
448,796.06	3,308,209.50	178,043.58
449,688.44	3,308,206.75	178,043.58
448,812.53	3,307,991.00	178,043.58
448,614.78	3,307,802.00	178,043.58
448,421.69	3,307,797.00	178,043.58
455,441.59	3,304,905.75	178,043.58
454,647.12	3,304,879.00	178,043.58
455,049.31	3,304,652.00	178,043.58
454,254.69	3,304,639.50	178,043.58
455,419.16	3,304,248.50	178,043.58
456,247.25	3,304,248.25	178,043.58
455,883.03	3,304,244.50	178,043.58
454,998.09	3,304,231.25	178,043.58
450,052.12	3,304,185.50	178,043.58
449,477.19	3,304,180.25	178,043.58
450,240.25	3,304,173.25	178,043.58
449,380.88	3,304,172.50	178,043.58
449,848.66	3,304,166.25	178,043.58
448,283.88	3,304,109.00	178,043.58
449,084.16	3,304,102.00	178,043.58
448,781.75	3,304,099.75	178,043.58
455,381.22	3,304,091.00	178,043.58

Appendix A—*Continued*

Well Coordinates		Estimated Well Withdrawal Rate (gpd)
UTM *x*	UTM *y*	
456,269.12	3,303,849.25	178,043.58
455,868.22	3,303,845.25	178,043.58
450,661.09	3,303,785.25	178,043.58
449,081.97	3,303,735.25	178,043.58
448,688.88	3,303,639.25	178,043.58
449,081.44	3,303,473.50	178,043.58
451,071.50	3,303,399.00	178,043.58
450,685.31	3,303,382.25	178,043.58
450,630.44	3,303,379.25	178,043.58
449,862.62	3,303,372.25	178,043.58
450,251.47	3,303,370.75	178,043.58
449,494.62	3,303,362.00	178,043.58
450,607.56	3,302,994.75	178,043.58
449,890.47	3,302,965.75	178,043.58
450,292.91	3,302,952.50	178,043.58
453,499.28	3,302,814.25	178,043.58
451,343.31	3,302,772.25	178,043.58
452,706.88	3,302,753.50	178,043.58
451,819.03	3,302,750.25	178,043.58
446,873.41	3,302,694.50	178,043.58
447,494.69	3,302,623.00	178,043.58
450,210.53	3,302,575.00	178,043.58
453,083.16	3,302,500.25	178,043.58
453,076.75	3,302,462.75	178,043.58
452,896.59	3,302,444.00	178,043.58
453,096.00	3,302,419.25	178,043.58
451,596.50	3,302,417.50	178,043.58
446,851.53	3,302,297.75	178,043.58
447,494.25	3,302,248.25	178,043.58
452,042.84	3,302,192.75	178,043.58
451,838.03	3,302,177.50	178,043.58
451,474.69	3,302,173.75	178,043.58
451,082.94	3,302,119.00	178,043.58
448,531.25	3,301,959.25	178,043.58
446,849.00	3,301,931.50	178,043.58
451,767.12	3,301,858.00	178,043.58
447,174.50	3,301,845.25	178,043.58
447,493.31	3,301,838.75	178,043.58
451,092.72	3,301,810.00	178,043.58
451,407.06	3,301,807.00	178,043.58
447,873.50	3,301,768.75	178,043.58
449,231.19	3,301,711.75	178,043.58
449,403.03	3,301,697.25	178,043.58
447,179.34	3,301,694.00	178,043.58
452,158.59	3,301,681.75	178,043.58

Well Coordinates		Estimated Well Withdrawal Rate (gpd)
UTM *x*	UTM *y*	
451,934.16	3,301,669.25	178,043.58
449,106.81	3,301,638.50	178,043.58
448,688.00	3,301,618.00	178,043.58
450,800.22	3,301,572.75	178,043.58
450,698.50	3,301,551.25	178,043.58
447,449.97	3,301,530.50	178,043.58
451,715.59	3,301,507.25	178,043.58
451,517.00	3,301,390.50	178,043.58
449,442.44	3,301,360.50	178,043.58
449,621.59	3,301,360.00	178,043.58
449,181.34	3,301,350.00	178,043.58
447,062.62	3,301,322.50	178,043.58
447,466.81	3,301,322.00	178,043.58
447,463.28	3,301,320.25	178,043.58
447,463.28	3,301,320.25	178,043.58
446,664.34	3,301,314.50	178,043.58
448,069.31	3,301,137.75	178,043.58
446,668.09	3,301,133.50	178,043.58
447,467.50	3,301,075.00	178,043.58
448,575.59	3,300,943.00	178,043.58
448,278.00	3,300,943.00	178,043.58
447,664.34	3,300,935.75	178,043.58
448,268.22	3,300,934.75	178,043.58
448,401.72	3,300,928.75	178,043.58
451,573.81	3,300,693.00	178,043.58
448,558.19	3,300,538.75	178,043.58
462,528.12	3,300,354.50	178,043.58
451,479.81	3,300,286.00	178,043.58
452,730.75	3,300,151.25	178,043.58
452,710.69	3,300,148.00	178,043.58
452,915.78	3,300,144.00	178,043.58
451,129.12	3,300,027.00	178,043.58
452,165.34	3,300,017.00	178,043.58
452,717.94	3,299,943.75	178,043.58
451,550.03	3,299,915.50	178,043.58
452,198.19	3,299,908.25	178,043.58
452,195.56	3,299,907.25	178,043.58
462,669.12	3,299,749.50	178,043.58
452,314.88	3,299,738.75	178,043.58
452,514.72	3,299,734.25	178,043.58
447,469.06	3,299,733.25	178,043.58
451,530.84	3,299,726.25	178,043.58
451,079.53	3,299,514.25	178,043.58
451,067.38	3,299,351.50	178,043.58
452,587.88	3,299,339.75	178,043.58
452,587.88	3,299,339.75	178,043.58
452,220.41	3,299,336.50	178,043.58

