REGIONAL GROUND-WATER FLOW MODELING FOR EAST-CENTRAL FLORIDA WITH EMPHASIS ON ORANGE AND SEMINOLE COUNTIES

Prepared for

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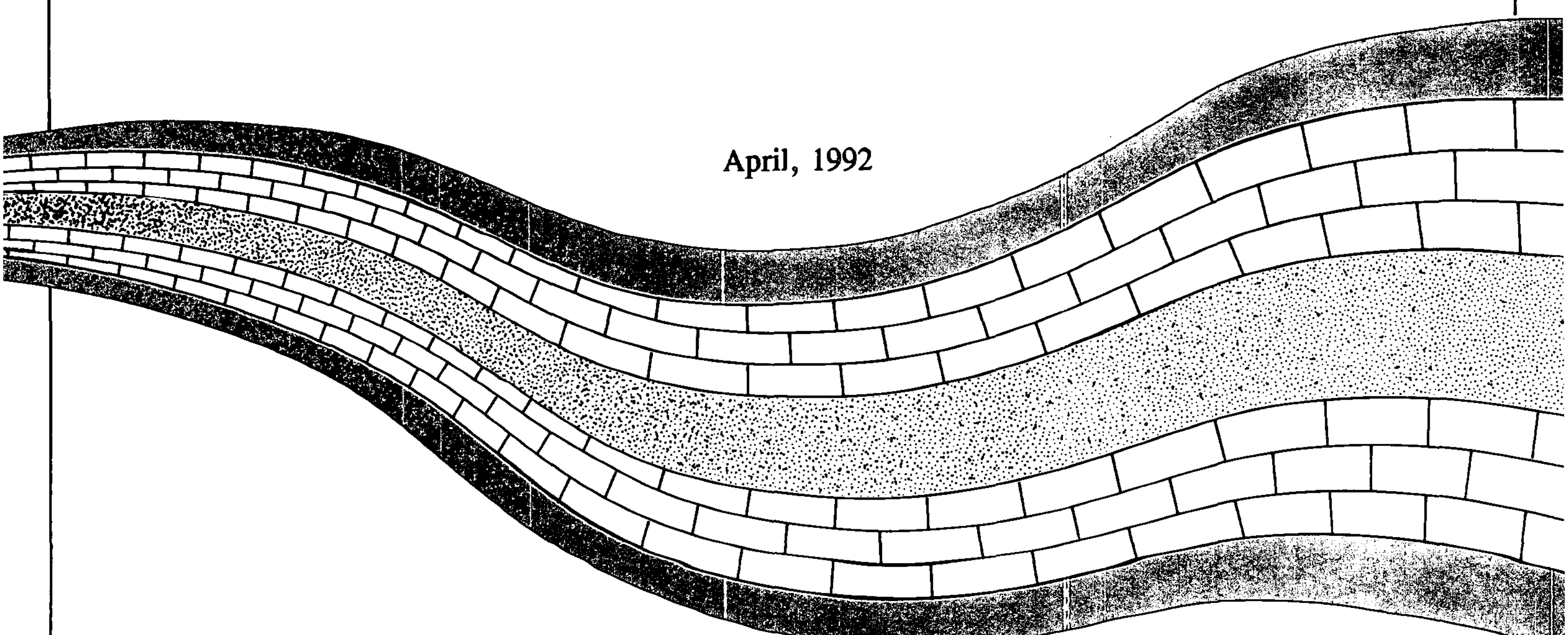
April, 1992



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EXECUTIVE SUMMARY

In 1988 the Florida Department of Environmental Regulation (FDER) amended Chapter 17-40 of the Florida Administrative Code, Water Policy, to include the requirement that each of the five water management districts prepare assessments of water supply needs and sources. The St. Johns River Water Management District (SJRWMD), as part of their needs and sources assessment effort, requested that HydroGeoLogic, Inc. revise and expand upon an existing ground-water flow model of east-central Florida that includes Orange and Seminole counties, and portions of Lake, Volusia, Brevard and Osceola counties. The model to be amended was constructed by HydroGeoLogic (Blandford et al., 1991) as part of the East-Central Florida Ground-water Modeling project (Phase I) funded by the SJRWMD, the City of Cocoa, and Orange County Public Utilities Division (OCPUD). The primary purpose of this effort is to assess the impacts of utilizing sources of fresh ground water in Orange and Seminole counties, given the projected demand for the twenty-year planning period. Specific objectives are as follows:

- Simulate the effects on the ground-water resource caused by existing (1988) withdrawals
- Estimate the future impacts on the ground-water resource due to the long term effects of projected withdrawals from the Floridan aquifer for the year 2010
- Determine areas where projected 2010 withdrawals will significantly impact each other under steady state conditions.

The first portion of this study involved developing a finer discretization of the existing model grid, changing the spring discharge and recharge to the Upper Floridan to be head-dependent, and the subsequent calibration of the model to average predevelopment and average 1988 conditions. Blandford et al. (1991) had only calibrated their model to average 1988 conditions. The model calibration was conducted by varying the leakance of the upper confining unit, spring conductances, and (in limited regions) Upper Floridan transmissivity. The fine discretization of the model grid permitted most MI pumping centers to be located within individual grid blocks, which is useful because drawdown impacts due to individual users may be more easily assessed. The fact that the model could be calibrated to predevelopment, as well as postdevelopment, conditions indicates that the model may be useful for predicting ground-water flow conditions for periods of time other than 1988.

Within the primary area of interest (Orange and Seminole Counties in the vicinity of Orlando), the differences between the observed Upper Floridan potentiometric surface and that simulated by the model are generally less than about 2 ft. At some locations within the model domain, however, differences exceeding 8 ft exist. These large differences do not occur over substantial portions of the study area, and they tend to occur in regions of high hydraulic gradients where slight variations in potentiometric surface contours lead to comparatively large differences between simulated and observed hydraulic heads.

A subsequent sensitivity analysis conducted for 1988 conditions illustrated that the Upper Floridan potentiometric surface is highly sensitive to the leakance of the upper confining unit, moderately sensitive to Upper Floridan transmissivity and spring conductance, and only slightly sensitive to transmissivity of the Lower Floridan and leakance of the middle semiconfining unit. It was important, therefore, to determine appropriate values of upper confining unit leakance, Upper Floridan transmissivity and spring conductance. Recharge, which is a direct function of leakance of the upper confining unit, was calibrated using a map provided in Tibbals (1990). This map was spot-checked using 1988 data and was found to be accurate for most locations within the study region. Furthermore, the calibrated Upper Floridan transmissivity values and spring conductances lie within a reasonable range as determined by aquifer tests and previous modeling studies. It is, therefore, believed that the calibrated model parameters are reasonable on a regional scale. The lack of piezometric head data for the Lower Floridan precluded a calibration of this model layer. It would be quite useful to have more information on this aquifer, and the SJRWMD may consider more intensive data collection for the Lower Floridan in the future.

A comparative simulation was conducted using the 1988 calibrated model for all currently (1991) permitted withdrawals within the study area. All of the inputs for this simulation were the same as those for the 1988 calibration, except a pumping file consisting solely of permitted discharge values was substituted for the 1988 pumping file. The results of this simulation indicated widespread drawdowns of 2-4 ft throughout the study area when compared to 1988 conditions. The increased drawdown was due to larger permitted MI and citrus pumping in the Upper Floridan than was determined for 1988 average conditions. The pumpage for citrus irrigation obtained from the permit files appears to be especially high.

Two predictive simulations for the year 2010 were conducted using the calibrated model. Estimates of municipal and industrial pumping rates for the year 2010 were provided by the SJRWMD, and the 1988 values for agricultural pumping and drainage well recharge were used in each simulation. The first simulation incorporated all of the pumping centers expected to be operational in 2010; the results of this simulation indicate that substantial drawdowns will occur by the year 2010 throughout much of Orange and Seminole Counties. The largest drawdowns (about 30 ft) are predicted to occur at Orange County's proposed Eastern Regional well field (ERWF). Large drawdowns (15 ft) are also predicted to occur in the vicinity of the town of Sanford in the northwest Seminole County. This simulation indicated a 16 percent decrease in total spring flows throughout the study area. A second predictive simulation was run with the only difference being that the estimated 2010 ERWF withdrawal was deleted. This simulation indicated maximum drawdowns of 10-15 ft throughout central Orange County and northwest Seminole County. This simulation indicated a 13 percent decrease in total spring flows throughout the study area.

Comparison of the two 2010 predictive simulations indicates that, throughout central Orange County and south-central Seminole County, proposed withdrawals from the ERWF increase drawdowns by about 5 ft as compared to predicted drawdowns with the ERWF not in operation. Over a relatively local region in the vicinity of the ERWF increased drawdowns (due only to the ERWF) of 10-15 ft are predicted.

The large drawdowns that presumably will occur in response to 2010 pumping warrant careful, further study. The first item to be addressed should be the accuracy of the estimated 2010 pumping values. Although MI pumping doubled overall from the 1988 to 2010 condition, some locations had huge increases (ten to twenty times) in estimated discharge from the 1988 values. The validity of these increases should be critically examined by District staff.

If the estimated 2010 withdrawal rates are deemed to be reasonable, the District should initiate immediate action to investigate ways to mitigate the severe depletions. The first step would be to apply the calibrated ground-water flow model to evaluate resource planning and utilization alternatives. An example of one such alternative would be to distribute the proposed pumping at large well fields, such as Orange County's ERWF, over a larger region. It might also be prudent to site new well fields in the western regions of the study area where the water quality is good and the recharge rates to the Upper Floridan are, or have the potential to be, high.

Finally, the results of this study indicate that it will be a difficult task for the District to effectively manage the available ground-water resources in central Seminole and Orange Counties throughout the coming years. Significant increases in withdrawals for various municipalities throughout the region, if they occur, will place a critical, and possibly irreversible stress on existing ground-water resources. Upper Floridan ground water with chloride concentrations of 250 parts per million (ppm) or greater already exists throughout significant portions of Seminole and eastern Orange Counties. The extent of non-potable water in the Lower Floridan is poorly defined, but at many locations in central Orange and Seminole Counties ground water with chloride concentrations greater than 250 ppm probably underlies existing and proposed well fields. The potential for lateral encroachment and upconing of poor quality water is clearly evident. To compound the problem, most of the well fields in the identified region of concern are, or will be, located in poor recharge areas. This is important because as pumping increases, the volume of water that will be obtained from increased recharge from the surficial aquifer will be limited (at least in the immediate vicinity of the well field), and therefore larger drawdowns will occur than if the same increases in pumping had taken place in a region of high recharge potential.

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1 INTRODUCTION

1.1 Background

In 1988 the Florida Department of Environmental Regulation (FDER) amended Chapter 17-40 of the Florida Administrative Code, Water Policy, to include the requirement that each of the five water management districts prepare assessments of water supply needs and sources. The St. Johns River Water Management District (SJRWMD), as part of their needs and sources assessment effort, requested that HydroGeoLogic, Inc. revise and expand upon an existing ground-water flow model of east-central Florida that includes Orange and Seminole counties, and portions of Lake, Volusia, Brevard and Osceola counties. The model to be amended was constructed by HydroGeoLogic (Blandford et al., 1991) as part of the East-Central Florida Ground-water Modeling project (Phase I) funded by the SJRWMD, the City of Cocoa, and Orange County Public Utilities Division (OCPUD). The primary purpose of this effort is to assess the impacts of utilizing sources of fresh ground water in Orange and Seminole counties. Since the Floridan aquifer is the primary source of water supply for the east-central Florida region, the major emphasis in this study is placed on the Floridan aquifer system.

1.2 Purpose and Scope of Work

The purpose of this modeling effort is to assess the impacts of utilizing sources of fresh ground water in Orange and Seminole counties, given the projected demand for the twenty-year planning period. Specific objectives are as follows:

- Simulate the effects on the ground-water resource caused by existing (1988) withdrawals
- Estimate the future impacts on the ground-water resource due to the long term effects of projected withdrawals from the Floridan aquifer for the year 2010

- Determine areas where projected 2010 withdrawals will significantly impact each other under steady state conditions.

The above objectives were to be achieved through the modification and recalibration of an existing regional, three-dimensional, steady-state ground-water flow model. The scope of work necessary for the completion of the above objectives includes the following activities.

- Data compilation and analysis for predevelopment, 1988, 1991 permitted and 2010 pumping conditions
- Refinement of the existing model grid throughout most of Orange and Seminole counties to isolate public supply pumping centers (1 per model cell) to the degree possible
- Recalibration of the regional model to predevelopment (pre-pumping) steady-state conditions
- Recalibration of the regional model to average 1988 steady-state conditions
- Completion of predictive simulations using the calibrated steady-state model for permitted (1991) pumping and estimated 2010 withdrawals
- Fully document all the data sources and procedures used, and the assumptions made for the technical effort

1.3 Organization of Report

This report is divided into seven chapters designed to lead the reader through the technical effort in a sequential and logical manner. Chapter 1 provides background introductory materials, and Chapter 2 outlines the general technical approach. Chapter 3 provides a synopsis of the hydrogeological setting. Chapter 4 presents the data types and sources used, as well as any technical analysis performed on the raw data. Chapter 5 provides the specifics of the ground-water modeling effort, including the details of the model construction and calibration for predevelopment and postdevelopment conditions. Chapter 6 documents the results of the predictive simulations, and Chapter 7 consists of technical conclusions. Basic data are included in the Appendices, as well as on a diskette (primarily in the form of Lotus spreadsheet files) provided with the original report. Copies of the diskette are available from SJRWMD upon request.

2 TECHNICAL APPROACH

2.1 Overall Approach

The overall technical approach for this study consisted of five major steps. First, the available data required for input to the ground-water flow model were collected, reviewed, and where appropriate, analyzed. Much of the data used was collected during the previous modeling study (Blandford et al., 1991). However, significant amounts of new data pertaining to municipal and industrial (MI) and agricultural pumping for the 1988 calibration period, the 1991 consumptive use simulation and the 2010 predictive scenarios had to be collected and analyzed. The second task involved the following changes to the existing ground-flow model:

- The model grid was refined to separate (one per model cell) MI pumping wells as much as possible.
- The model cells that contained springs were changed from prescribed discharge to head-dependent discharge cells.
- The boundary condition at the top of the Upper Floridan was changed from prescribed recharge to head-dependent recharge.

Next, the calibrated model parameters from the existing model were used as initial input parameters for the new mesh, and the refined model was calibrated to predevelopment and 1988 average (steady state) conditions. Finally, the 1991 permitted consumptive use and the 2010 predictive simulations were conducted and analyzed.

2.2 Data Review and Acquisition

The data reviewed and used for this study were obtained from various reliable sources such as publications of the United States Geological Survey (USGS), SJRWMD, the Florida Agricultural Statistics Service, and private consultants. An extensive bibliography of reports concerning the geology and hydrogeology of east-central Florida is presented in Blandford et al., 1991. No new field work was conducted to support this effort.

A large portion of the raw data used in the modeling was supplied by the SJRWMD. Most of this data consisted of ground-water withdrawal rates and locations for municipal, industrial and agricultural purposes throughout the study area. The SJRWMD also assisted the modeling effort by supplying a number of base maps for the study area. The base maps constructed and supplied by the SJRWMD include:

- general base map showing the location of roads and surficial hydrology (lakes and streams) throughout the study area
- overlay map with the finite difference grid, county boundaries, and pumping locations (Upper and Lower Floridan)
- overlay map with the sections, townships and ranges designated

2.3 Code Selection

The USGS three-dimensional ground-water flow code MODFLOW (McDonald and Harbaugh, 1988) was selected for use in this study because it is a well-accepted, public domain ground-water code developed by the USGS; it has been used in many previous studies to model regional ground-water flow in various parts of Florida, including Orange, Brevard and Osceola counties; it has the capability to incorporate the appropriate system features; it is computationally efficient and relatively easy to use; and it was used in the previous modeling effort on which this study is based (Blandford et al. 1991). There is also a great deal of accessory software, such as ModelCad (Geraghty and Miller, 1989), that enhances use of the model by providing efficient pre- and postprocessing capabilities.

MODFLOW is designed to simulate steady-state or transient ground-water flow through heterogeneous, anisotropic porous media in three dimensions, subject to a variety of complex boundary conditions. The code, therefore, is quite versatile in that it can be used to simulate a wide variety of hydrogeological conditions that may exist in the field. There are, however, certain intrinsic limitations associated with MODFLOW. These limitations, primarily as they relate to the current work, are listed below.

- MODFLOW is designed to simulate ground-water flow in porous media; the code may not be used to explicitly model flow in individual fractures, faults, or solution cavities.

- The effects of density and/or temperature on the ground-water flow field are not considered. Therefore, in regions where the dissolved solids content of the ground water is high enough to effect the pattern of ground-water flow, these concentration (density) effects are neglected.

- The aquifer material within individual grid cells is assumed to be homogeneous, and the grid is assumed to be aligned with the principal directions of hydraulic conductivity if the aquifer material is anisotropic.

- Stresses applied to a grid cell (e.g. pumping) are assumed to be distributed uniformly over the cell face.

3 HYDROGEOLOGICAL SETTING

3.1 Introduction

The geological and hydrogeological setting of the study region has been described by numerous authors (see Appendix A of Blandford et al. 1991). One of the most recent and comprehensive discussions is provided by Tibbals (1990). The following Sections are not intended to reproduce, but rather to summarize, the previous body of relevant literature as it pertains to the study at hand.

3.2 Geological Framework

A simplified geological section and corresponding hydrogeologic units, adapted from Tibbals (1990), is illustrated in Figure 3.1. Only about the upper 2,500 ft of sediments and geologic formations are of concern in this study. In general, the subsurface within the study area is dominated by the Lower Tertiary Ocala Limestone and the Avon Park, Oldsmar and Cedar Keys Formations. This thick sequence of carbonate rocks is overlain by the Hawthorn Formation, which consists of marine interbedded sands and clays that are often phosphatic. The Hawthorn Formation is in turn overlain by surficial Quaternary deposits consisting of undifferentiated sands, silts and clays. A series of isopach and depth-to-surface maps for the major units within the study area were produced by Miller (1986) and are reproduced in Tibbals (1990). The correlation of principal geologic and hydrologic units is based primarily on the permeability of the geologic media (which is closely related to lithology), and is discussed in Section 3.4.

Structural discontinuities within the Tertiary carbonate rocks exist due to faulting and sinkhole formation. The major faults within the study area tend to be aligned with major rivers such as the St. Johns and Kissimmee. However, except in the vicinity of Blue Spring, vertical displacement due to faulting is relatively minor (Tibbals, 1990). Sinkholes occur due to the dissolution of carbonate rocks over time. As a sufficient volume of rock is dissolved and carried away by ground water, the remaining infrastructure will eventually collapse under the weight

GEOLOGIC UNITS

Geologic Age	Thickness (feet)	Lithology/ Hydrogeology
Quaternary	20-100	Primarily quartz sand with varying amounts of clay and shell. Forms major portion of the surficial aquifer.
Miocene- Hawthorn Formation	0-200+	Marine interbedded quartz sand, silt and clay, often phosphatic. Generally relatively impermeable, but may form secondary artesian aquifer locally due to presence of limestone, shell and sand beds.
Upper Eocene- Ocala Limestone	0-125	Cream to tan, fine, soft to firm marine limestone. Moderately high transmissivity; forms the top of the Upper Floridan.
Middle Eocene- Avon Park Formation	600-1600	Upper section mostly cream to tan crystalline porous limestone. Lower section is brown, crystalline layers of dolomite alternating with chalky, fossiliferous layers of limestone. Upper portion forms about lower 2/3 of Upper Floridan. Lower portion forms upper part of Lower Floridan. Central portion has decreased porosity and forms middle semiconfining unit.
Lower Eocene- Oldsmar Formation	300-1350	Light brown to chalky, white, porous limestone with interbedded brown, porous crystalline dolomite. Forms significant portion of Lower Floridan.
Paleocene- Cedar Keys Formation	500-2200	Marine dolomite with considerable anhydrite and gypsum. Forms impermeable base of Floridan aquifer.

PRINCIPAL HYDROGEOLOGIC UNITS

Surficial Aquifer
Upper Semiconfining Unit
Upper Floridan Aquifer
Middle Semiconfining Unit
Lower Floridan Aquifer
Lower Confining Unit
Basement Rocks

Figure 3.1. Principal geologic and corresponding hydrogeologic units in east-central Florida. Based on Faulkner (in Tibbals, 1990), Lichtler et al. (1968), and McKenzie-Arenberg and Szell (1990).

of the overburden. The collapse may be sudden or occur very gradually over time. If the resulting circular depression is filled with water, the feature is referred to as a "sinkhole lake". There are many such lakes in the western and central regions of the study area.

3.3 Surface Water

Surface water features within the study area consist of rivers, lakes, swamps, canals and ditches. Three major surface water drainage basins intersect within the study area. The St. Johns River drains the east and east-central portion of the study area; the Oklawaha River (which is a major tributary to the St. Johns River north of the study area) drains the western portion of the study area; and the Kissimmee River drains the south-central portion of the study region.

There are numerous lakes within the study area, many of which are connected by natural streams and rivers or by manmade ditches and canals. Numerous swamps are also present; they occur primarily in the eastern portion of the study area and in the vicinity of major springs and streams. Depending upon their location, the surface water bodies may be either recharge areas or discharge areas for the ground-water flow system (see Figure 4.7). The St. Johns and Kissimmee Rivers, and their associated lakes and swamps, are dominant discharge areas within the study region.

3.4 Ground water

3.4.1 Surficial Aquifer

Three distinct aquifers separated by two semiconfining units compose the ground-water flow system in east-central Florida. The surficial aquifer is unconfined and is composed of interbedded, Quaternary-age sands, silts, clays and some peat. Thickness of the surficial aquifer sediments range from about 20 ft to a value perhaps as high as 100 ft. Although the surficial aquifer is capable of supplying limited quantities of water to wells, due to its high iron content and the highly productive nature of underlying aquifers, the surficial aquifer is used only locally for irrigation and (primarily near the coast) domestic supply. The water table is generally at or near the land surface in the vicinity of lakes and swamps, but may be tens of feet below land surface in the rolling highlands, where it tends to mimic the topography.

The primary sources of recharge to the surficial aquifer are rainfall, irrigation return flow, seepage from surface water bodies such as lakes, streams and ditches, and (in Floridan aquifer discharge areas) upward leakage from the underlying Floridan aquifer system. The primary sources of discharge from the surficial aquifer are evapotranspiration, seepage to surface water bodies, downward leakage to the Floridan aquifer system (in Floridan aquifer recharge areas) and pumping.

Depending upon the relative differences in hydraulic head, the primary hydrologic function of the surficial aquifer on a regional scale is to either recharge the underlying Upper Floridan aquifer, or to discharge ground water to surface water bodies such as lakes, streams, ditches and swamps.

3.4.2 Upper Confining Unit

The upper confining unit, which is composed of sands, sandy-clay and clay (often phosphatic) of the Hawthorn Formation and other Miocene and post-Miocene sediments, separates the surficial aquifer from the highly productive Tertiary limestones that form the Floridan aquifer system. Throughout the study area, the primary hydrologic functions of the upper confining unit are to confine the Floridan aquifer system under artesian pressure, and to transmit water between the surficial and Upper Floridan aquifers. The interchange of water decreases with decreasing head difference between the two aquifers, decreasing hydraulic conductivity of the confining bed, and increasing confining bed thickness.

It is important to note that the sediments of the upper confining unit confine the underlying Floridan aquifer system because their permeability is substantially less than that of the Upper Floridan aquifer. However, in the vicinity of the Cocoa well field, portions of the Hawthorn Formation form what is called the secondary artesian aquifer (or the "intermediate aquifer system"), which is considered as a potential source of water supply (CH2M Hill, 1988 and Tibbals and Frazee, 1976). McKenzie-Arenberg and Szell (1990) report that the intermediate aquifer occurs randomly throughout large portions of the study area at depths of 60-150 ft below land surface. Occurrence of the secondary artesian aquifer is related to the presence of highly permeable lenses of sand and shell within the Hawthorn Formation or within the post-Miocene sediments that directly overlay the Hawthorn Formation. On a regional scale, these lenses are relatively local geologic features (Tibbals and Frazee, 1976), and they therefore have limited regional significance.

3.4.3 Floridan Aquifer System

The Floridan aquifer system lies below the upper confining unit and is the major source of ground water within the study area. Tibbals (1990) states "The top of the Floridan is defined as the first occurrence of vertically persistent, permeable, consolidated, carbonate rocks." The thickness of the Floridan aquifer system ranges from about 2,000 ft in the northwest corner of the study area to about 2,800 ft in the southeast corner of the study area (Miller, 1986 in Tibbals, 1990).

The Floridan aquifer system has two distinct producing zones separated by a middle semiconfining unit. The upper production zone is referred to as the Upper Floridan aquifer, or simply the "Upper Floridan". The Upper Floridan consists entirely of the Tertiary age Ocala Limestone and the top portion of the Avon Park Formation. These marine limestones form an extremely prolific aquifer due to their high secondary porosity. The thickness of the Upper Floridan is approximately 300-400 ft throughout most of the study area, but in the southeastern corner of the study area the Upper Floridan thickness exceeds 500 ft (Miller, 1986).

The middle semiconfining unit separates the Upper Floridan and Lower Floridan production zones. This unit is composed of the Middle Eocene members of the Avon Park Formation, which are less permeable dolomitic limestones. The thickness of the middle semiconfining unit ranges from about 100 ft at the western edge of the study area to about 800 ft in the central and some far eastern portions of the study area (Miller, 1986 in Tibbals, 1990). The flow of ground-water between the Upper and Lower Floridan is controlled by the relative head differences between each zone as well as the permeability and thickness of the middle semiconfining unit.

The Lower Floridan is composed primarily of the Middle Eocene Avon Park Formation and the Lower Eocene Oldsmar Formation. Although capable of providing vast quantities of water, utility of the Lower Floridan for municipal water supply is limited in the eastern portion of the study area due to high saline content. In the central portion of the study area, however, the Lower Floridan supplies high quality water to several major pumping centers in the vicinity of Orlando and Apopka. The Paleocene Cedar Keys Formation forms the base of the Lower Floridan throughout the study area. These beds are relatively impermeable due to high amounts of gypsum and anhydrite.

Hydrogeologic data for the Lower Floridan is very limited, and it is difficult to accurately determine aquifer parameters. Tibbals (1990) determined through computer simulations of the Floridan aquifer system that the exchange of water between the Upper and Lower Floridan is relatively small compared to flow occurring within the Upper Floridan.

Recharge to the Upper Floridan is primarily by downward leakage from the surficial aquifer, except in the vicinity of Orlando where there are numerous drainage wells completed in the Upper Floridan scattered about the city. Discharge from the Upper Floridan occurs as spring flow, pumping, downward leakage to the Lower Floridan and upward leakage to the surficial aquifer. The source of recharge to the Lower Floridan is downward leakage from the Upper Floridan through the middle semiconfining unit. Discharge from the Lower Floridan occurs as upward leakage to the Upper Floridan and pumping.

Most pumping in east-central Florida for municipal, industrial and agricultural purposes occurs in the Upper Floridan, except in the vicinity of Orlando, where withdrawals are limited to small public supplies because of high bacterial levels (Schiner and German, 1983).

4 DATA ANALYSIS

4.1 Potentiometric Surface Maps

4.1.1 Potentiometric Surface Prior to Development

Figure 4.1 illustrates the potentiometric surface of the Upper Floridan within the study area prior to ground-water development. This figure was adapted from a multistate potentiometric surface map of the entire Tertiary limestone aquifer presented by Johnston et al. (1980). In reference to this map, Tibbals (1981) states

> "This map is a composite of many other maps: recent potentiometric surface maps in areas where pumping has been light; and older maps or modifications of them were ground-water development has been extensive. The map is intended to show the best estimate that can be made with available data of the 'average' potentiometric surface as it existed prior to development."

Since ground water flows from areas of high potentiometric surface levels to areas of low potentiometric surface levels, the predevelopment regional ground-water flow in the Upper Floridan is predominantly from the southwest towards the northeast. The potentiometric surface depressions caused by the discharge of springs within the study area is reflected by the 50 ft and 40 ft potentiometric surface contours in northwestern Orange County. No information is available for the potentiometric surface of the Lower Floridan prior to ground-water development, but it is generally believed that regional ground-water flow directions in the Lower Floridan tend to mimic those in the Upper Floridan.

A comparison of the predevelopment potentiometric surface map with the average 1988 potentiometric surface map (Figure 4.2 in Section 4.1.2) indicates three regions where the 1988 potentiometric surface is higher than the predevelopment surface. These regions are 1) a portion of western Orange County and all of southern Lake County which is included in the study area; 2) portions of northern Lake County and southwest Volusia County in the vicinity of the north-central model boundary; and 3) a relatively small region in northern Orange County in the

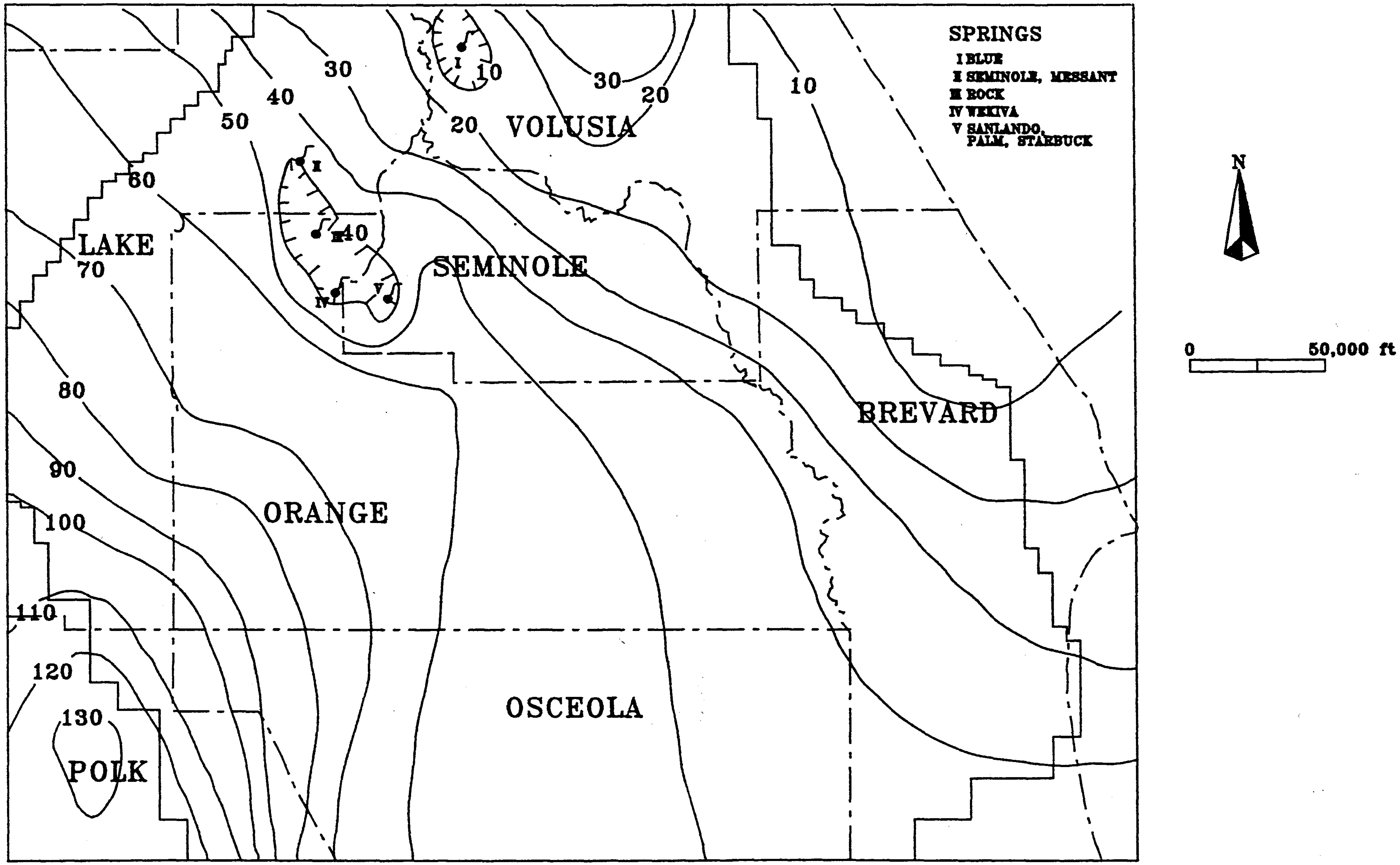

Figure 4.1. Average Upper Floridan potentiometric surface map for predevelopment conditions in feet above msl. Adapted from Johnston et al. (1980).

vicinity of Wekiva Spring. Since it would generally be expected that the postdevelopment (1988) Upper Floridan potentiometric surface would be lower than the average predevelopment surface, it is believed that the predevelopment surface may be somewhat in error in the regions that exhibit a discrepancy.

4.1.2 Potentiometric Surface for 1988

Potentiometric surface maps for the Upper Floridan aquifer are constructed bi-annually by the USGS for the months of May and September. These two periods are believed to be indicative of the extreme potentiometric surface fluctuations within the Floridan aquifer system. The May map represents the potentiometric surface following the relatively dry period in Spring, which is usually a period of relatively large aquifer withdrawals. The September map represents theeffects of recharge to the Upper Floridan following the wet summer period, which is usually a period of relatively small aquifer withdrawals.

It has been noted by previous researchers that, in general, the potentiometric surface of the Upper Floridan does not change appreciably from year to year. Blandford et al. (1991) compared the potentiometric surface maps for 1987, 1988 and 1989 and this was indeed found to be the case. Furthermore, although seasonal fluctuations were observed in some regions of the study area, in the vicinity of the boundaries of this study seasonal fluctuations were found to be relatively small. These observations suggest that the ground-water flow regime in the Upper Floridan in east-central Florida existed in a quasi steady-state condition during 1987-1989, with a superimposed cyclic variation due to seasonal variations in climate and pumping.

Since the primary objective of this study is to develop a long-term, steady-state predictive capability for ground-water flow in the Upper Floridan, the postdevelopment model calibration was performed using an average potentiometric surface for the calendar year 1988. The average Upper Floridan potentiometric surface map for 1988 (Figure 4.2) was derived by averaging the respective potentiometric surface maps for May (Schiner, 1988) and September (Rodis, 1989). The procedure used is as follows: 1) the potentiometric surface maps for May and September

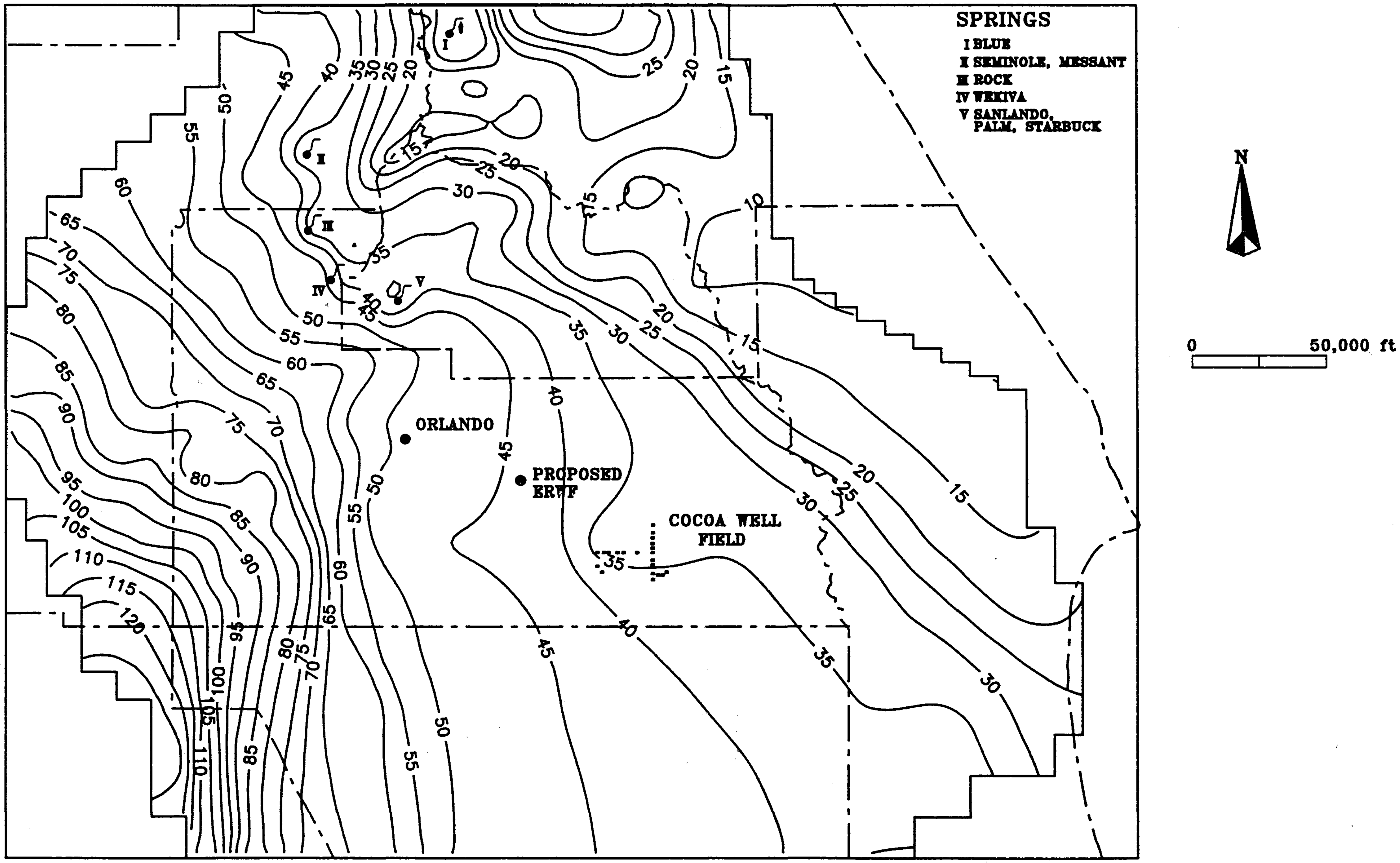

Figure 4.2. Average Upper Floridan potentiometric surface map for 1988 in feet above msl.

1988 were digitized; 2) each of the maps was plotted using the SURFER software package (Golden Software) to ensure that the potentiometric surface could be accurately reproduced; 3) the SURFER grid files for May and September were averaged to obtain the average 1988 head field; and 4) the contour plot produced using the averaged head file was spot-checked manually to ensure its accuracy.

Figure 4.2 clearly illustrates many of the major features of the ground-water flow system within the study area. The pronounced cone of depression about the Cocoa well field is clearly displayed by the 35 ft contour line in eastern Orange County. Discharge points formed by the Sanlando, Palm and Starbuck Springs trio; Wekiva Spring and Miami Spring; Rock Spring; Seminole Spring and Messant Spring; and Blue Springs are all evident. The steepest gradients and the highest potentiometric surface values are in the southwest quarter of the project area, which lies just east of the Green Swamp potentiometric high (Pride et al., 1966). Along the eastern edge of the study area in central and northern Brevard County, ground water tends to move due north, approximately parallel to the coast, due to the presence of a ground-water trough in this region. In general, ground water in the Upper Floridan moves from the southwest towards the northeast within the study area.