Appendix A—*Continued*

Well Coordinates		Estimated Well Withdrawal Rate (gpd)
UTM x	UTM y	
448,151.47	3,299,336.50	178,043.58
448,023.41	3,299,335.25	178,043.58
451,209.50	3,299,331.00	178,043.58
452,502.84	3,299,322.25	178,043.58
451,550.56	3,299,316.25	178,043.58
451,040.19	3,299,027.25	178,043.58
451,040.19	3,299,027.25	178,043.58
448,614.84	3,298,931.00	178,043.58
450,607.22	3,298,930.75	178,043.58
448,565.97	3,298,926.25	178,043.58
448,378.75	3,298,918.50	178,043.58
447,905.16	3,298,906.50	178,043.58
447,881.44	3,298,890.50	178,043.58
447,882.97	3,298,720.25	178,043.58
453,142.34	3,298,637.00	178,043.58
450,630.06	3,298,624.50	178,043.58
447,909.66	3,298,514.25	178,043.58
447,182.25	3,298,498.75	178,043.58
448,298.59	3,298,493.25	178,043.58
447,481.12	3,298,486.75	178,043.58
450,962.94	3,298,340.25	178,043.58
450,960.34	3,298,338.75	178,043.58
452,168.62	3,298,129.00	178,043.58
450,955.53	3,298,120.00	178,043.58
450,955.16	3,298,120.00	178,043.58
453,317.66	3,298,008.00	178,043.58
453,579.62	3,297,824.25	178,043.58
455,965.88	3,297,759.75	178,043.58
456,380.62	3,297,751.50	178,043.58
462,777.72	3,297,557.25	178,043.58
453,572.81	3,297,518.25	178,043.58
453,972.06	3,297,516.75	178,043.58
453,938.62	3,297,338.50	178,043.58
453,169.62	3,297,185.00	178,043.58
455,972.19	3,297,170.00	178,043.58
456,395.12	3,297,170.00	178,043.58
452,368.38	3,297,129.00	178,043.58
452,976.09	3,296,917.25	178,043.58
452,291.84	3,296,911.25	178,043.58
456,194.88	3,296,793.75	178,043.58
453,980.62	3,296,782.75	178,043.58
453,586.69	3,296,729.00	178,043.58
457,020.75	3,296,656.25	178,043.58
458,412.69	3,296,626.50	178,043.58
457,611.62	3,296,623.00	178,043.58

Well Coordinates		Estimated Well Withdrawal Rate (gpd)
UTM x	UTM y	
458,822.19	3,296,617.25	178,043.58
457,919.47	3,296,616.25	178,043.58
458,830.38	3,296,615.00	178,043.58
457,730.97	3,296,604.75	178,043.58
459,196.31	3,296,596.00	178,043.58
456,586.16	3,296,594.25	178,043.58
458,002.38	3,296,588.00	178,043.58
459,820.09	3,296,579.75	178,043.58
456,823.22	3,296,567.50	178,043.58
452,984.38	3,296,564.00	178,043.58
452,391.44	3,296,548.75	178,043.58
452,588.09	3,296,532.00	178,043.58
451,966.59	3,296,522.75	178,043.58
453,587.72	3,296,493.00	178,043.58
451,776.72	3,296,488.50	178,043.58
453,997.00	3,296,448.50	178,043.58
453,130.78	3,296,401.75	178,043.58
457,586.12	3,296,382.25	178,043.58
452,726.19	3,296,355.75	178,043.58
452,672.03	3,296,316.50	178,043.58
458,409.81	3,296,203.00	178,043.58
455,194.72	3,296,155.25	178,043.58
452,135.72	3,296,111.00	178,043.58
452,265.47	3,296,110.75	178,043.58
452,337.78	3,296,099.25	178,043.58
452,555.19	3,296,104.50	178,043.58
452,107.62	3,296,094.50	178,043.58
458,813.50	3,296,033.25	178,043.58
454,816.44	3,295,942.75	178,043.58
453,241.41	3,295,863.00	178,043.58
457,204.34	3,295,814.25	178,043.58
458,005.72	3,295,778.75	178,043.58
455,190.66	3,295,759.75	178,043.58
454,408.97	3,295,758.25	178,043.58
452,838.78	3,295,738.25	178,043.58
451,880.56	3,295,737.00	178,043.58
453,002.81	3,295,734.50	178,043.58
455,124.44	3,295,725.00	178,043.58
451,720.16	3,295,714.50	178,043.58
453,595.81	3,295,710.50	178,043.58
452,815.00	3,295,676.50	178,043.58
453,229.28	3,295,664.00	178,043.58
452,355.16	3,295,661.25	178,043.58
451,598.69	3,295,574.75	178,043.58
457,119.25	3,295,545.75	178,043.58
454,916.84	3,295,540.00	178,043.58
456,401.59	3,295,531.50	178,043.58