The 45 ft potentiometric surface contour (Figure 4.2) shows a pronounced inflection west of the Cocoa well field. At first glance, this contour would seem to be indicative of a cone of depression. However, there are no major pumping centers within this particular region. The May and September potentiometric surface maps each show similar inflections west of the Cocoa well field, although they are less pronounced. On the May map, the inflection lies to the west of its location in Figure 4.2, and on the September map, the inflection lies well east of its location on Figure 4.2. Although this 45 ft contour inflection should probably be slightly less pronounced (more rounded) than it is on the average potentiometric surface map, its existence may not be attributed to the averaging process. The physical processes or properties that cause this inflection are unknown, although it is due in part to drawdown effects caused by the Cocoa well field.

In addition to the Cocoa well field, the location of Orange County's proposed Eastern Regional well field (ERWF) is also indicated on Figure 4.2 and the subsequent figures in this report. Although not currently in existence, this well field has a major effect on the predictive simulations discussed in Chapter 6, and its location is therefore provided for reference purposes.

4.2 Ground-Water Withdrawal Rates for 1988 Calibration

Ground-water withdrawals within the study area can be classified into three major categories: 1) municipal and industrial (MI) pumping; 2) agricultural (citrus and non-citrus) pumping; and discharge due to abandoned flowing wells. In 1988 the MI pumping accounted for about 72% of the total withdrawals, while agricultural pumping for citrus and non-citrus crop irrigation accounted for about 12% and 16% of the total pumping respectively (Table 4.1). The withdrawal estimates assigned to each grid block within the study area are listed in Appendix A by category. Aside from some municipal pumping in the vicinity of Orlando and east of Lake Apopka, and several locations that have pumping from both the Upper and Lower Floridan, all of the withdrawals were derived from the Upper Floridan. The values listed in Appendix A are considered average pumping rates for 1988, and may or may not be valid for other years. The data sources used, and the assumptions made to obtain the MI and agricultural pumping estimates are outlined in the following two sections. Withdrawals for heat pump, lawn irrigation and self-supplied domestic purposes were not incorporated directly into pumping estimates, but were rather considered to be incorporated within the model areal discharge rates as described in Section 5.1. This approach was adopted because insufficient data was available to develop accurate, site-specific discharge rates for these withdrawal categories.

4.2.1 Municipal and Industrial Withdrawals

The MI pumping rates used in this study were generally the same as those used for the previous modeling effort (Blandford et al., 1991). As detailed in that report, the 1988 MI pumping rates

Table 4.1. Total pumpage estimates for 1988 by category.

Source of Pumping	Discharge		Percent of Total
	(ft^3/d)	MGD	
MI - Upper Floridan	24,530,781	183.49	51.00
MI - Lower Floridan	9,967,942	74.56	20.71
Agriculture - Citrus	5,368,773	40.16	11.16
Agriculture - Non-Citrus	5,756,903	43.06	11.96
Deseret Ranches and Duda Sod Farm	2,164,983	16.19	4.50
Abandoned Flowing Wells	331,504	2.48	0.69
Total	48,120,886	359.94	100.00

were supplied by SJRWMD in the form of Monthly Operating Reports (MOR's) that listed pumping per well or well field in mgm (million gallons per month) or mgd (million gallons per day). Where lumped discharge values were provided for multiple wells or a well field, the total discharge for 1988 was divided by the number of wells to obtain an average pumping rate per well. For a small number of pumping centers, primarily those within the Reedy Creek Improvement District, 1988 discharge values were not available and 1989 values were used instead. Also, some additional pumping locations were discovered and included in the present study that were not included in Blandford et al. (1991).

The MI pumping is documented in the LOTUS files PH4M&IQ.WK1 and PH488Q.WK1 on the diskette provided with this report. The first file, PH4M&IQ.WK1, contains the names, latitude, longitude and average annual discharge of individual wells identified within the study area. The file PH488Q.WK1 contains the model grid layer, row and column and the associated MI discharge.

MI discharge values were assigned to model cells using the latitude and longitude values for the well locations. The program POINTS.EXE, supplied by SJRWMD, was used to obtain State Plane coordinates for each latitude/longitude pair. Since the State Plane coordinates of the four corners of the model grid were known, it was a simple task to assign any given point to the appropriate model cell. The location of model cells that had MI pumping specified within them for 1988 are shown for the Upper Floridan and Lower Floridan model layers in Figures 4.3 and 4.4, respectively. The model grid and boundary conditions are also presented in these figures; a detailed discussion of these features is provided in Chapter 5.

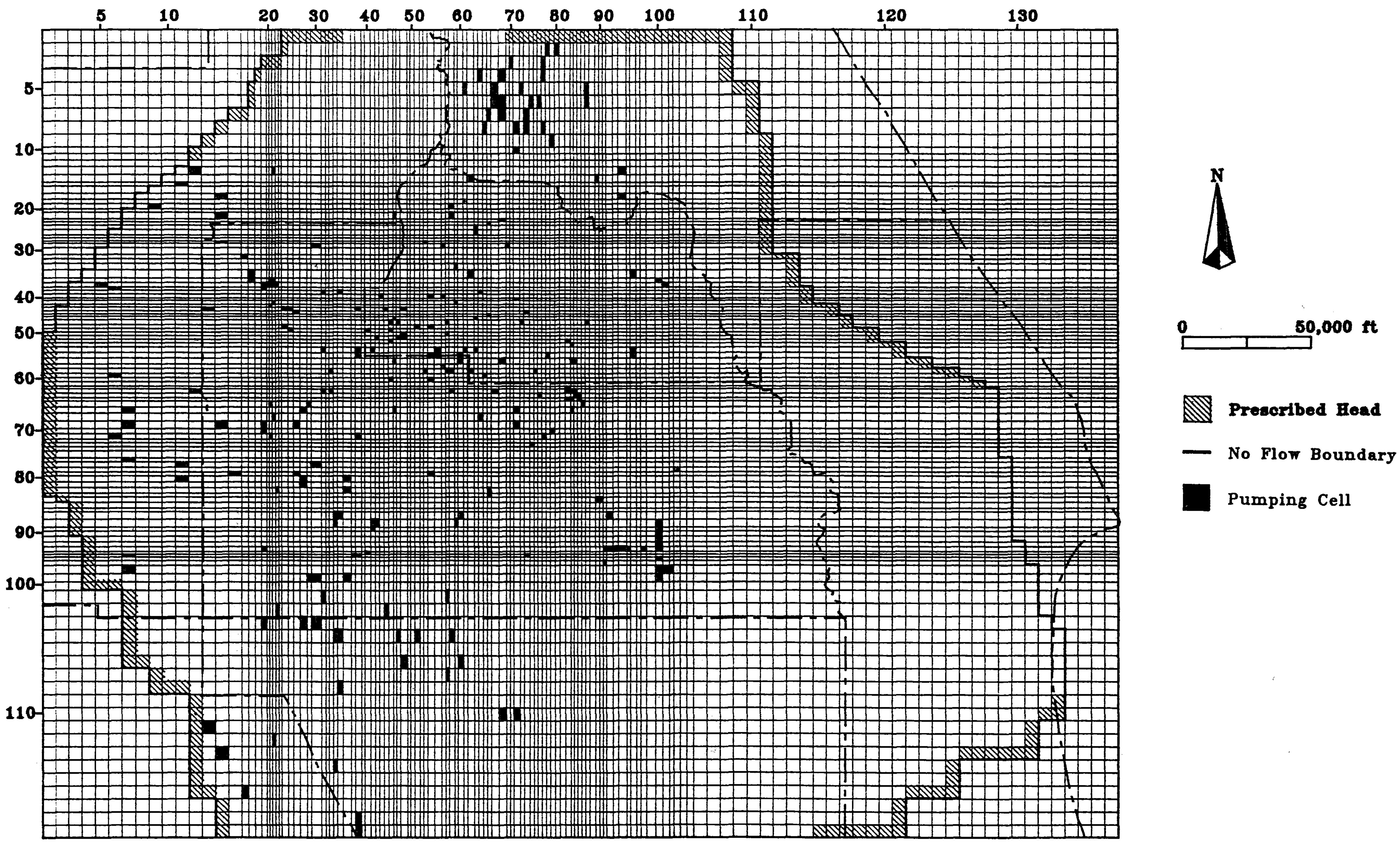

Figure 4.3. MI pumping locations and boundary conditions for Upper Floridan (model layer 1). No flow boundaries exist wherever prescribed head boundary is not indicated.

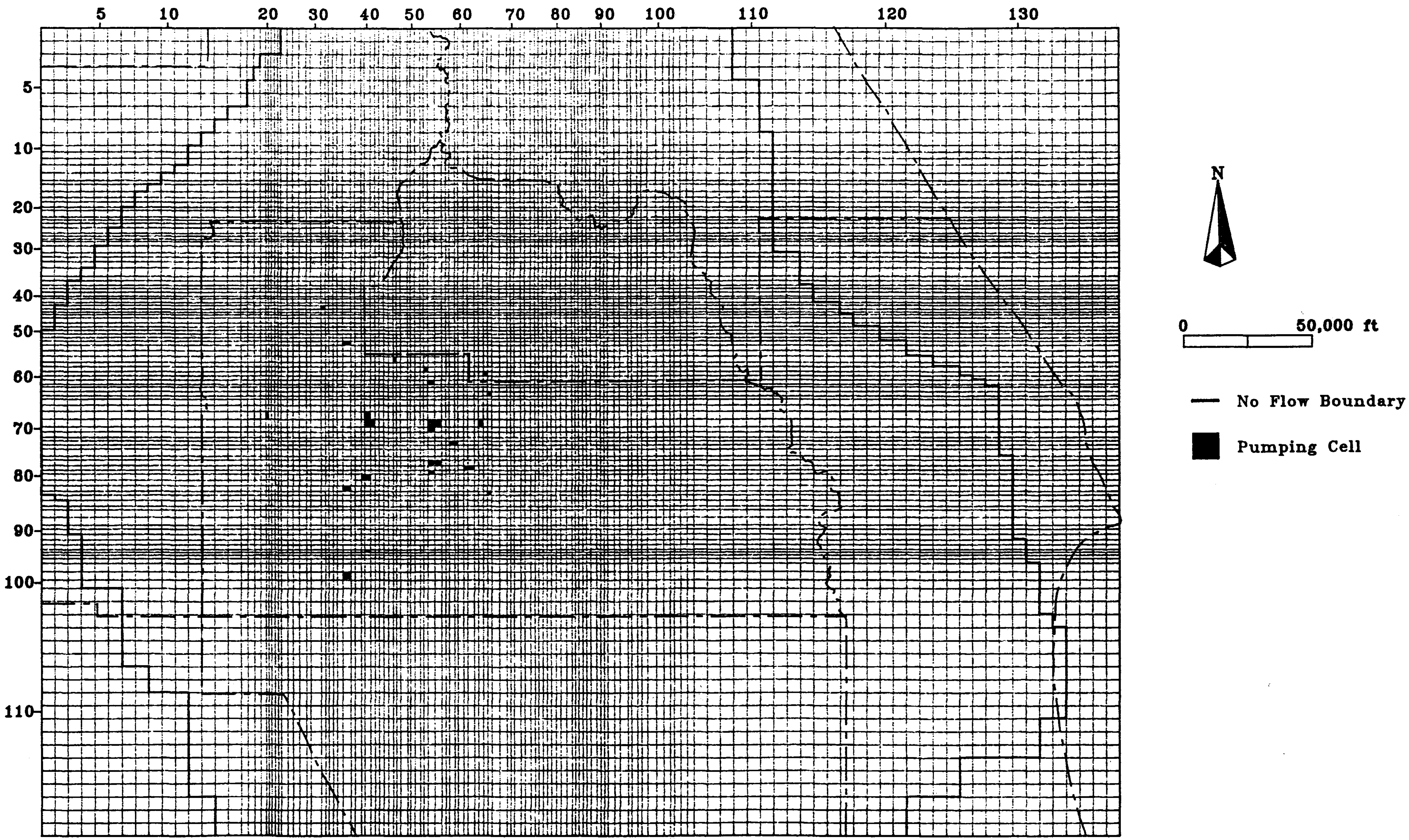

Figure 4.4. MI pumping locations and boundary conditions for Lower Floridan (model layer 2).

4.2.2 Agricultural Withdrawals for 1988

4.2.2.1 Irrigation Requirement for Citrus Crops

A table of citrus tree acreage and location (by section, township and range) was obtained from the Florida Agricultural Statistics Service (FASS). FASS compiled the table using areal photography, and they also field checked an unknown portion of the determined acreage. In general, only sections with more than 50 acres of citrus were included in the table. This information was used by SJRWMD staff to compute the 1988 irrigation requirement for citrus crops within the study area using the District's modified Blaney-Criddle method (Appendix B.3 of Blandford et al. 1991). The required temperature and rainfall input data were obtained from National Oceanic and Atmospheric Administration (NOAA) climatological stations. Major assumptions used to obtain the listed irrigation requirements include:

- the average irrigation efficiency for 1988 was 82.5%
- the irrigation requirement per section was supplied entirely by pumpage from the Upper Floridan
- the irrigation requirements are average rates spread evenly throughout the year.

The location of each section that had a citrus irrigation requirement was plotted on the base map, and the estimated requirement (pumping) was assigned to the model cell that incorporated the center of the designated section (Figure 4.5). The major assumptions involved in this method of estimating agricultural pumping for citrus are: 1) the irrigation requirements calculated using the Blaney-Criddle method are indicative of actual average withdrawal rates, and 2) the irrigation wells reside close to the section centers for which a citrus irrigation requirement was reported. Some citrus groves southwest of Orlando are irrigated by re-use water as part of Orange County's and the City of Orlando's Conserve II Project. These groves were deleted from the above analysis.

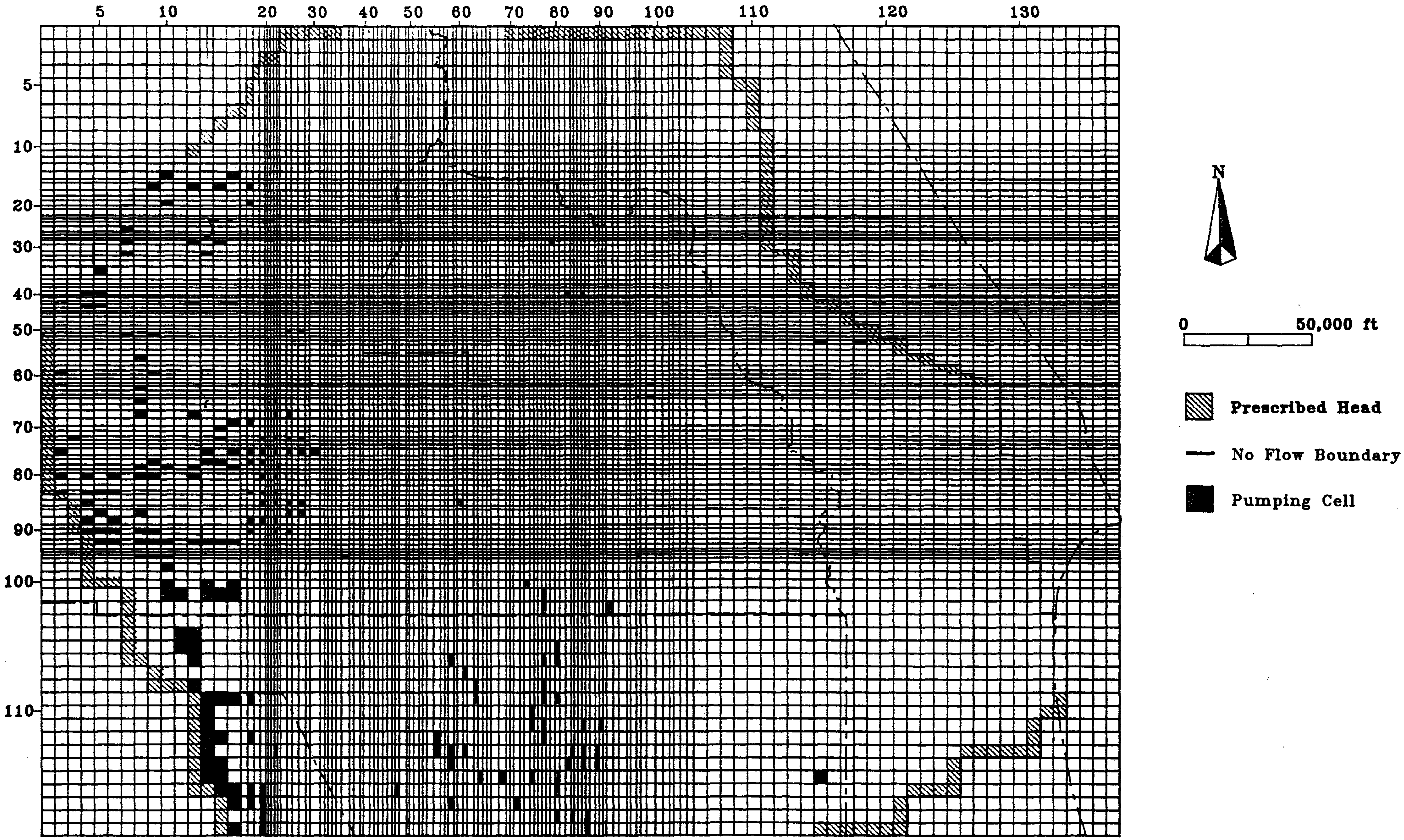

Figure 4.5. Locations of citrus withdrawals for 1988 in the Upper Floridan.

An effort was made to independently verify the estimated citrus irrigation requirements using the Benchmark Farms Project citrus groves within the study area. The comparison in Table 4.2 shows that the irrigation requirements computed using the modified Blaney-Criddle method lie between the two extreme values measured at Benchmark Farms sites that were reported to have "good" quality data. The Benchmark Farms reported values differed considerably at several sites that were in close proximity to one another. The reason(s) for this are unknown, although the differences might be due primarily to local variation in meteorological variables such as rainfall. Although the Blaney-Criddle estimates of the citrus irrigation requirements are undoubtedly averaged values (the extreme high and extreme low local values are not accounted for), in light of the purposes of this study they are believed to be reasonable estimates of average pumping for the irrigation of citrus during 1988. It is also interesting to note that if the Benchmark Farms average requirement is taken neglecting the three lowest values, an average irrigation requirement very close to the average requirement calculated using the modified Blaney-Criddle method is obtained.

4.2.2.2 Irrigation Requirement for Non-Citrus Crops

The 1988 irrigation requirement for non-citrus crops was obtained from Lynne and Kiker (1991), who present estimated agricultural water use for 1990, 1995 and 2010. This data is hereafter referred to as the Institute of Food and Agricultural Sciences (IFAS) data. The 1990 water use estimates were computed using permitted acreages and crop types (from the SJRWMD) in conjunction with the AFSIRS irrigation requirement simulation model (Smajstrla, 1990). There are two major assumptions inherent in this approach: 1) the irrigation requirements for 1990 are assumed to be similar to those of 1988, and 2) the permitted acreages are assumed to be indicative of actual irrigated acreages. The applicability of each of the above assumptions is unknown. However, since Lynne and Kiker (1991) provide the most recent and comprehensive assessment of irrigation requirements within the SJRWMD, it was deemed appropriate that, in lieu of a better methodology, their data be used.

Table 4.2. Comparison of irrigation requirements computed using the Blaney-Criddle method and measured at Benchmark Farms sites.

Data Source	Irrigation Requirement (in/yr)		
	High	Low	Average
Blaney-Criddle Method	17.05	8.66	13.82
Benchmark Farms	26.3	0.0013	9.37

* Note - out of the 13 Benchmark Farms sites with good data quality in the study area, if the lowest 3 sites are deleted from the data set, the average requirement becomes 13.5 in/year.