Appendix A—*Continued*

Well Coordinates		Estimated Well Withdrawal Rate (gpd)
UTM *x*	UTM *y*	
453,026.97	3,295,516.75	178,043.58
454,236.84	3,295,422.25	178,043.58
458,814.38	3,295,422.00	178,043.58
458,425.81	3,295,409.00	178,043.58
457,625.03	3,295,378.25	178,043.58
457,593.41	3,295,377.25	178,043.58
456,820.84	3,295,367.00	178,043.58
454,017.38	3,295,364.50	178,043.58
453,500.47	3,295,303.75	178,043.58
454,429.41	3,295,216.00	178,043.58
452,109.66	3,295,214.50	178,043.58
456,815.38	3,295,167.00	178,043.58
454,830.84	3,295,136.00	178,043.58
453,862.31	3,295,119.00	178,043.58
454,414.50	3,295,071.25	178,043.58
459,606.53	3,295,028.75	178,043.58
458,036.19	3,295,009.25	178,043.58
457,184.66	3,295,003.00	178,043.58
458,422.47	3,294,980.00	178,043.58
457,830.03	3,294,954.25	178,043.58
457,216.19	3,294,940.75	178,043.58
459,622.50	3,294,860.50	178,043.58
457,842.72	3,294,776.75	178,043.58
456,798.25	3,294,749.00	178,043.58
454,028.06	3,294,741.50	178,043.58
456,420.66	3,294,740.75	178,043.58
457,219.03	3,294,667.00	178,043.58
459,241.22	3,294,620.25	178,043.58
460,041.38	3,294,608.75	178,043.58
454,420.62	3,294,600.75	178,043.58
458,293.34	3,294,586.50	178,043.58
458,033.62	3,294,577.50	178,043.58
453,610.19	3,294,518.50	178,043.58
457,245.00	3,294,457.25	178,043.58
456,831.94	3,294,406.75	178,043.58
453,914.97	3,294,384.50	178,043.58
457,196.53	3,294,352.25	178,043.58
459,450.53	3,294,202.50	178,043.58
457,624.38	3,294,148.50	178,043.58
457,662.81	3,294,147.25	178,043.58
459,633.91	3,294,072.25	178,043.58
457,170.78	3,293,956.75	178,043.58
458,834.31	3,293,828.75	178,043.58
458,834.31	3,293,828.75	178,043.58
455,025.91	3,293,547.25	178,043.58

Well Coordinates		Estimated Well Withdrawal Rate (gpd)
UTM *x*	UTM *y*	
459,242.91	3,293,212.00	178,043.58
458,814.72	3,293,188.75	178,043.58
458,946.06	3,292,979.00	178,043.58
453,267.38	3,292,968.75	178,043.58
456,455.00	3,292,925.25	178,043.58
453,888.41	3,292,895.75	178,043.58
454,241.53	3,292,698.25	178,043.58
453,253.53	3,292,687.75	178,043.58
454,426.69	3,292,633.75	178,043.58
458,837.62	3,292,593.00	178,043.58
459,456.47	3,292,592.25	178,043.58
453,968.56	3,292,582.25	178,043.58
460,064.31	3,292,573.50	178,043.58
458,052.53	3,292,563.75	178,043.58
453,274.94	3,292,504.00	178,043.58
454,823.81	3,292,504.00	178,043.58
454,822.53	3,292,502.75	178,043.58
453,248.59	3,292,500.75	178,043.58
454,425.88	3,292,476.00	178,043.58
454,815.56	3,292,314.00	178,043.58
458,046.88	3,292,163.75	178,043.58
453,923.38	3,292,083.00	178,043.58
452,897.81	3,292,081.75	178,043.58
453,448.47	3,292,071.50	178,043.58
453,670.81	3,292,069.75	178,043.58
453,206.00	3,292,067.25	178,043.58
452,675.75	3,291,684.75	178,043.58
453,971.34	3,291,670.50	178,043.58
453,204.81	3,291,669.25	178,043.58
453,189.09	3,291,663.75	178,043.58
454,654.47	3,291,285.75	178,043.58
454,261.91	3,291,281.25	178,043.58
454,001.66	3,291,267.50	178,043.58
454,735.72	3,291,134.25	178,043.58
454,590.12	3,291,121.00	178,043.58
455,188.44	3,290,913.00	178,043.58
452,549.50	3,290,879.00	178,043.58
452,561.31	3,290,481.25	178,043.58
452,529.06	3,290,478.50	178,043.58
455,089.47	3,290,469.50	178,043.58
452,565.69	3,290,267.00	178,043.58
452,610.12	3,290,078.00	178,043.58
454,239.53	3,290,001.00	178,043.58
454,441.69	3,289,340.50	178,043.58
453,177.50	3,289,143.75	178,043.58
453,543.75	3,289,124.50	178,043.58
454,847.78	3,289,095.00	178,043.58