A series of LOTUS spreadsheet files, organized by county (Orange, Seminole, Lake, Volusia and Osceola), were obtained from IFAS at the University of Florida (Cynthia Moore, personal communication, 1991). Each of these spreadsheet files lists irrigation well locations in latitude and longitude, SJRWMD permit number, and estimated irrigation requirements by month. The information obtained from these files was screened to delete permitted withdrawals that were emplaced after July, 1988. Permitted withdrawals that used surface water exclusively were also omitted. Permitted withdrawals indicating that a combination of surface water and ground water would be used were divided to the extent possible. For example, permits that listed ground water as a backup source only were omitted, while permits that listed surface water as a backup source only were included in the analysis. If the primary source of the permitted withdrawal was not evident, 50 percent of the permitted value was assumed to be ground water. The SJRWMD also supplied a data file of actual irrigated acreage for fernerys in Seminole and Volusia County obtained through a series of field checks. For the most part, the permitted acreages were the same as the field checked acreages. Where there was a discrepancy the IFAS irrigation requirement was adjusted accordingly (e.g., if the true acreage was one-half of the permitted acreage, the irrigation requirement was reduced by half). Since the irrigation requirements were organized by the latitude and longitude of individual wells, the withdrawals were assigned to model grid blocks in the same manner as the MI pumping (Section 4.2.1). Figure 4.6 illustrates the distribution of the non-citrus agricultural withdrawal points.

For the portion of the study area within the South Florida Water Management District (SFWMD), there was some permitted pumping for non-citrus agricultural purposes. For these withdrawal locations, the permitted discharge value was used as documented in the SFWMD permit files. These withdrawals were located in the model grid manually, since the SFWMD permit files contain locations in Section - Township - Range format, rather than latitude and longitude.

The primary users of ground water for the irrigation of non-citrus crops in the southeast quarter of the study area are Deseret Ranches and the Duda Sod Farm. Since estimated irrigation requirements for pasture and sod in Osceola and Brevard counties were not available in the IFAS

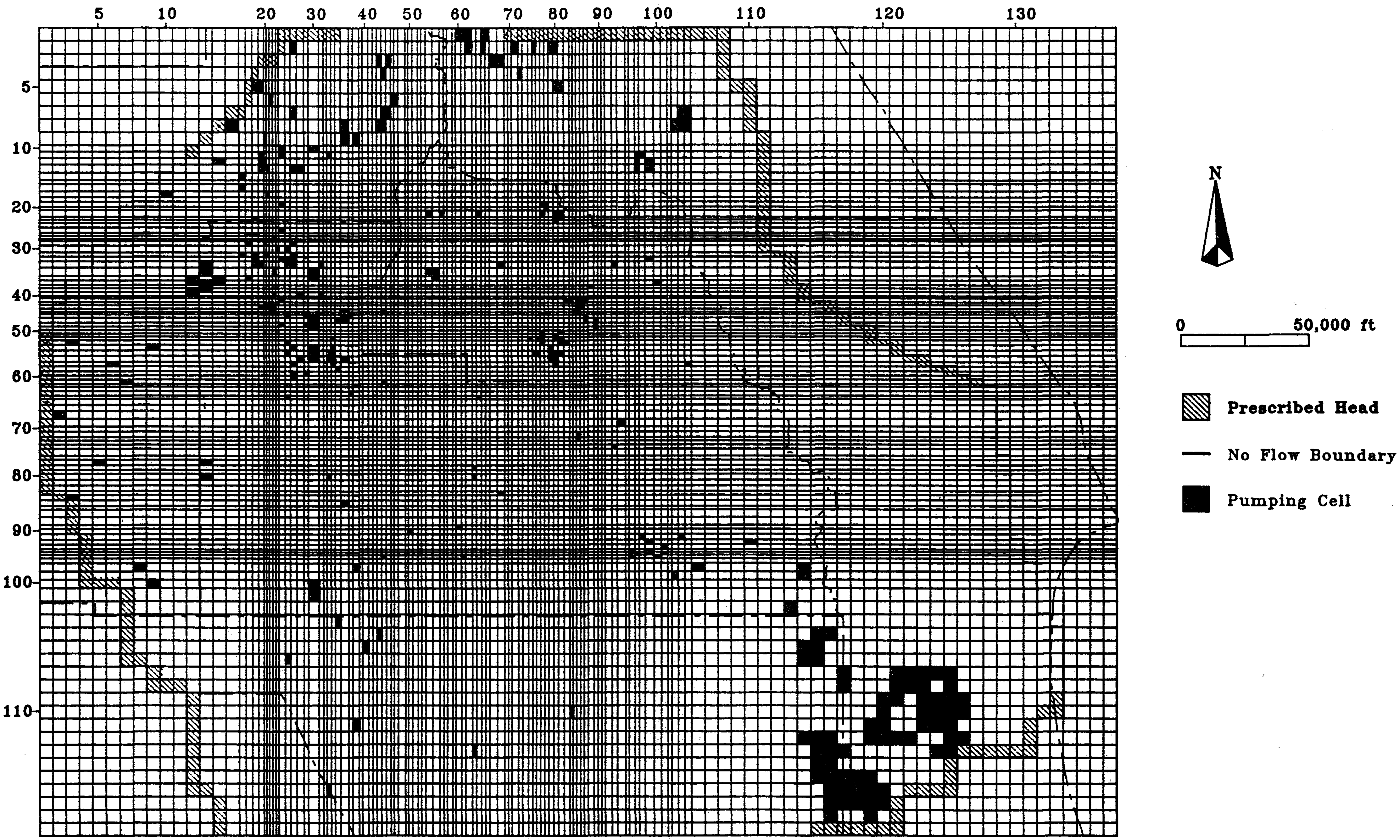

Figure 4.6. Locations of agricultural (non-citrus) withdrawals for 1988 in the Upper Floridan.

files, a different approach was taken to estimating withdrawals due to these two users. The eleven CUP quadrangles that cover the holdings of Deseret Ranches and the Duda Sod Farm (Narcoossee; Narcoossee NW, NE, and SE; Lake Poinsett and Lake Poinsett NW and SW; Cocoa; Deer Park and Deer Park SE; and Eau Gallie) were supplied by the SJRWMD. Using these quadrangle maps in conjunction with the consumptive use permitting files, the wells that belonged to Deseret Ranches and the Duda Sod Farm were plotted on the model grid. The number of wells in each respective grid block and the owners were then tabulated.

The next step was to assign discharge estimates to each of the wells. Crop types and acreages were categorized by user using the CUP files. A summary of this information is presented in Table 4.3. Deseret Ranches was permitted for 14,120 acres of pasture, and the Duda Sod Farm was permitted for 23,295 acres of pasture and 730 acres of sod. It is not known how closely these totals agree with the actual irrigated acreage for 1988. However, in the 1988 Water Use Survey (Florence, 1990), a total of 11,180 acres of irrigated improved pasture is listed for Osceola County. This value should be due almost exclusively to Deseret Ranches (Pers. Comm., Brian McGurk, SJRWMD); and it is relatively close to the CUP value of 14,120 acres. Similarly, the Water Use Survey reports a total of 1,000 irrigated acres of sod in Brevard County - a value that is reasonably close to the CUP estimate for Duda Sod Farm of 730 acres.

Finally, the estimated irrigated crop acreages were multiplied by the estimated irrigation requirement factors derived in Blandford et al. (1991). This procedure provided a total discharge per user. The total discharge was then divided by the number of wells to provide an average discharge per well (Deseret Ranches had 112 wells and Duda Sod Farm had 95). This procedure is identical to that used by Blandford et al. (1991). However, it was determined in that study, through model calibration, that the irrigation requirements in this region computed using permitted acreages were probably overestimated by at least 50 percent. This conclusion is consistent with Lynne and Kiker (1991), who state that much of the pasture land in the SJRWMD does not seem to be irrigated at all. The final withdrawal values assigned to the Deseret Ranches and Duda Sod Farm were reduced by 50 percent.

Table 4.3. Major agricultural users in Deseret Ranches/Duda Sod Farm area.

Owner	Acreage	Crop	County
Deseret Ranches	13,480	Pasture	Orange, Osceola, Brevard
Duda & Sons, Inc.	23,295	Pasture	Brevard
	730	Sod	
Deseret Ranches	640	Pasture Land	Orange
	5,000	Beef Cattle*	

* Beef cattle were not included in the agricultural withdrawal estimates

4.2.3 Abandoned Flowing Wells

Abandoned flowing (artesian) wells within the study area that had, or were likely to have, discharges greater than 70 gpm (13,475 ft^3/d) were selected from the SJRWMD abandoned well inventory (Steele, 1990). Appendix B.5 of Blandford et al. (1991) provides a listing of the selected wells, along with their locations, and reported or assigned discharges. Although these wells were included in this study for the sake of completeness, their effect on the regional ground-water flow field, as determined through the numerical simulations discussed in Chapter 5, is insignificant. However, it is not known how complete the existing abandoned well inventory is within the study area. All flow from abandoned wells was assumed to be from the Upper Floridan.

4.3 Spring Discharges

There are 16 documented springs with significant discharges within the study area; 9 of these had gauged discharge values for 1988. Table 4.4 lists each spring, its latitude and longitude,its State Plane coordinate pair, and its location (row and column) within the model grid. Table 4.5 lists the predevelopment and postdevelopment (1988) discharge values measured or estimated for each spring. All of the spring discharge was assumed to come from the Upper Floridan.

The measured spring discharge values for 1988 in Table 4.5 were obtained from the Water Resources Data Report for Florida (USGS, 1989 and 1990). For most of the springs, the May and September reported discharges were averaged to obtain an average discharge for 1988. Seminole Springs and Messant Springs only had May values reported, and these were used as input to the model. Blue Springs is by far the largest spring in the study area, and it is monitored on a bi-monthly basis. For this spring, each of the six discharge estimates available for the 1988 water year were averaged to obtain an average discharge of 12,340,800 ft^3/d.

Table 4.4. Spring locations in latitude and longitude, State Plane coordinates, and model grid row and column.

Spring	Lat	Long	State Plane Coord. X(ft)	State Plane Coord. Y(ft)	Row	Col
Apopka	283400	814051	281454.92	1539285.85	68	11
Rock	284520	812958	339968.20	1607676.72	30	33
Witherington	284353	812922	343136.34	1598876.62	34	35
Wekiva	284243	812736	352545.92	1591769.23	38	39
Miami	284236	812634	358063.98	1591041.36	38	42
Sanlando	284119	812345	373086.74	1583211.73	44	51
Palm	284127	812334	374069.09	1584016.47	43	51
Starbuck	284148	812328	374610.41	1586135.63	42	51
Lake Jessup	284236	811605	414072.91	1590874.46	38	71
Clifton	284156	811414	423948.75	1586813.70	41	77
Seminole	285044	813122	332635.48	1640432.44	13	30
Messant	285121	812956	340299.19	1644136.52	12	34
Island	NA	NA	NA	NA	15	48
Gemini	285144	811839	400504.71	1646254.18	11	65
Blue	285650	812023	391346.12	1677185.25	4	60
Camp La-No-Che	285702	813224	327295.68	1678635.29	4	28

Table 4.5. Predevelopment and postdevelopment (1988) spring discharge.

Spring	Predevelopment Q		Postdevelopment Q	
	(ft^3/s)	(ft^3/d)	(ft^3/s)	(ft^3/d)
Apopka*	61.25	5292000	61.25	5292000
Rock	65.00	5616000	58.50	5054400
Witherington*	4.00	345600	4.00	345600
Wekiva	74.00	6393600	69.50	6004800
Miami	5.00	432000	5.15	444960
Sanlando	19.00	1641600	19.50	1684800
Palm	10.00	864000	6.25	540000
Starbuck	17.00	1468800	14.50	1252800
Lake Jessup*	1.00	86400	0.65	56160
Clifton*	2.00	172800	1.30	112320
Seminole	36.00	3110400	39.00	3369600
Messant	20.00	1728000	14.00	1209600
Island*	6.00	518400	6.00	518400
Gemini*	8.00	691200	8.00	691200
Blue	160.00	13824000	142.83	12340800
Camp La-No-Che*	1.00	86400	0.70	60480
	489.25	42271200	451.13	38977920

* Annual discharge not monitored

For the seven springs denoted by asterisks in Table 4.5, annual discharge measurements are not performed. For each of these springs except Apopka, the flows were estimated using data provided in Tibbals (1990). Observations were reported for four of the springs at various times as follows; Clifton Spring (5/73), Island Springs (5/82), Gemini Spring (4/72) and Camp La-No-Che Spring (3/72). To determine whether or not the observed spring flows in 1972, 1973 and 1982 are indicative of 1988 conditions, a comparison was made between spring flows reported by Tibbals (1990) and those reported in the Water Resources Data Report (USGS, 1989). The comparison is presented in Table 4.6, which illustrates that the spring flow measurements reported by Tibbals (1990) for 1973 and 1981 compare quite favorably with those measured in 1988. Therefore, for the four springs listed above the discharges measured at earlier times are deemed reasonable for use as 1988 spring flows.

For Witherington Spring, Tibbals's value of 4 ft^3/s derived from a numerical simulation for the year 1978 was used. For Lake Jessup Spring, a value one-half that of Clifton Spring was used after data reported in Tibbals (1990). During 1988 the USGS measured Apopka Spring discharges of 58.5, 64.0 and 70.4 ft^3/s during the months of May, September and November respectively (Doug Durden, personnel communication, SJRWMD). The average of the May and September measurements (61.25 ft^3/s) was used as the 1988 and the predevelopment discharge for Apopka Spring. All of the other predevelopment spring flows were taken from Tibbals (1990).

The springs within the study area have a very significant impact on the regional flow system. Figures 4.1 and 4.2 illustrate the pronounced depressions in the average potentiometric surface of the Upper Floridan north of Orlando. The combined 1988 spring discharge of 38,977,920 ft^3/d (451 ft^3/s) is approximately 14 percent greater than the total estimated withdrawals from the Upper and Lower Floridan for municipal and industrial purposes.

Table 4.6. Comparison of spring discharges documented at various times.

Spring	Date	Discharge (ft^3/s)[a]	Date	Discharge (ft^3/s)[b]
Wekiva	5/73	72	5/88	67
Rock	5/73	62	5/88	58
Miami	5/73	5	5/88	4.9
Sanlando	5/73	20	5/88	19
Palm	5/73	9	5/88	6.1
Starbuck	5/73	15	5/88	15
Seminole	4/81	32	5/88	39
Messant	4/81	14	5/88	14
TOTAL		229		223

[a] From Tibbals (1990)
[b] From USGS (1989)

Note: 1 ft^3/s = 86,400 ft^3/d

4.4 Areal Recharge and Discharge

Figure 4.7 is a map of recharge and discharge areas for the Upper Floridan adapted from Tibbals (1990). The accuracy of this map was spot-checked for 1988 hydrologic conditions using measured lake level elevations and the May and September potentiometric surface maps for the Upper Floridan. Using the relative heads in the vicinity of approximately 19 lakes, the direction of ground-water flow (downward for recharge or upward for discharge) could be determined. At each of the selected locations, the relationship indicated in Figure 4.7 could be verified. The general features of the map were also cross-checked against other publications such as Aucott (1988), Phelps (1984) and McKenzie-Arenberg and Szell (1990).

A detailed check of Figure 4.7 was also conducted using the average 1988 Upper Floridan potentiometric surface (Figure 4.2) and the determined nodal values of hydraulic head in the surficial aquifer (Section 4.5). The surficial aquifer heads were determined based upon the elevation of surface water bodies within a model cell as indicated by USGS 1:24,000 scale (7½ minute) topographical maps. Although there is some error inherent in this approach since the topographical maps were constructed or revised during various years (generally the 1960's and 1970's), it has generally been assumed by other researchers (e.g. Tibbals (1990)) that head fluctuations in the surficial aquifer do not vary significantly (relative to head in the upper Floridan) through time. Furthermore, the uncertainty inherent in the interpolated surficial aquifer head values would only affect the determination of the direction of flow in marginal recharge or discharge areas.

Overall, the recharge distribution illustrated in Figure 4.7 agreed well with that determined using the average 1988 potentiometric surface and the estimated surficial aquifer heads. However, there were two significant marginal recharge areas (recharge of 1-3 inches/yr) delineated in Figure 4.7 that were determined to be discharge areas for 1988 conditions. These are the low-lying region that extends from the northwest shore of Lake Apopka to the general vicinity of Lake Harris, and the northwest-southeast trending region in the vicinity of Blackwater Creek

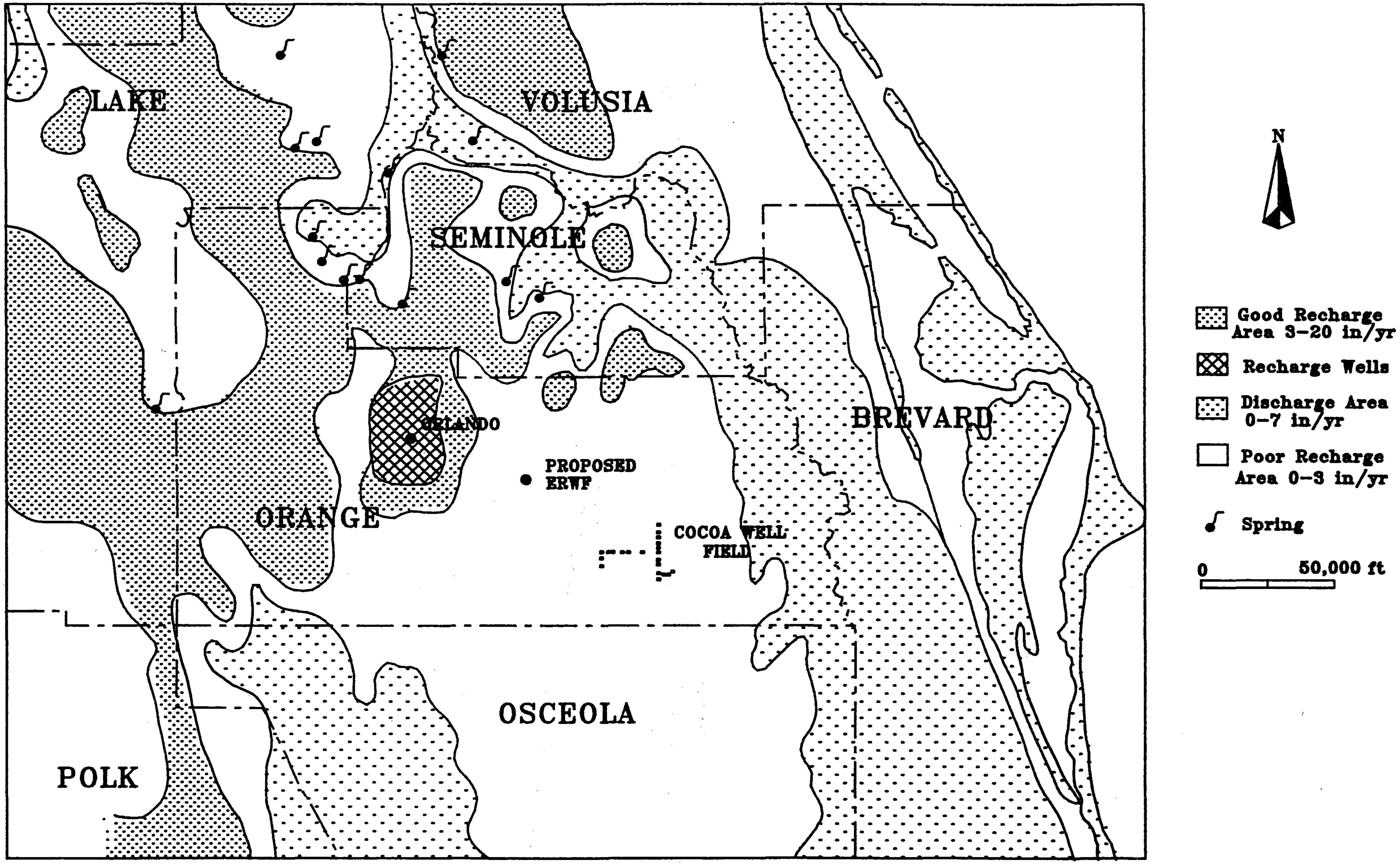

Figure 4.7. Areal recharge-discharge map for Upper Floridan in east-central Florida. Adapted from Tibbals (1990).

north of Wekiva Swamp (the general area of Camp-La-No-Che, Seminole and Messant Springs). Also, the region just west of Lake Tohopekaliga appears to be a very marginal recharge area for 1988 conditions, and it is delineated as a discharge area in Figure 4.7. Finally, the position of the Geneva freshwater lens in northeast Seminole County should be shifted slightly to the east of its position in Figure 4.7 (Tibbals, 1977). Since the direction of leakage is far easier to determine than the quantity of leakage, the magnitudes of the recharge/discharge indicated on Figure 4.7 were used as general guidelines of actual hydrologic conditions.