Appendix A—*Continued*

Well Coordinates		Estimated Well Withdrawal Rate (gpd)
UTM *x*	UTM *y*	
449,821.88	3,289,047.00	178,043.58
455,260.41	3,288,886.50	178,043.58
455,662.44	3,288,884.50	178,043.58
456,014.00	3,288,882.25	178,043.58
455,601.88	3,288,874.25	178,043.58
453,791.94	3,288,851.25	178,043.58
449,654.59	3,288,848.25	178,043.58
449,395.50	3,288,732.25	178,043.58
449,659.72	3,288,644.75	178,043.58
449,658.06	3,288,643.25	178,043.58
449,424.06	3,288,583.00	178,043.58
456,047.38	3,288,443.25	178,043.58
455,235.88	3,288,437.25	178,043.58
449,256.09	3,288,325.75	178,043.58
454,442.09	3,288,307.00	178,043.58
454,854.91	3,288,058.00	178,043.58
454,441.03	3,288,053.75	178,043.58
449,655.88	3,288,051.25	178,043.58
453,877.88	3,287,997.75	178,043.58
455,264.03	3,287,996.75	178,043.58
449,258.97	3,287,847.50	178,043.58
454,326.22	3,287,659.50	178,043.58
454,858.28	3,287,656.75	178,043.58
449,259.97	3,287,652.25	178,043.58
455,265.38	3,287,638.75	178,043.58
449,260.72	3,287,538.50	178,043.58
452,704.97	3,287,509.75	178,043.58
454,028.28	3,287,486.00	178,043.58
454,424.09	3,287,457.25	178,043.58
455,668.56	3,287,333.00	178,043.58
457,307.62	3,287,264.50	178,043.58
449,706.12	3,287,261.25	178,043.58
454,863.97	3,287,254.75	178,043.58
455,611.72	3,287,252.00	178,043.58
449,264.22	3,287,236.75	178,043.58
452,652.12	3,287,043.25	178,043.58
450,439.34	3,286,882.00	178,043.58
452,024.62	3,286,854.00	178,043.58
455,269.81	3,286,852.50	178,043.58
455,961.41	3,286,851.50	178,043.58
452,755.78	3,286,844.00	178,043.58
449,264.25	3,286,838.25	178,043.58
457,299.91	3,286,835.00	178,043.58
450,290.75	3,286,761.50	178,043.58
451,438.94	3,286,445.00	178,043.58

Well Coordinates		Estimated Well Withdrawal Rate (gpd)
UTM *x*	UTM *y*	
451,101.28	3,286,443.50	178,043.58
450,475.72	3,286,440.75	178,043.58
456,086.47	3,286,431.75	178,043.58
456,900.31	3,286,284.25	178,043.58
449,652.81	3,286,249.75	178,043.58
456,491.81	3,286,249.25	178,043.58
450,470.97	3,286,244.00	178,043.58
451,213.50	3,286,136.25	178,043.58
456,099.47	3,286,018.00	178,043.58
451,813.97	3,285,881.25	178,043.58
450,464.78	3,285,873.25	178,043.58
450,764.41	3,285,861.00	178,043.58
452,071.56	3,285,818.25	178,043.58
451,052.16	3,285,690.25	178,043.58
457,321.62	3,285,676.50	178,043.58
456,922.50	3,285,664.50	178,043.58
450,765.06	3,285,663.75	178,043.58
453,050.28	3,285,645.00	178,043.58
456,458.47	3,285,619.25	178,043.58
451,399.44	3,285,557.50	178,043.58
451,353.38	3,285,485.75	178,043.58
453,062.19	3,285,437.25	178,043.58
458,135.78	3,285,276.00	178,043.58
451,053.34	3,285,251.75	178,043.58
451,054.00	3,285,249.25	178,043.58
451,926.56	3,285,249.00	178,043.58
451,474.38	3,285,056.75	178,043.58
451,680.12	3,285,055.00	178,043.58
451,464.94	3,285,038.25	178,043.58
449,422.84	3,284,863.50	178,043.58
451,255.66	3,284,856.00	178,043.58
457,744.47	3,284,854.75	178,043.58
456,936.97	3,284,853.75	178,043.58
451,435.09	3,284,850.25	178,043.58
457,238.94	3,284,847.25	178,043.58
456,939.12	3,284,838.25	178,043.58
452,080.22	3,284,641.00	178,043.58
452,920.56	3,284,637.25	178,043.58
456,532.78	3,284,574.75	178,043.58
456,140.50	3,284,568.75	178,043.58
449,380.38	3,284,529.75	178,043.58
455,388.31	3,284,506.00	178,043.58
457,290.56	3,284,442.00	178,043.58
456,942.31	3,284,431.75	178,043.58
452,917.94	3,284,391.75	178,043.58
451,670.50	3,284,372.00	178,043.58
457,787.34	3,284,242.00	178,043.58