Figure 4.7 also shows the region about Orlando within which there are numerous drainage wells. Szell (1987) reports 374 active drainage wells used to dispose of storm water runoff from roads, lakes and creeks; industrial wastes of various types; air conditioning cooling water; and sewage effluent. Out of the 374 active drainage wells, only ten are open to the Lower Floridan (Szell, 1987). Tibbals (1990) reports an average recharge due to the drainage wells of 33 mgd, while Kimrey (1978) suggested a higher value of perhaps as much as 50 mgd.

Recharge to the Upper Floridan due to drainage wells was incorporated into the postdevelopment simulations in the following manner. A file of drainage well locations (latitude-longitude) supplied by the District was analyzed to determine the number of drainage wells per model cell. The flux value of 33 mgd was then divided among the model cells in accordance with the number of wells contained in each cell. The major assumption involved in this process is that each drainage well disposes of the same volume of water, on an average annual basis, as does every other drainage well. The recharge due to drainage wells is listed by model cell in Appendix B.

Another source of artificial recharge are the City of Orlando's and Orange County's Conserv II project rapid infiltration basins. These large, sand-lined basins are located west of Orlando near the Lake/Orange County border, and they dominate Sections 9, 16, 17, 19, 29 and 32 in Township 23 South, Range 27 East.

4.5 Hydraulic Head in the Surficial Aquifer

To incorporate variable leakage to or from the Upper Floridan via the surficial aquifer as a head-controlled flux boundary condition (Section 5.1), it was necessary to estimate a hydraulic head value (water-table elevation) representative of the surficial aquifer for each model cell in the top layer of the finite difference grid. Initial values of surficial aquifer head were assigned to the model cells using a data set (obtained through the District) from the USGS's so called "moveable" model of east-central Florida. The USGS data set is based on uniform grid spacings with each cell size being 1 minute × 1 minute. The surficial heads assigned to each cell were determined by USGS personnel using 1:24,000 scale topographic maps (Charles Tibbals, USGS, personnel communication). As a first-cut approximation, the moveable model surficial aquifer heads were assigned to the model cells used in this study based upon which 1 minute grid block the center of each cell resided within. At this point, plots were made to determine the direction of leakage (recharge or discharge) that would exist at each model cell based upon the assigned surficial aquifer head and the average 1988 Upper Floridan potentiometric surface. If discharge was indicated in regions of recharge, or recharge was indicated in regions of discharge, the surficial aquifer head assigned to the model cells that showed a discrepancy were adjusted (where applicable) based upon the elevation of various surface-water features on USGS 1:24,000 scale maps.

4.6 Floridan Aquifer Parameters

4.6.1 Transmissivity

Transmissivity (T) is defined as the hydraulic conductivity of an aquifer multiplied by the aquifer thickness; this physical parameter is a measure of the aquifer's ability to transmit ground-water flow. Table 4.7 provides a list of the high and low aquifer parameter values used in several previous modeling studies that incorporated all or part of the study region. In general, the high and low values are of the same order of magnitude. There have been a number of aquifer tests conducted in the Upper Floridan, but the results are often viewed with skepticism on a regional scale because many of the wells only partially penetrate the aquifer, and the high secondary porosity of the limestone aquifer creates extreme local contrasts in aquifer permeability.

Table 4.7. Ranges of transmissivities for the Upper and Lower Floridan and leakance of the upper and middle semiconfining units from selected modeling studies in east-central Florida.

Study	Upper Floridan T (ft^2/d)		Lower Floridan T (ft^2/d)		Leakance of Upper Semiconfining Unit (d^{-1})		Leakance of Middle Semiconfining Unit (d^{-1})	
	High	Low	High	Low	High	Low	High	Low
Tibbals (1990)	400,000	10,000	130,000	30,000	6×10^{-4}	1×10^{-6}	5×10^{-5}*	5×10^{-5}
CH2M Hill (1988)	133,680	6,684	66,840	6,684	2.6×10^{-3}	1×10^{-6}	1.3×10^{-2}	1.3×10^{-2}
Jammal & Associates, Inc. (1990a)	250,000	40,000	275,000	100	NA	NA	8.6×10^{-2}	1×10^{-5}
GeoTrans (1991)	300,000	10,000	570,000	30,000	5×10^{-4}	3×10^{-5}	2×10^{-3}	2×10^{-4}

* Tibbals used a constant leakance except in the vicinity of Blue Springs, where he used a large value.

Few aquifer tests have been conducted in the Lower Floridan. One test, conducted by Lichtler et al. (1968), yielded a transmissivity of about 570,000 ft^2/d. More recent tests were conducted at the proposed site for Orange County's Western Regional Wellfield (Post, Buckley, Schuh & Jernigan, Inc., 1989). These test results yielded transmissivities ranging from 144,385 ft^2/d to 935,829 ft^2/d. The transmissivity values listed in Table 4.7 were obtained by model calibration only.

4.6.2 Leakance

The leakance (or "leakage coefficient") is defined as the ratio of the vertical hydraulic conductivity of a confining bed to the thickness of the confining bed. Tibbals (1990) reports a range of leakances for the upper confining unit of 1×10^{-6} d^{-1} to 6×10^{-4} d^{-1}. The range of leakances used in previous modeling studies for the upper semi-confining unit generally conform to these limits (Table 4.7).

No measured values for leakance of the middle semiconfining unit within the modeled region are available. The values in Table 4.7 range from 5×10^{-5} d^{-1} to 8.6×10^{-2} d^{-1} and were obtained through model calibration. Tibbals (1990) comments that the middle semiconfining unit leakance may be quite high in the vicinity of Blue Springs, where a fault probably extends through the Upper Floridan and into the Lower Floridan. Also, based on the middle semiconfining unit thickness maps of Miller (in Tibbals 1990), higher leakance values might be expected in the western portion of the study area where the thicknesses are relatively small (100-200 ft).

5 GROUND-WATER FLOW MODELING

As detailed in Chapter 2, the USGS computer code MODFLOW (McDonald and Harbaugh, 1988) was selected to perform the steady-state regional ground-water flow analysis. This chapter is devoted primarily to discussions of the conceptual modeling framework, model calibration procedure and subsequent sensitivity analysis.

5.1 Conceptual Model and Modeling Assumptions

The conceptual model adopted for the quantitative analysis of ground-water flow in the Floridan aquifer system in east-central Florida is illustrated in Figure 5.1. The basic model is that of a dual aquifer system separated by a semiconfining unit. The system is bounded at its base by an impermeable boundary, and at its top by a head-dependent flux boundary that provides areally distributed recharge or discharge directly to the Upper Floridan. For postdevelopment conditions pumpage occurs in both aquifers.

The approach of dividing the Floridan aquifer system into two distinct producing zones separated by a semiconfining unit is well accepted and has been used in numerous modeling studies. In this approach, only the vertical leakage of water (up or down) through the middle semiconfining unit is simulated; horizontal ground-water flow through the semiconfining unit is assumed to be insignificant and is not accounted for. The error associated with this assumption is insignificant because of the large contrast in hydraulic conductivities between the Upper and Lower Floridan production zones and the middle semiconfining unit. Conversely, ground-water flow within the Upper and Lower Floridan is assumed to be horizontal. This is a reasonable assumption throughout the study area, although it could be violated somewhat in the vicinity of high recharge and discharge (e.g. springs) areas.

Recharge to, and discharge from, the Upper Floridan is accounted for in the model using a head-dependent flux (third-type) boundary condition at the top of model layer one. This approach is

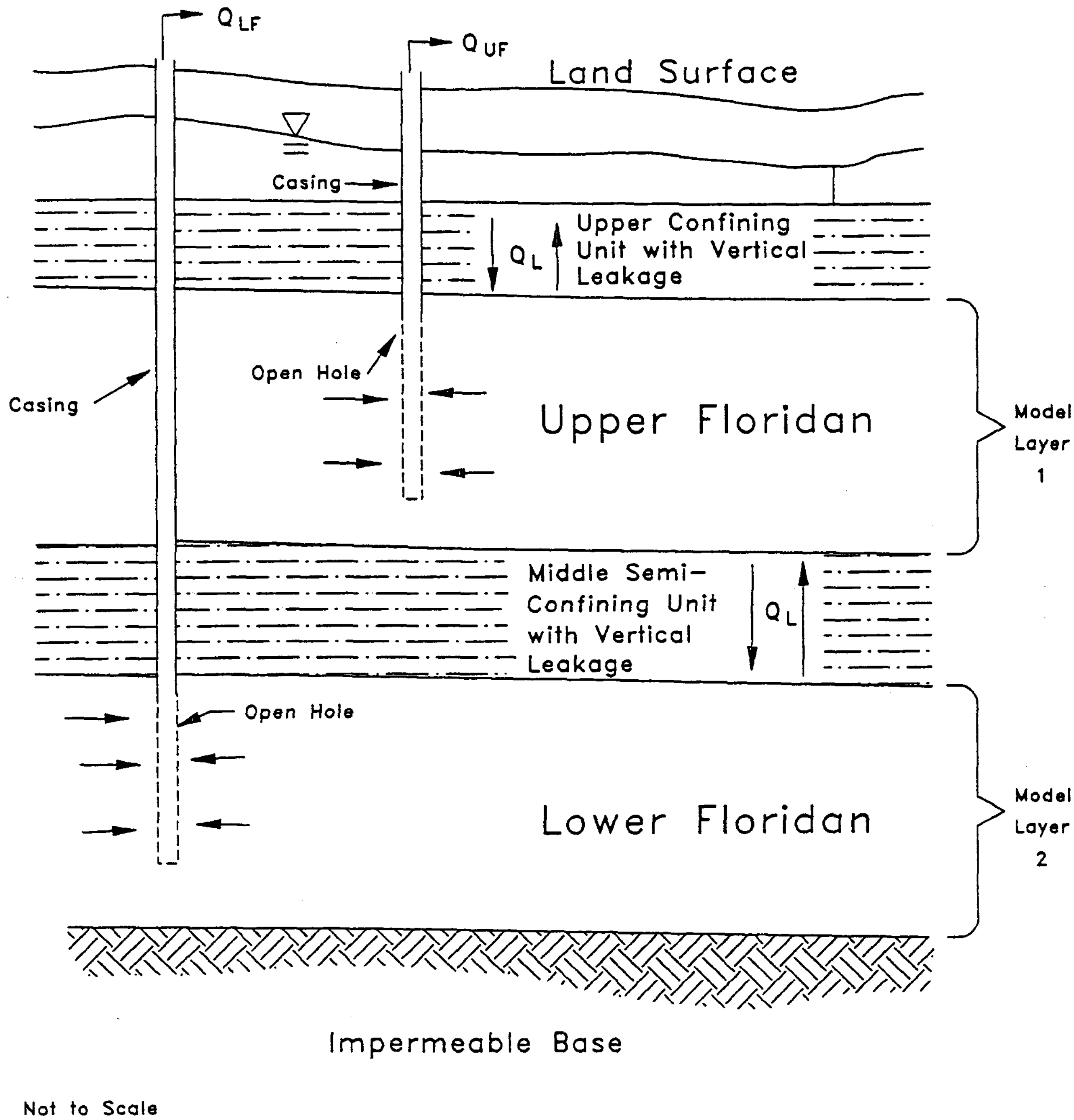

Figure 5.1 Conceptual model for modeling Floridan aquifer system in east-central Florida.

preferable to that of adding a third model layer as was done in several previous modeling studies (e.g., Tibbals (1990), GeoTrans (1991)) because computational storage requirements are significantly reduced. In this study, the adopted approach reduced the number of active model cells by 16,303. Ground water that flows vertically to or from the Upper Floridan must pass through the upper confining unit and into, or out of, the surficial aquifer. The magnitude of the vertical ground-water flux may be calculated using Darcy's law:

$$q_v = \frac{-K' (h_u - h_s)}{b'} \tag{5.1}$$

where q_v is the vertical Darcy flux entering or exiting the Upper Floridan, h_s is the water-table elevation in the surficial aquifer, h_u is the hydraulic head in the Upper Floridan, and K' and b' are the hydraulic conductivity and thickness of the upper confining unit, respectively. Note that if h_s is less than h_u, the q_v term is negative and water discharges, rather than recharges, the system. The term h_u is calculated by the flow model, while the remaining terms on the right-hand-side of equation 5.1 (h_s, K', b') are input parameters. Each of the four terms used to calculate q_v exhibit substantial spatial variability.

The MODFLOW code RIVER package was used to implement the variable flux recharge condition described above. Each of the terms required to compute q_v (or Q_v, which is the total vertical flux through the top boundary of a model cell) have equivalent input definitions in the MODFLOW code as outlined in Table 5.1. For each model cell a value of the MODFLOW input parameter RBOT (see Table 5.1) was back-calculated to enforce a maximum allowable recharge rate to the Upper Floridan of 20 inches/yr. This maximum allowable rate is consistent with data provided in Tibbals (1990) and analysis conducted by GeoTrans (1991).

Ground-water efflux from the Upper Floridan due to springs within the study area was also modeled using a head-dependent flux boundary condition at the layer one model cells that contained springs. Using this modeling approach, the discharge from a spring (Q_s) is calculated using

Table 5.1. Equivalence of MODFLOW RIVER package input parameters and physical parameters for modeling vertical leakage between the surficial aquifer and the Upper Floridan.

MODFLOW Code Convention		Physical Modeling Convention	
Notation	Definition	Notation	Definition
K	Hydraulic conductivity of riverbed material	K'	Vertical hydraulic conductivity of upper semi-confining unit
M	Thickness of riverbed	b'	Thickness of upper semi-confining unit
L	Length of river reach	Δy_i	Cell length in y-direction
W	River width	Δx_i	Cell width in x-direction
QRIV	Leakage through reach of riverbed	Q_v	Vertical flux (leakage) to or from Upper Floridan
HAQ	Head on aquifer side of riverbed	h_u	Head in Upper Floridan
HRIV	Head on river side of riverbed	h_s	Water-table elevation in surficial aquifer
CRIV	Conductance of riverbed reach: CRIV=KLW/M	None	Leakance (K'/b') multiplied by the cell area
RBOT	Elevation of riverbed bottom. If HAQ drops below this elevation, the influx (QRIV) becomes constant.	None	Artificial parameter, the value of which may be set to enforce a maximum permissible leakage rate.*

* The maximum permitted recharge rate was set to 20 inches/yr in this study.

$$Q_s = C_s (h_u - h_{sp}) \tag{5.2}$$

where h_{sp} is the spring pool elevation, h_u is the head in the Upper Floridan as defined previously, and C_s is an empirical conductance term unique to each spring and each modeling configuration. The DRAIN package of the MODFLOW code was used to implement this modeling conceptualization. For input into this package, the spring pool elevation is entered as the head in the drain, and the spring conductance is entered as the conductance of the interface between the cell and the drain. If the head in the Upper Floridan drops below or is equal to that of the spring pool elevation ($h_u \leq h_{sp}$), the resulting efflux (Q_s) is set to zero. This approach differs markedly from that used by Blandford et al. (1991). In that work, the spring fluxes were entered explicitly at the appropriate cells. With the head-dependent flux conceptualization, the spring discharge is computed by the model based on the simulated Upper Floridan hydraulic head (h_u) and the C_s and h_{sp} input parameters. Consequently, the spring fluxes in this study are calibration targets rather than input parameters.

All stresses (pumpage and recharge due to drainage wells) to the Floridan aquifer system were averaged over the calendar year; pumping values were input in ft^3/d. Therefore, even though some pumpage was seasonal, such as that for irrigation, the amount of pumpage was assumed to be spread evenly throughout 1988. This approach is reasonably accurate for determining Floridan aquifer parameters for the regional system over the long term.

The effects of pumpage for heat pumps, lawn irrigation and domestic uses (discharge) in Brevard County were incorporated into the recharge calculated for the Upper Floridan under postdevelopment conditions. Similar approaches were adopted by CH2M Hill (1988) and Jammal and Associates (1990a). Obtaining accurate data to model these withdrawals directly would be very difficult if not impossible. Maps of well density in Brevard County for small diameter irrigation wells, domestic wells and ground-water heat pump wells for the year 1976 are available (Brevard County Division of Natural Resources, 1989), but the accuracy of these maps relative to 1988 conditions is unknown, and there is no detailed flux data available for each of these categories of pumping. Furthermore, if the 1976 well density maps are, in general, indicative of 1988 conditions, then the regions of highest well density in Brevard County lie outside the active model domain.

As discussed in Section 5.4, a model calibration to both predevelopment and postdevelopment conditions in the Upper Floridan was performed. The basic physical processes and aquifer parameters that control the configuration of the potentiometric surface within the Floridan aquifer system do not vary with time. The magnitude of certain fluxes, however, do vary between the average predevelopment and average postdevelopment conditions. An outline of the major differences between the predevelopment and postdevelopment calibration periods relative to the conceptual model is presented below:

- Spring fluxes were higher (at most springs) under predevelopment conditions compared to postdevelopment conditions.
- Under predevelopment conditions there was no discharge from water wells, or recharge from drainage wells.
- Areal ground-water recharge and discharge may vary in magnitude between predevelopment and postdevelopment conditions. The general distribution (pattern) of recharge and discharge regions are believed to be similar for the two hydrologic conditions.
- Aquifer parameters such as transmissivity and leakance are identical for predevelopment and postdevelopment conditions.

5.2 Grid Design

The model grid is a two-layer, block-centered grid representing the Lower and Upper Floridan, and encompassing all of Orange and Seminole counties, and significant portions of Lake, Volusia, Brevard, Osceola and Polk counties (Figure 5.2). Each layer of the grid consists of 119 rows and 137 columns. Thus, the total number of nodes in the grid is $119 \times 137 \times 2 =$ 32,606; of which only 27,802 were active due to the configuration of the boundary conditions. Because the main region of interest is Orange and Seminole counties, this area was given the finest discretization. The smallest column spacing (Δx) is 1,050 ft, and the smallest row spacing

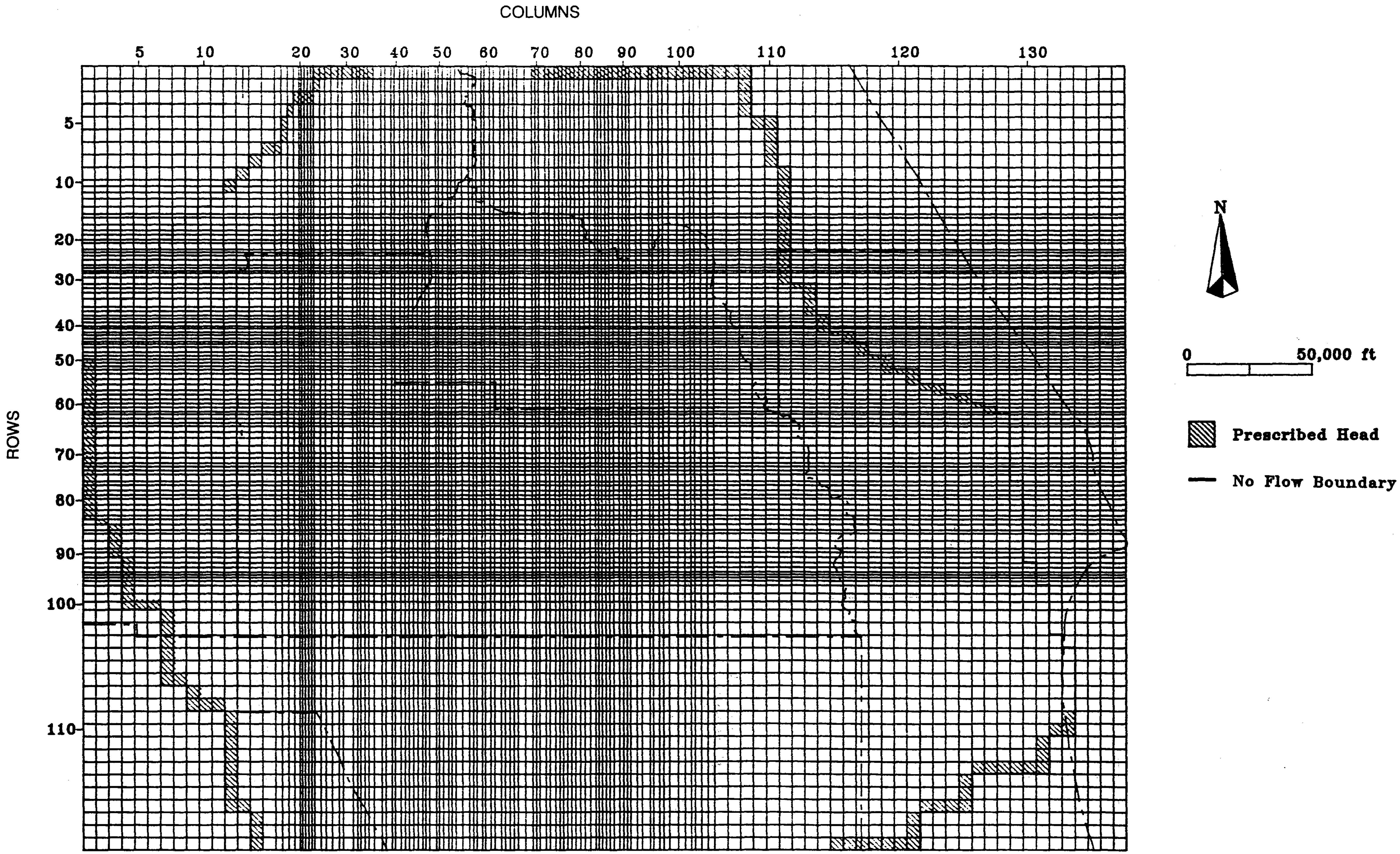

Figure 5.2. Model grid and Upper Floridan boundary conditions used in east-central Florida modeling study.

(Δy) is 900 ft. This level of discretization was necessary to locate most of the MI pumping wells in individual model cells. The largest model cell dimensions are 1 mi × 1 mi (1 mi = 5,280 ft). The model cell dimensions are listed in Appendix C. The four corners of the model grid used in this study correspond to those used by Blandford et al. (1991).

The outer boundaries of the grid were placed in such a way as to allow the utilization of natural boundary conditions that occur about the region of interest. Such boundary conditions include the Green Swamp potentiometric high in the southwestern corner of the study region, and dividing ground-water flow pathlines that exist along the southern, northwestern, and to some extent the northern boundaries of the study region.

Because MODFLOW requires that pumping values be specified at grid-block centers, the grid was designed so that many of the major pumping centers would be located near the centers of grid blocks. However, due to the large number of pumping locations within the study area, as well as their random distribution, this goal could not always be achieved.

5.3 Model Input Data

5.3.1 Boundary Conditions

The boundary conditions used for the Upper Floridan in the simulations are illustrated in Figure 5.2. No-flow conditions were specified along ground-water flow pathlines for the northwest boundary, portions of the northern boundary, much of the southern boundary, and a significant portion of the east-central boundary. Elsewhere a prescribed head condition was used. The prescribed head values and the position of the pathlines were determined using the predevelopment potentiometric surface map and the average Upper Floridan 1988 potentiometric surface map (Figures 4.1 and 4.2). Note that along the northern and southern boundaries where there is no boundary condition symbol, MODFLOW will use a no-flow boundary condition by default.

The boundary condition types did not change for each calibration period; no-flow boundaries for the predevelopment calibration were at the same location as no-flow boundaries for the 1988 calibration, and likewise for prescribed head boundaries. Inspection of Figures 4.1 and 4.2 will indicate that this approach is reasonable.

It is possible to over constrain the numerical solution to the ground-water flow problem by prescribing head values for too many model cells. The distribution between no-flow and prescribed head boundary cells for the Upper Floridan is approximately fifty-fifty; there are 229 no-flow boundary cells and 232 prescribed head boundary cells. The prescribed head model cells used were required to obtain reasonable calibration results. It is felt that the prescribed head boundaries used in this study are reasonable and do not over constrain the solution to the physical problem.

The boundary conditions for the Lower Floridan were set as no-flow on all sides of the domain. This was the modeling framework adopted by Tibbals (1990). The justification for such an approach is as follows. If the Floridan aquifer system is considered on a statewide scale, the Lower Floridan is recharged by the Upper Floridan in areas where the Upper Floridan is receiving high recharge from the surficial aquifer, where the middle semiconfining unit is thin or permeable, and where a vertically downward hydraulic gradient between the Upper and Lower Floridan exists. These conditions are by and large prevalent near the center of the state, which is the vicinity of the western study area boundary. Furthermore, a hydraulic ground-water flow divide should exist approximately along the peninsular divide. On one side of the divide, ground-water recharge will flow towards the Atlantic Ocean, and on the other side it will flow towards the Gulf of Mexico. Once water moves vertically into the Lower Floridan, it will move laterally away from the recharge areas toward the discharge areas in the vicinity of the coastline. As ground water in the Lower Floridan approaches this region, it will be forced upward by existing water of increasing salinity.

The western no-flow boundary, therefore, is conceptualized as approximating the hydraulic flow divide near the center of the state; the northern and southern no-flow boundaries follow approximately ground-water flow pathlines from the central regions of the state toward the coast, and the eastern (coastal) no-flow boundary is associated with the "pinching out" zone of the freshwater flow field at the lateral saltwater-freshwater interface. This conceptualization is only approximate at best. In reality, there are undoubtedly some lateral fluxes at depth to and from the Lower Floridan. However, in consideration of the extremely limited data available for the Lower Floridan, as well as the fact that flow in the Lower Floridan seems to have a limited effect upon ground-water flow in the Upper Floridan, the stated Lower Floridan boundary conditions are thought to be reasonable on a regional scale.

5.3.2 Physical Parameters

The physical parameters input into the model are as follows: water-table elevation in the surficial aquifer, model conductance of the upper confining unit (leakance multiplied by model cell area), transmissivities for the Upper and Lower Floridan, leakance of the semiconfining unit between the Upper and Lower Floridan, the discharges due to pumping in the Upper and Lower Floridan (for postdevelopment conditions only), the recharge to the Upper Floridan due to drainage wells (for postdevelopment conditions only), and the spring conductances and pool elevations. The pumping rates and drainage well recharge rates used were detailed in Chapter 4. The initial values of aquifer transmissivities and middle semiconfining unit leakance used were those documented in Blandford et al. (1991).

5.4 Model Calibration

Model calibration is the general procedure of adjusting model input parameters within reasonable ranges until the model output (in this case hydraulic head in the Upper Floridan and spring fluxes) resembles conditions observed in the field within some prescribed error tolerance. In this study, the major calibration parameters were spring conductance and leakance of the upper confining unit. The observed field conditions that the model was calibrated to are the predevelopment and 1988 average potentiometric surface maps for the Upper Floridan (Figures 4.1 and 4.2) and the various spring discharges for these two periods. Due to insufficient data, the potentiometric surface in the Lower Floridan could not be calibrated. Hydraulic head values are available for the Lower Floridan only at a very limited number of locations within the study area, most of which are in the vicinity of Orlando.

5.4.1 Calibration Procedure

For this study, the calibrated model parameters obtained by Blandford et al. (1991) were used as initial estimates of the model input parameters. These parameters were obtained from a model calibration to average 1988 Upper Floridan potentiometric surface conditions. Since the model grid in this study is much finer than that used in the previous study, the parameter values of Blandford et al. were interpolated onto the finer grid. Once the interpolation was completed, MODFLOW was rerun and the results of the fine grid were compared to those of the coarse grid. The predicted Upper Floridan 1988 potentiometric surfaces were nearly identical. However, there were some small differences due to the finer discretization and slightly different pumping well distributions. For example, some new MI and non-citrus agricultural pumping which was not present in the coarse grid was incorporated in the fine grid.

Once the calibrated parameters of Blandford et al. (1991) were incorporated into the finely discretized mesh used in this study, the model calibration was performed in the following manner.

1) The first set of calibration runs were conducted with recharge to the Upper Floridan specified directly rather than using the head-dependent flux approach. The initial recharge distribution obtained from Blandford et al. was double checked, refined and adjusted where appropriate using the recharge map of Tibbals (Figure 4.7) as a guide.

2) The recharge to the Upper Floridan due to drainage wells in the vicinity of Orlando was input explicitly as well recharge at the appropriate model cells, and the distribution of areal recharge to the Upper Floridan in the vicinity of Orlando was adjusted

accordingly (reduced) to maintain a reasonable fit between simulated and observed 1988 heads.

3) Model cells that contained springs were changed to head-dependent flux cells rather than cells with specified pumping. At this point the model was recalibrated to obtain a reasonable match between simulated and observed 1988 spring flows in addition to simulated and observed average hydraulic heads.

4) Using the calibrated 1988 recharge rates for each model cell, and the prescribed water-table elevation for each cell (the determination of which is outlined in Chapter 4), the leakance (K'/b') of the upper confining unit was back-calculated based upon equation 5.1, and the appropriate input parameters required for the MODFLOW code RIVER package were determined. The leakance values were checked to ensure their reasonableness.

5) The model was recalibrated to average 1988 conditions using the average Upper Floridan potentiometric surface and spring flows as calibration targets. The major calibration parameters were spring conductance, leakance of the upper confining unit, and (in selected areas) Upper Floridan transmissivity.

6) Once a satisfactory 1988 model calibration was achieved, the model was rerun for predevelopment conditions with groundwater pumping and recharge due to drainage wells deleted. The prescribed head boundary conditions were also adjusted to reflect predevelopment potentiometric surface values. The nodal water-table elevations estimated for the surficial aquifer remained constant for the predevelopment and postdevelopment simulations.

Steps 5 and 6 were repeated iteratively until a reasonable calibration was achieved for average 1988 and predevelopment conditions. More emphasis was placed on the 1988 calibration than on the predevelopment calibration due to the potentially large inherent uncertainties associated with the predevelopment potentiometric surface and some spring flows.

Finally, it should be understood that the physical parameters obtained through model calibration are effective, or average, parameters over a grid block. The degree of local variation that may be accounted for is necessarily restricted by the grid block size. Furthermore, model calibrated parameters may not be unique; or, in other words, the same (or a very similar) potentiometric surface might be obtained using different combinations and values of model parameters. The goal of this modeling study was to obtain realistic calibration parameters that conform to the overall hydrogeologic framework, and that lie within a reasonable range that may be verified using field observations.

5.4.2 Predevelopment Calibration Results

The average predevelopment potentiometric surface simulated by the calibrated flow model is presented in Figure 5.3. Figure 5.4 is a contour map of the difference between the observed and simulated potentiometric surfaces. Throughout most of the study area, the difference is less than 4 ft. In the vicinity of the major springs in eastern Orange County, the head difference is locally as high as 8 ft. Heads also differ by as much as 10 ft in the vicinity of Blue Spring and 6 ft in western Orange County. In general, the areas of head discrepancies of 4 ft or greater occur in regions of very high (steep) hydraulic gradient (e.g. the vicinity of springs and near the Green Swamp potentiometric high). The calibration presented herein is deemed reasonable given the uncertainties associated with the predevelopment potentiometric surface map, particularly in regions of high hydraulic gradients where a slight misplacement of a contour line may easily lead to map errors in excess of 4 ft.

The highest discrepancies in Figure 5.4 (approximately 10 ft) lie at the north-central border of the model domain just west of Blue Spring. The large differences between the observed and predicted heads in this region occur because the pronounced cone of depression presumably caused by Blue Spring is delineated on the potentiometric surface maps offset approximately 2.5 miles to the east of the actual spring location. The reason for this is unknown; it is possible that the predevelopment potentiometric surface map may be somewhat in error in this region.

Table 5.2 lists the percent discrepancy between the simulated discharge and observed discharge for springs within the study area for predevelopment conditions. Model-wide the discrepancy between the total observed and simulated spring discharge is excellent (one tenth of one

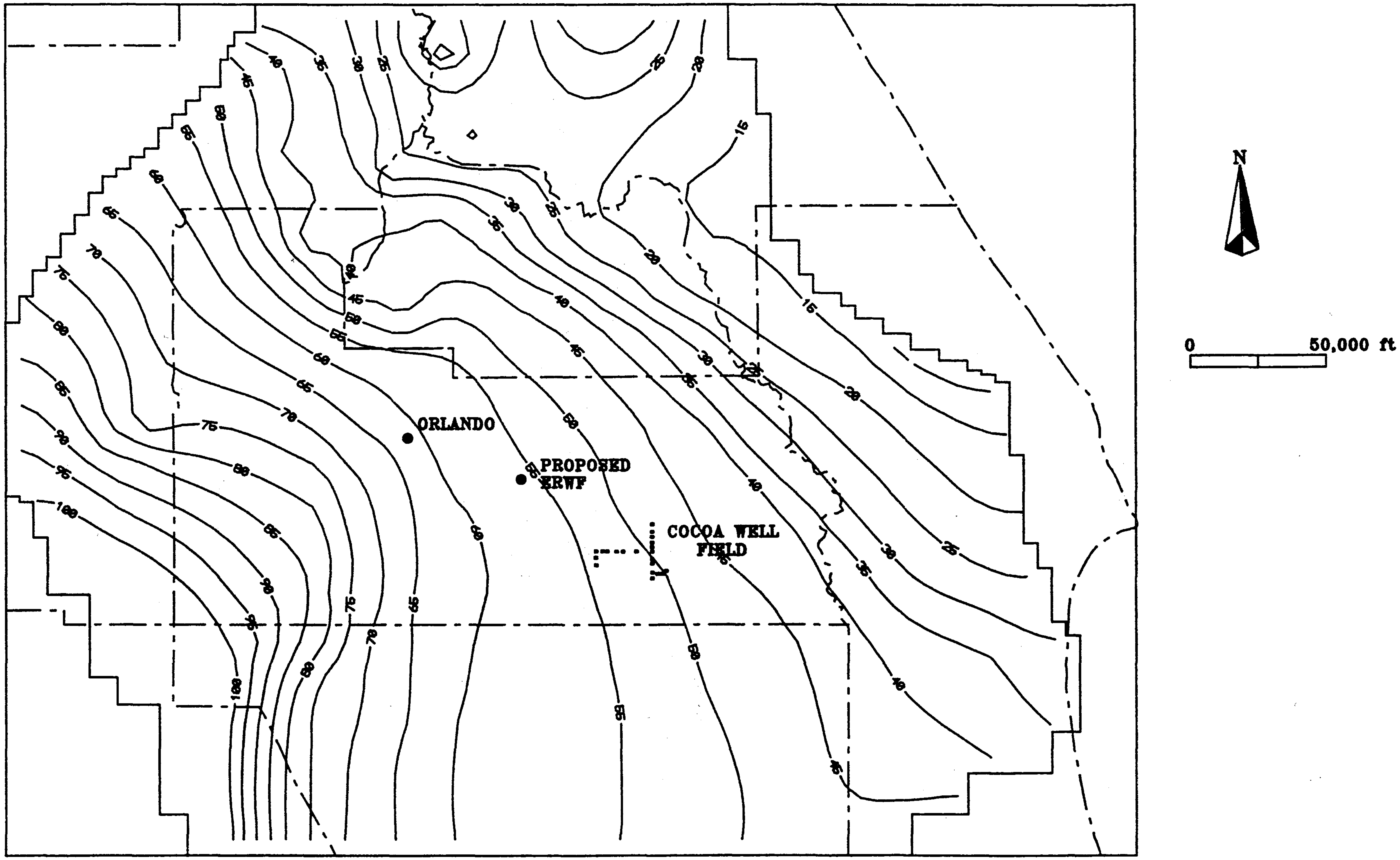

Figure 5.3. Final simulated predevelopment Upper Floridan potentiometric surface in feet above msl.

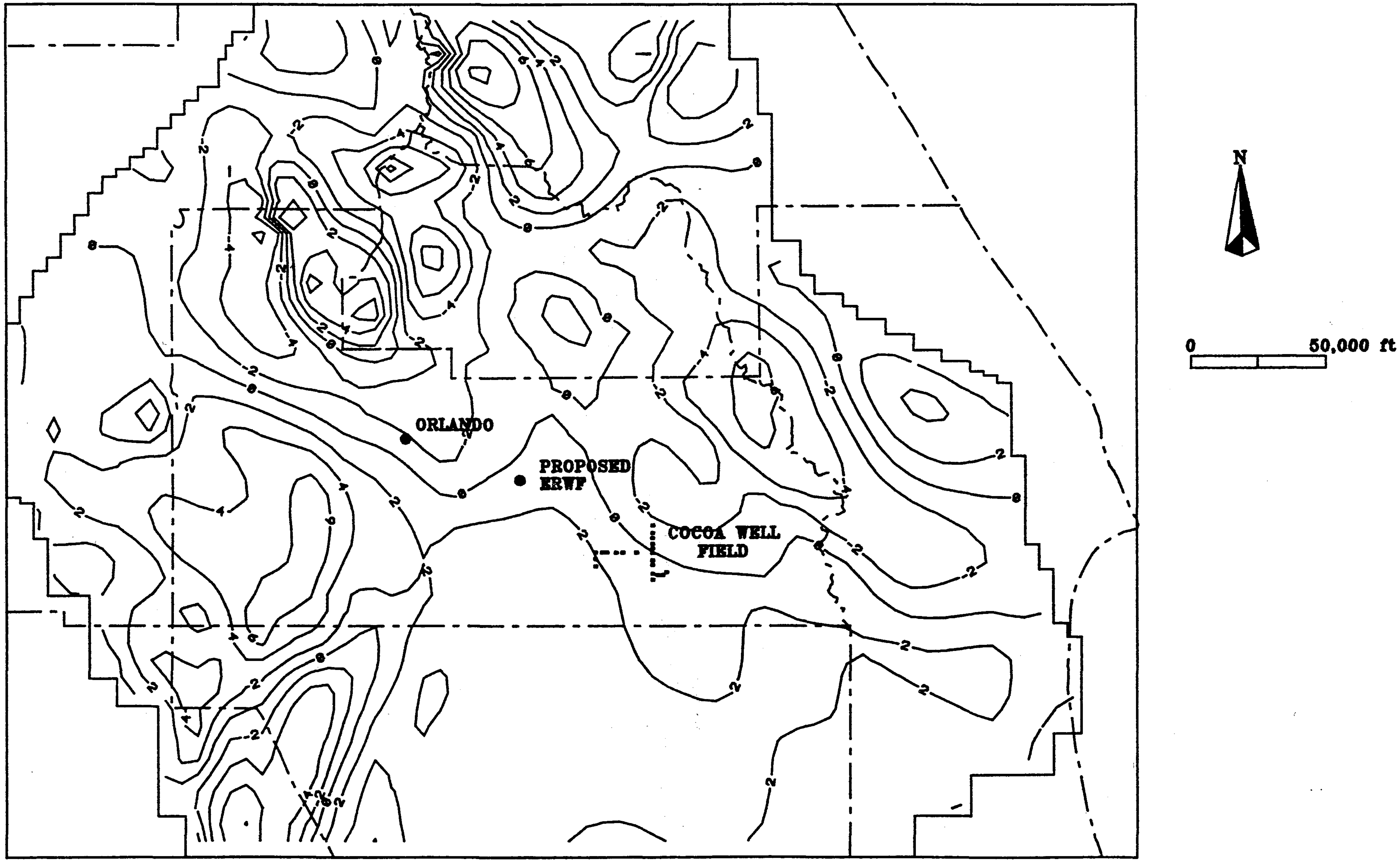

Figure 5.4. Difference between observed predevelopment potentiometric surface and simulated potentiometric surface for Upper Floridan in feet above msl.