Appendix A—*Continued*

Well Coordinates		Estimated Well Withdrawal Rate (gpd)
UTM *x*	UTM *y*	
453,799.59	3,284,145.75	178,043.58
450,930.47	3,284,073.75	178,043.58
452,072.91	3,284,058.25	178,043.58
451,474.69	3,284,045.75	178,043.58
456,107.91	3,284,032.25	178,043.58
449,333.19	3,284,021.25	178,043.58
449,432.91	3,284,019.25	178,043.58
456,749.19	3,284,019.25	178,043.58
456,540.66	3,284,018.50	178,043.58
453,503.75	3,284,003.75	178,043.58
452,543.09	3,283,929.00	178,043.58
450,050.00	3,283,806.50	178,043.58
454,212.41	3,283,735.75	178,043.58
454,213.28	3,283,735.75	178,043.58
453,196.88	3,283,641.50	178,043.58
453,197.69	3,283,639.75	178,043.58
452,559.88	3,283,637.75	178,043.58
451,888.28	3,283,636.50	178,043.58
453,723.56	3,283,632.00	178,043.58
455,653.22	3,283,598.00	178,043.58
456,024.75	3,283,588.75	178,043.58
451,245.19	3,283,588.25	178,043.58
452,085.75	3,283,458.50	178,043.58
452,912.28	3,283,437.25	178,043.58
451,478.94	3,283,429.25	178,043.58
453,310.50	3,283,305.00	178,043.58
457,675.47	3,283,242.25	178,043.58
453,059.97	3,283,180.25	178,043.58
451,178.72	3,283,034.75	178,043.58
452,092.62	3,283,033.75	178,043.58
454,601.25	3,282,978.25	178,043.58
458,919.88	3,282,908.25	178,043.58
456,566.44	3,282,896.25	178,043.58
454,092.62	3,282,858.00	178,043.58
456,959.62	3,282,834.75	178,043.58
458,569.03	3,282,832.75	178,043.58
452,504.72	3,282,773.00	178,043.58
451,347.78	3,282,709.25	178,043.58
452,093.31	3,282,679.50	178,043.58
458,971.38	3,282,556.00	178,043.58
451,057.84	3,282,513.25	178,043.58
456,962.66	3,282,452.75	178,043.58
452,903.94	3,282,418.25	178,043.58
458,571.22	3,282,413.50	178,043.58
454,398.53	3,282,404.00	178,043.58

Well Coordinates		Estimated Well Withdrawal Rate (gpd)
UTM *x*	UTM *y*	
451,845.81	3,282,361.75	178,043.58
451,567.06	3,282,358.25	178,043.58
454,391.19	3,282,236.75	178,043.58
452,948.16	3,282,203.50	178,043.58
458,971.19	3,282,156.25	178,043.58
454,114.25	3,282,096.00	178,043.58
453,744.47	3,282,065.00	178,043.58
451,767.38	3,282,044.50	178,043.58
451,640.81	3,282,041.75	178,043.58
451,061.28	3,282,035.50	178,043.58
452,524.50	3,281,975.00	178,043.58
453,711.25	3,281,889.25	178,043.58
454,880.72	3,281,836.00	178,043.58
450,812.94	3,281,815.75	178,043.58
452,517.38	3,281,681.75	178,043.58
453,081.34	3,281,630.75	178,043.58
454,110.31	3,281,630.25	178,043.58
453,870.25	3,281,599.75	178,043.58
451,874.62	3,281,585.75	178,043.58
451,322.72	3,281,581.75	178,043.58
451,711.62	3,281,349.75	178,043.58
453,722.31	3,281,205.75	178,043.58
453,773.22	3,281,153.50	178,043.58
453,094.94	3,281,144.50	178,043.58
451,453.38	3,281,127.50	178,043.58
453,007.97	3,281,114.50	178,043.58
451,253.06	3,280,972.50	178,043.58
451,075.53	3,280,951.50	178,043.58
451,697.31	3,280,926.25	178,043.58
452,901.00	3,280,762.00	178,043.58
453,738.75	3,280,748.75	178,043.58
451,300.75	3,280,728.50	178,043.58
451,081.97	3,280,687.00	178,043.58
451,590.31	3,280,551.75	178,043.58
452,904.44	3,280,379.25	178,043.58
452,916.41	3,280,373.50	178,043.58
451,308.75	3,280,366.25	178,043.58
452,307.22	3,280,359.00	178,043.58