Table 5.2. Spring conductance, observed discharge and simulated discharge for predevelopment model calibration.

Spring	Pool Elevation (ft above msl)	Conductance (ft^2/d)	Spring Discharge (ft^3/d)		Percent Discrepancy
			Observed	Simulated	
Camp La-No-Che	34.0	9,000	86,400	42,020	51
Blue	1.0	12,500,000	13,824,000	10,154,720	27
Gemini	1.0	47,500	691,200	745,472	8
Messant	26.0	130,000	1,728,000	1,294,792	-25
Seminole	34.0	1,300,000	3,110,400	3,475,615	12
Island	7.0	45,000	518,400	583,851	13
Rock	30.0	5,400,000	5,616,000	6,492,127	16
Witherington	25.0	25,000	345,600	419,774	21
Wekiva	13.0	360,000	6,393,600	7,204,771	13
Miami	15.0	19,000	432,000	484,379	12
Lake Jessup	3.0	1,900	86,400	74,433	-14
Clifton	3.0	4,000	172,800	148,857	-14
Starbuck	25.0	120,000	1,468,800	1,784,930	22
Palm	25.0	50,000	864,000	766,130	-11
Sanlando	26.0	140,000	1,641,600	2,044,619	25
Apopka	67.0	4,000,000	5,292,000	6,877,625	30
Totals			42,271,200	42,594,115	0.01

percent). The simulated discharge at most of the major springs differs from the observed values by 20 percent or less. In light of the inherent uncertainties associated with the predevelopment hydrologic data (i.e., the Upper Floridan potentiometric surface and some of the observed spring fluxes), the match of the simulated and observed spring fluxes presented in Table 5.2 is deemed acceptable. It should be noted here that the conductance values used for five springs (Seminole, Rock, Wekiva, Miami and Sanlando) in the predevelopment simulation are slightly lower (about 10 percent) than that used for the same springs in the 1988 calibration. The reasons and justification for this modeling approach are presented in Section 5.4.4.

Figures 5.5 and 5.6 illustrate the final, calibrated values of transmissivity and recharge to the Upper Floridan respectively. In general, the recharge values follow the patterns and have magnitudes within the ranges reported by Tibbals (1990). The transmissivities also lie within the bounds used by previous authors (see Table 4.7). The highest values of transmissivity (400,000 ft^2/d) generally occur just north and west of Orlando. Relatively low values of transmissivity (about 30,000 ft^2/d or less) occur in the eastern quarter of the study area and in the southwest corner of the study area. The central portion of the study area is in general a high transmissivity zone (60,000 - 400,000 ft^2/d), except in the vicinity of the Cocoa well field where values of 50,000 - 84,000 ft^2/d were required to reproduce the pronounced cone of depression caused by the Cocoa wells (Section 5.4.2.2). This range of values in the vicinity of the Cocoa well field matches well with other modeling studies such as Jammal and Assoc. (1990a) and CH2M Hill (1988), but is slightly lower than that reported by Tibbals (1990).

The zoning of transmissivities in the Upper Floridan is fairly complex; this is due to two reasons. First of all, the original estimates of transmissivity used by Blandford et al. (1991) were taken from Tibbals (1990), who had rather complex zonings in his model. Second, and most importantly, local variations in transmissivity were required to reproduce local irregularities in the potentiometric surface. The concept of large local variations in transmissivity is conceptually linked to the fact that the primary cause of Floridan aquifer permeability is secondary porosity, such as fractures and solution cavities. Therefore, hydraulic conductivity

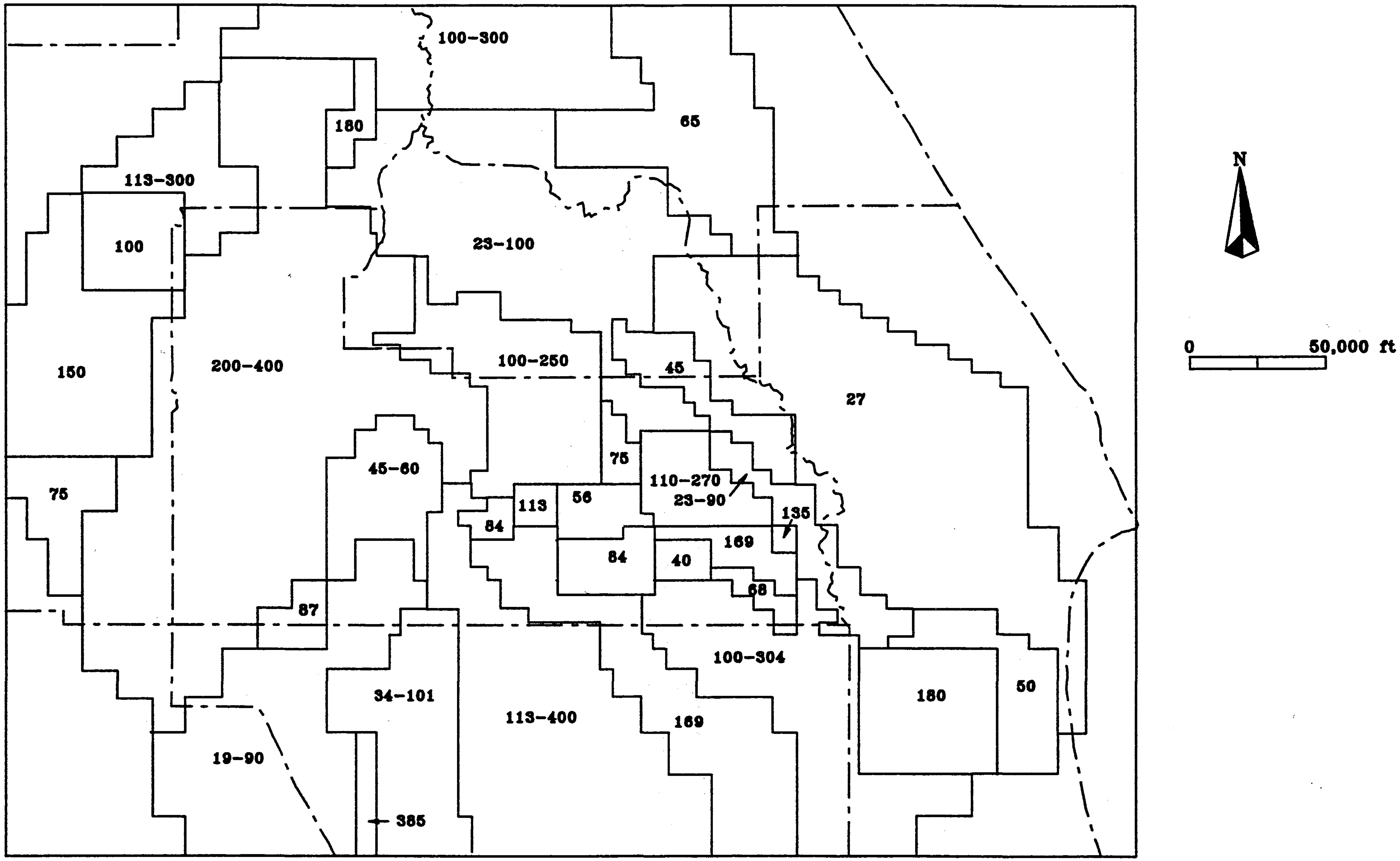

Figure 5.5. Upper Floridan transmissivity in thousands of ft^2/d.

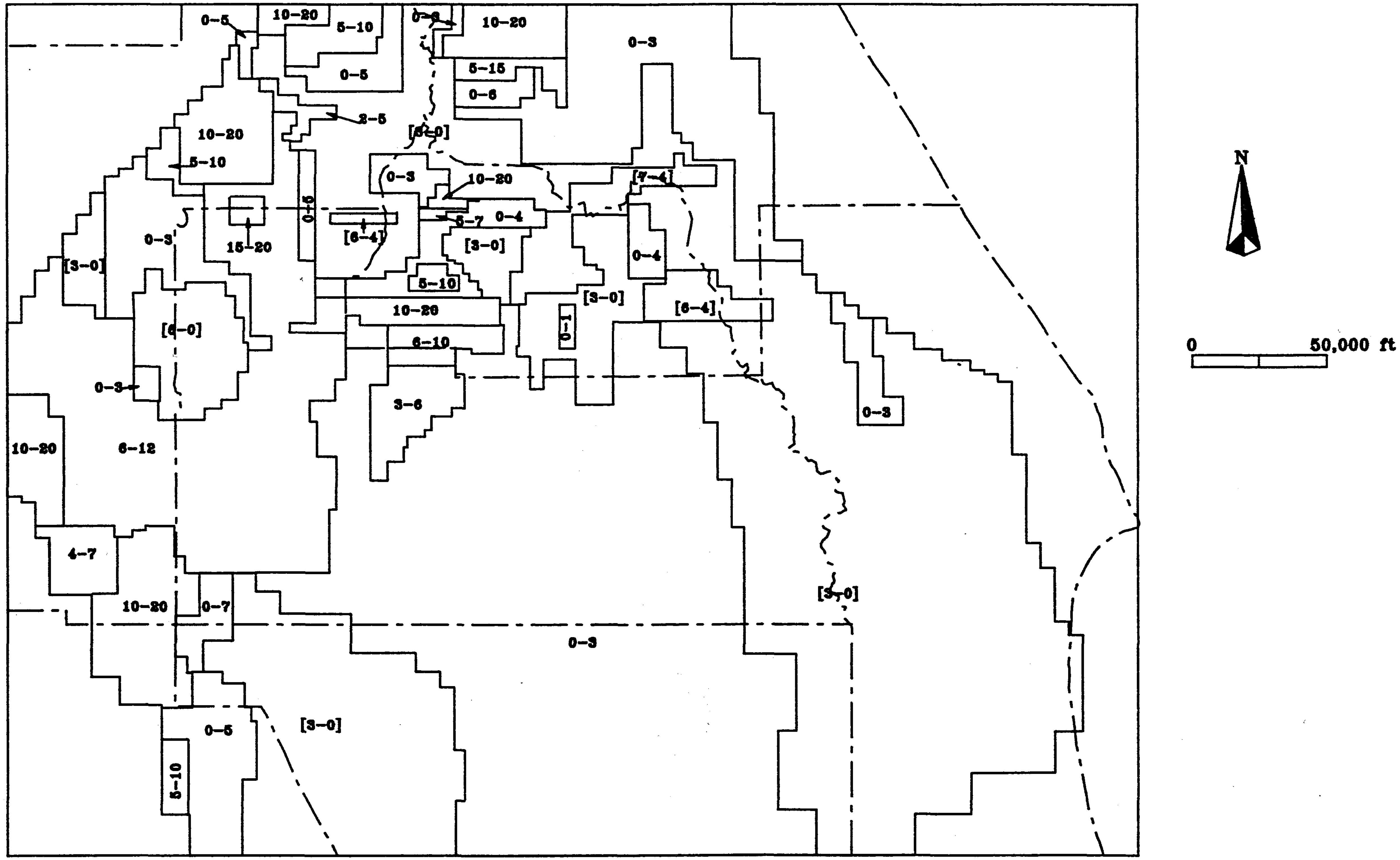

Figure 5.6. Recharge to the Upper Floridan for predevelopment conditions (inches/yr). Brackets indicate discharge.

of the Floridan aquifer system would expectedly be spatially variable, with large contrasts in transmissivities likely. This reasoning is supported by the results of numerous aquifer tests within the study area, many of which are in close proximity and indicate markedly different values of transmissivity. For example, three aquifer tests in the vicinity of the Cocoa well field indicated Upper Floridan transmissivities of 74,000, 210,000 and 510,000 ft^2/d (Tibbals 1990). Of course, some of the variation in transmissivities obtained from aquifer tests is due to factors such as differing degrees of well penetration and the length and type of analysis performed.

Throughout most of the study area, the calibrated predevelopment recharge rates (Figure 5.6) are consistent with those presented in Tibbals (1990). There are two general areas, limited in areal extent, in which the model wrongly simulates discharge from the Upper Floridan rather than recharge to the Upper Floridan. The first region in which this occurs is in south-central Volusia County, and the second region is in the vicinity of the Orange County-Osceola County boundary due south of the proposed ERWF. These regions of reversed recharge flux exist because it was not possible to precisely match the predevelopment potentiometric surface in these areas. These recharge discrepancies, therefore, are directly related to model calibration error. The error in recharge flux at these locations is not large enough to appreciably affect the predevelopment simulation results.

Figure 5.7 illustrates the final calibrated values of leakance between the surficial aquifer and the Upper Floridan (upper confining unit). All of the leakance values are on the order of 10^{-4}-10^{-6}, which is consistent with data reported in Tibbals (1990) and various other studies. In general, the highest leakances occur in the west and northwest portion of the study area, which is consistent with Tibbals (1990) and Miller (1986). The calibrated leakance values exhibit significant spatial variability throughout the study area. This result is conceptually valid since the leakance is a function of two parameters (the vertical hydraulic conductivity and thickness of the confining unit) that are themselves extremely variable in space. The leakance distribution is more variable than that presented in other modeling studies of the area since the leakances were back-calculated based upon calibrated recharge values and nodal estimates of water-table

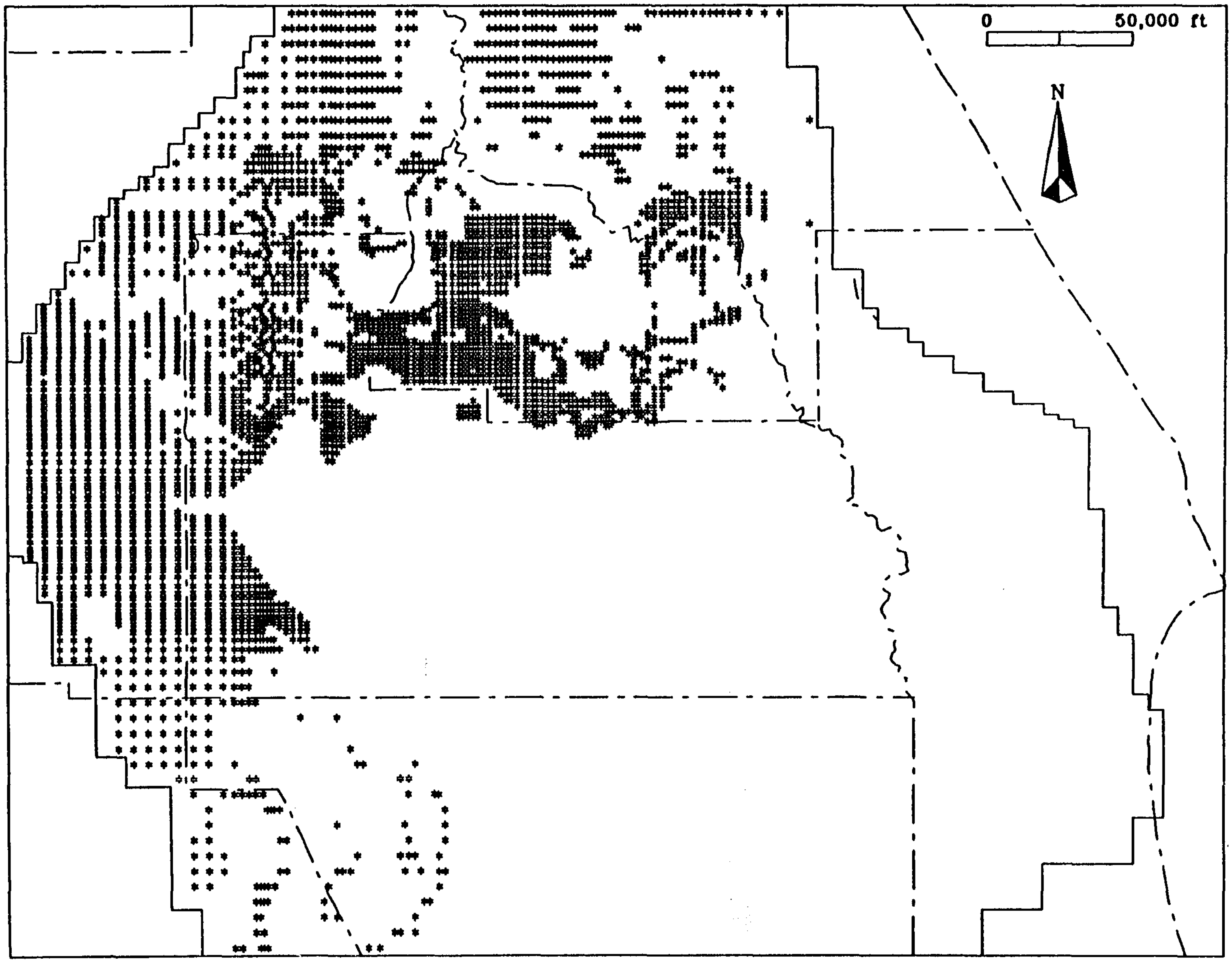

Figure 5.7a. Upper confining unit leakances on the order of 10^{-4} d^{-1}.