Note: gpd = gallons per day
UTM = Universal Transverse Mercator

Appendix B—Location and Hydrographs of Observation Wells

Figure B1. Locations of monitoring wells in study area

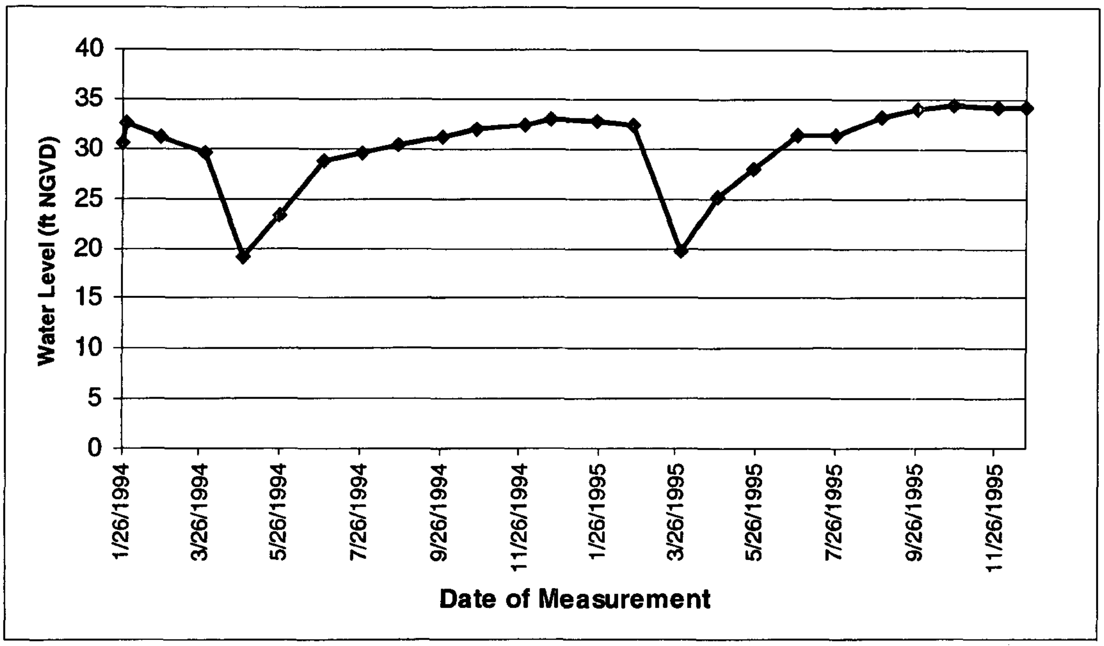

Figure B2. 1994 and 1995 water levels in well SJ0027

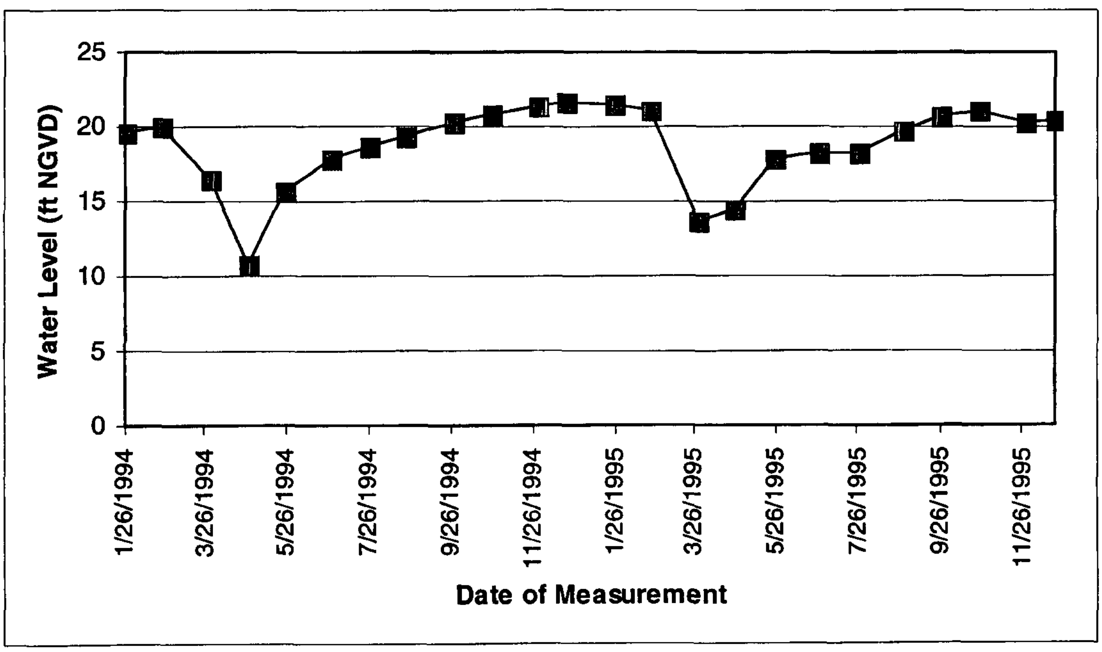

Figure B3. 1994 and 1995 water levels in well P0172

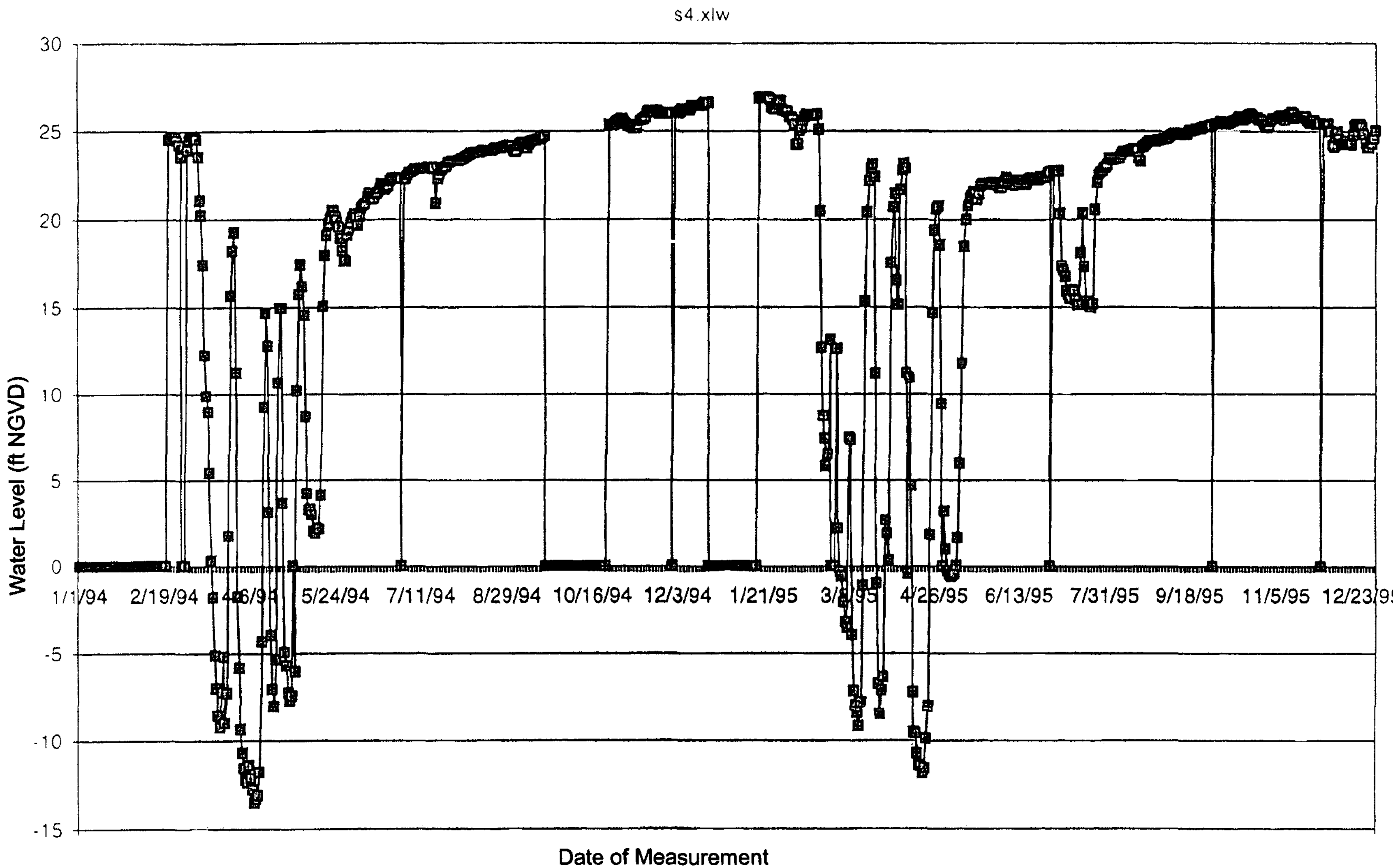

Figure B4. 1994–95 water levels in well SJ-0317

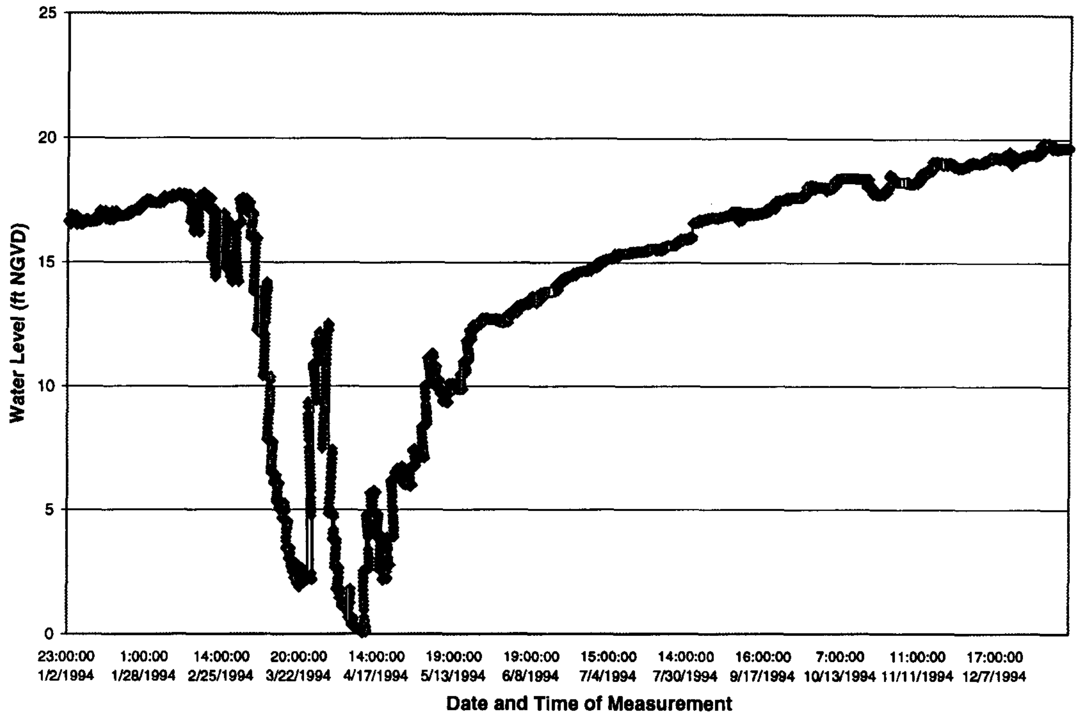

Figure B5a. 1994 water levels in well SJ0263

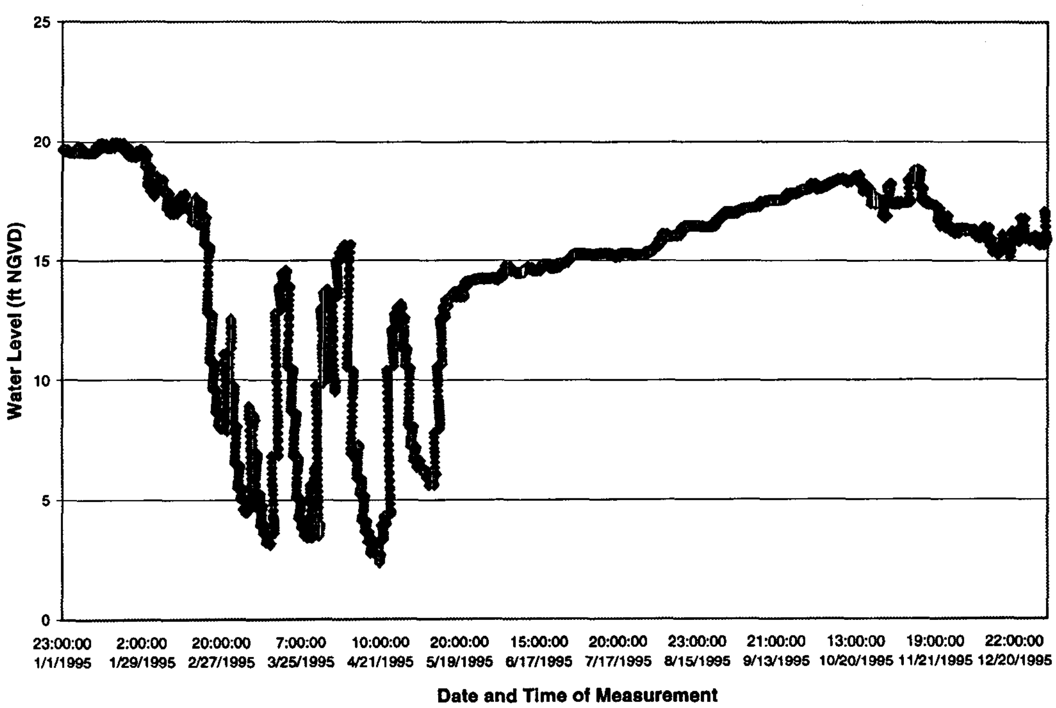

Figure B5b. 1995 water levels in well SJ0263