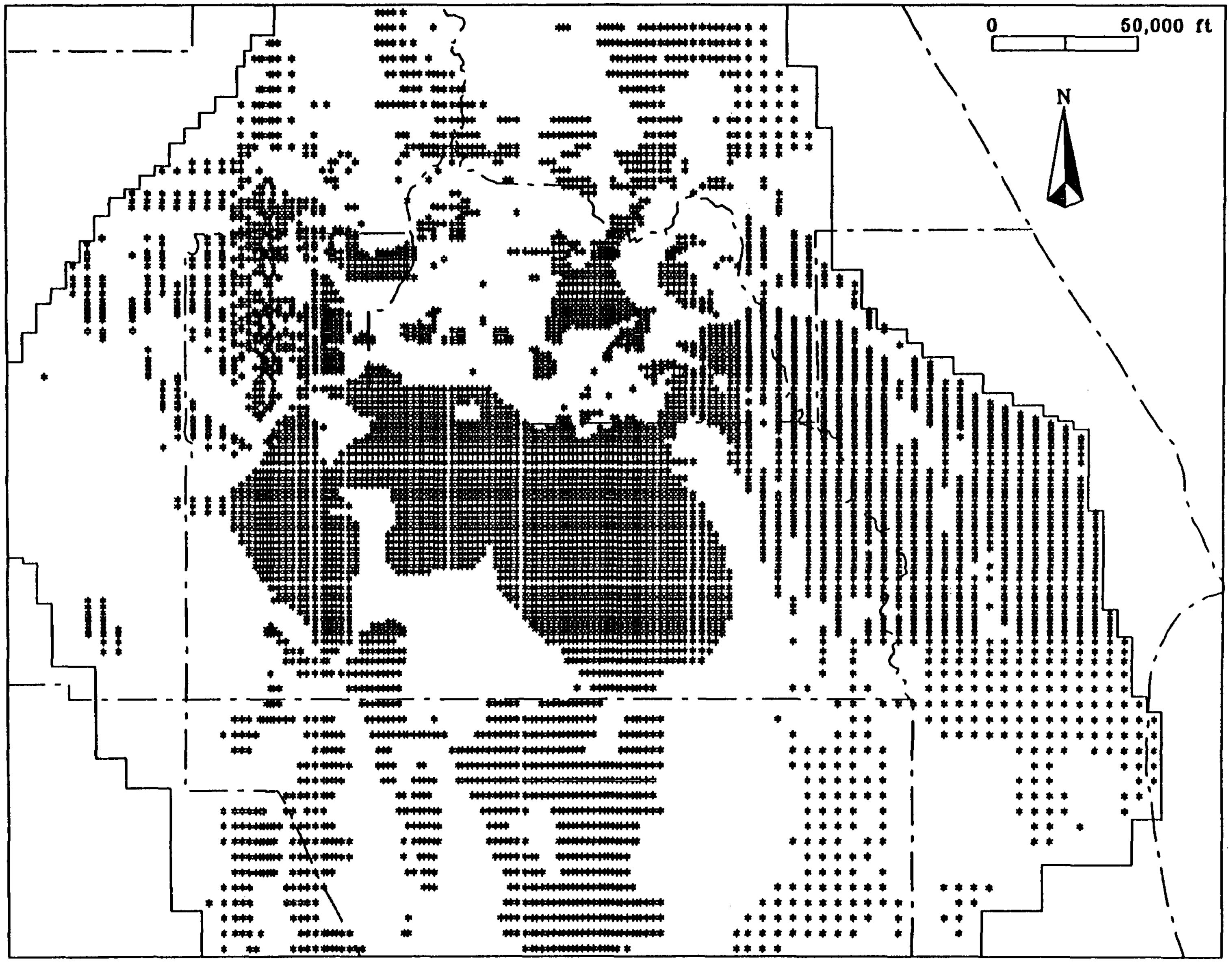

Figure 5.7b. Upper confining unit leakances on the order of 10^{-5} d^{-1}.

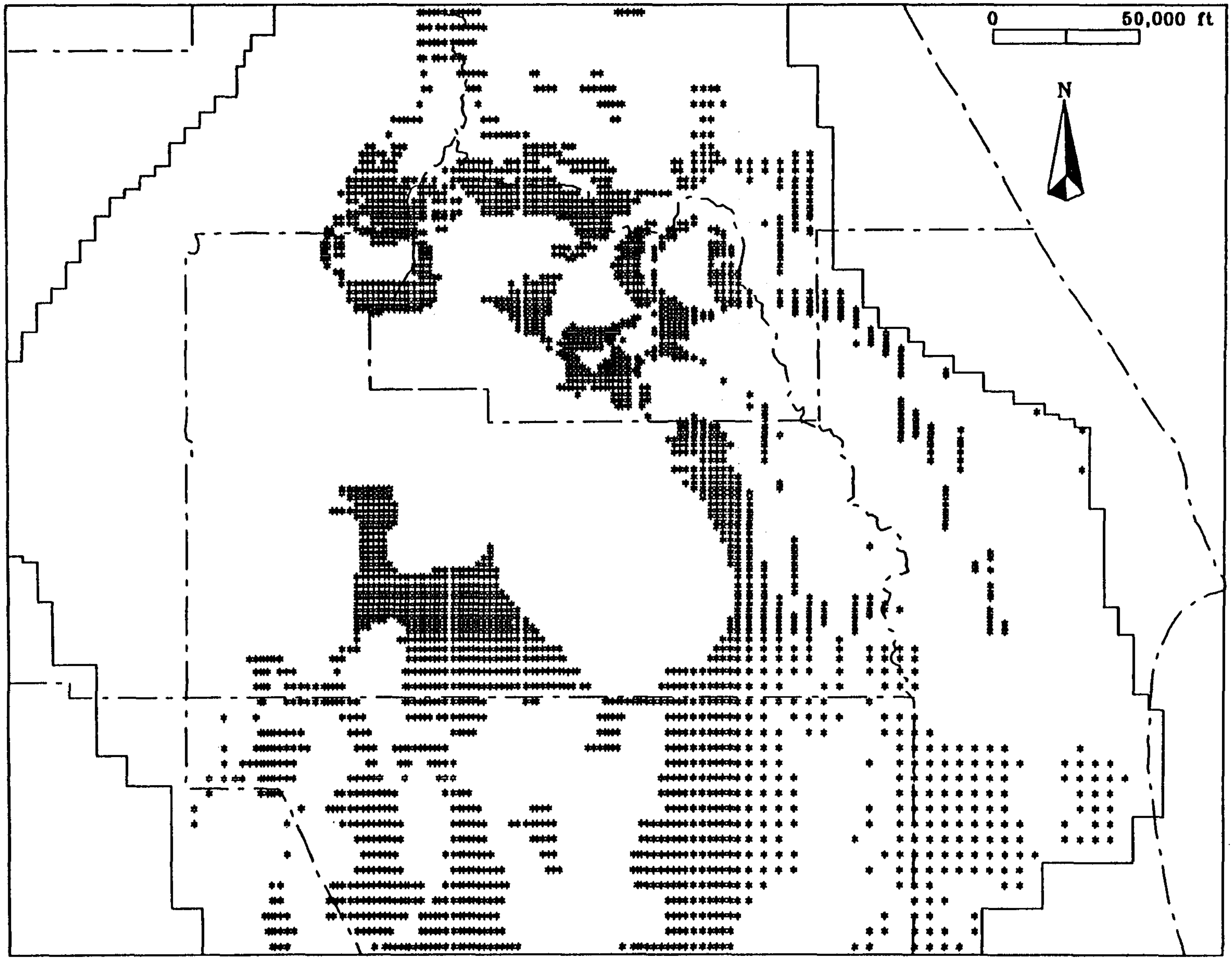

Figure 5.7c. Upper confining unit leakances on the order of 10^{-6} d^{-1}.

elevation. Figure 5.8 illustrates the final calibrated values of leakance between the Upper and Lower Floridan. Model results for the Upper Floridan were found to be only moderately sensitive to changes in leakance of the middle semiconfining unit. The default leakance value of 5×10^{-5} d^{-1} only varies in regions where it was determined by Blandford et al. (1991) that reasonable variations in transmissivity and recharge could not adequately reproduce the observed head field. Three major areas of decreased leakance (1×10^{-6} d^{-1}) occur in the northeast, south-central, and central (in the vicinity of Orlando) regions of the study area. An area of relatively high leakance (1×10^{-3} d^{-1}) was specified southwest of Orlando, and an area of very high leakance (1×10^{-2} d^{-1}) was specified in the vicinity of Blue Spring to simulate the good hydraulic connection between the Upper and lower Floridan in that region (Tibbals, 1990).

Figure 5.9 illustrates the Lower Floridan transmissivities used. These values were taken directly from Tibbals (1990) and were not adjusted by Blandford et al. (1991) during their model calibration.

5.4.3 Postdevelopment (1988) Calibration Results

The average 1988 Upper Floridan potentiometric surface simulated by the calibrated flow model is presented in Figure 5.10. Figure 5.11 is a contour map of the difference between the simulated and observed potentiometric surfaces. Throughout much of the study area, the differences are less than 2 ft. In general, the largest differences between the observed and simulated potentiometric surfaces is about 6 ft; local highs exist in the western and north-central regions of the study area. Each of these areas is a region of very steep hydraulic gradient caused in the north-central region by substantial spring discharge, and in the western region by high areal recharge. In addition, the observed potentiometric surfaces in these regions exhibit a complex curvature, presumably due to unknown local effects of aquifer parameters and recharge or discharge. It would be quite difficult to improve the match significantly in these regions using a regional-scale model of the type used in this study. Furthermore, although the

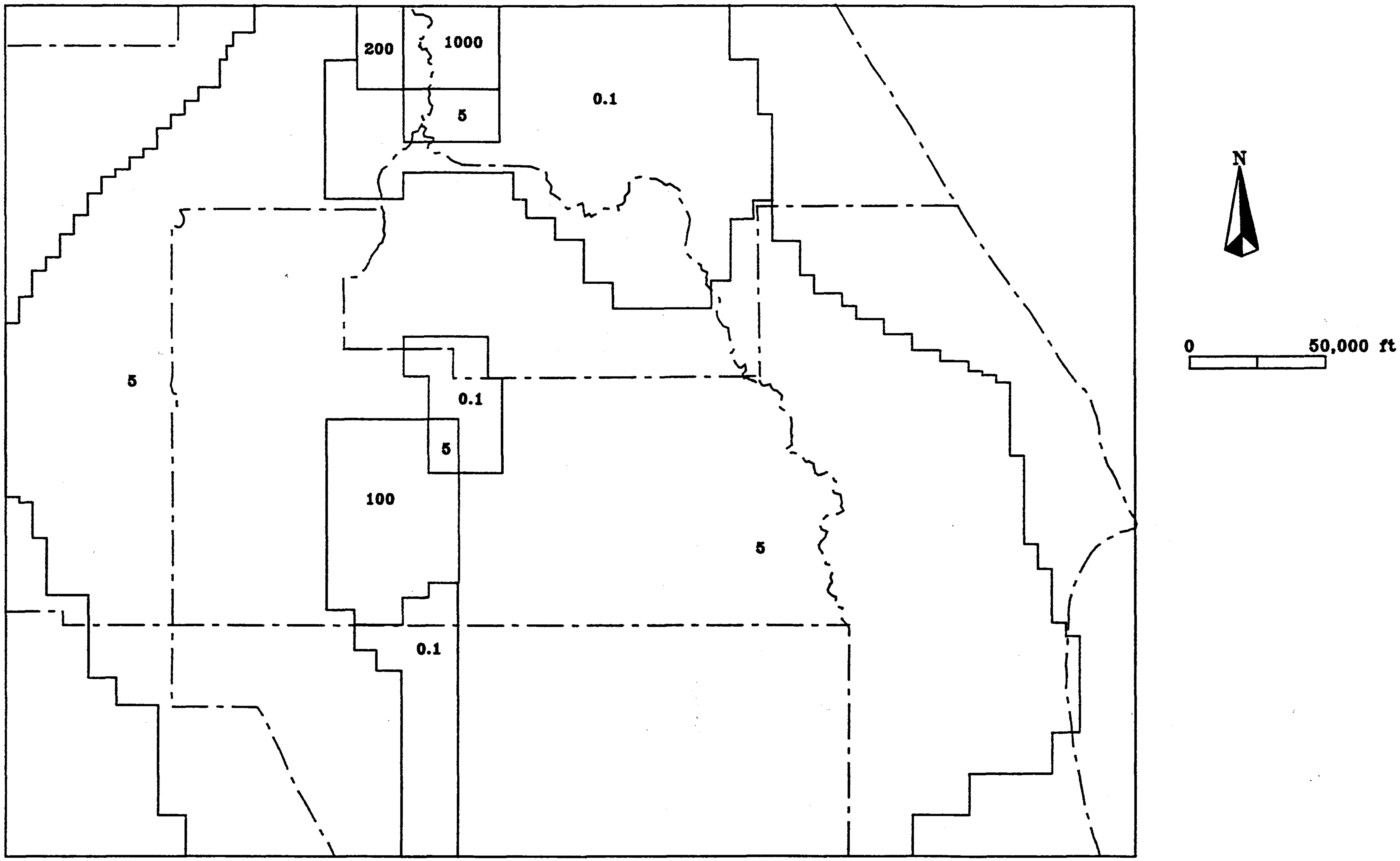

Figure 5.8. Leakance of the middle semiconfining unit times 10^{-5} d^{-1}.

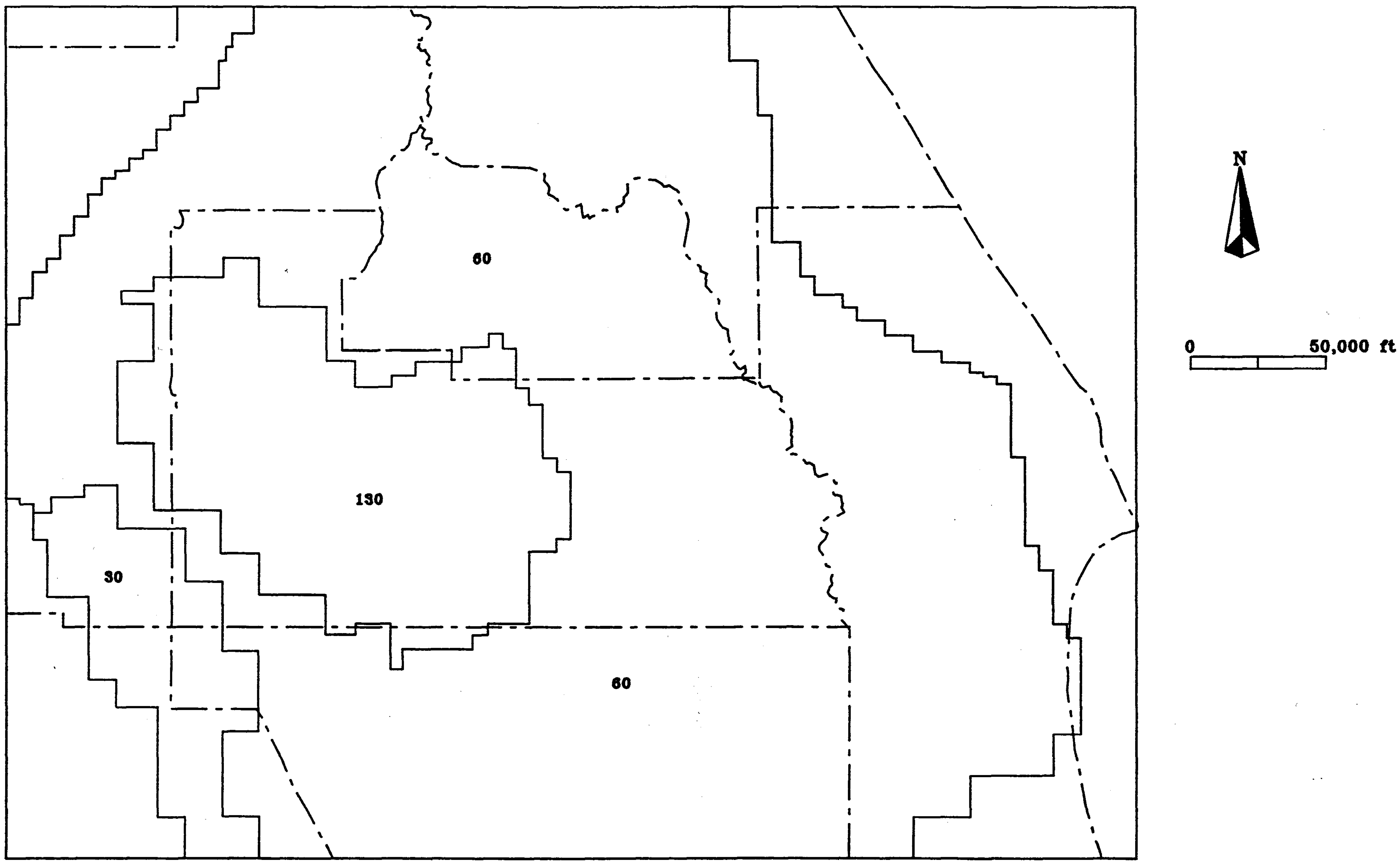

Figure 5.9. Transmissivity of Lower Floridan in thousands of ft^2/d, after Tibbals (1990).

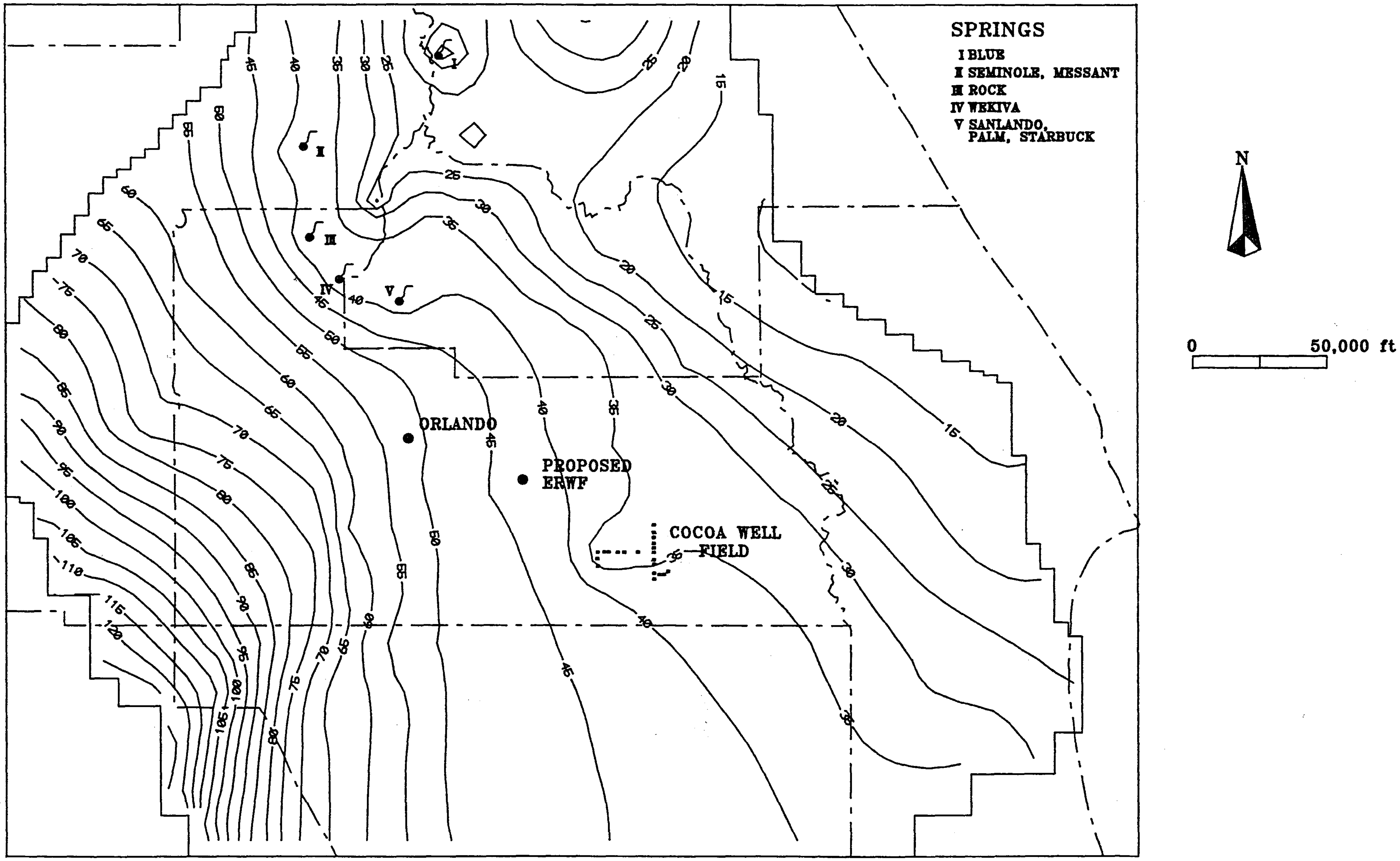

Figure 5.10. Final simulated Upper Floridan potentiometric surface for 1988 in feet above msl.

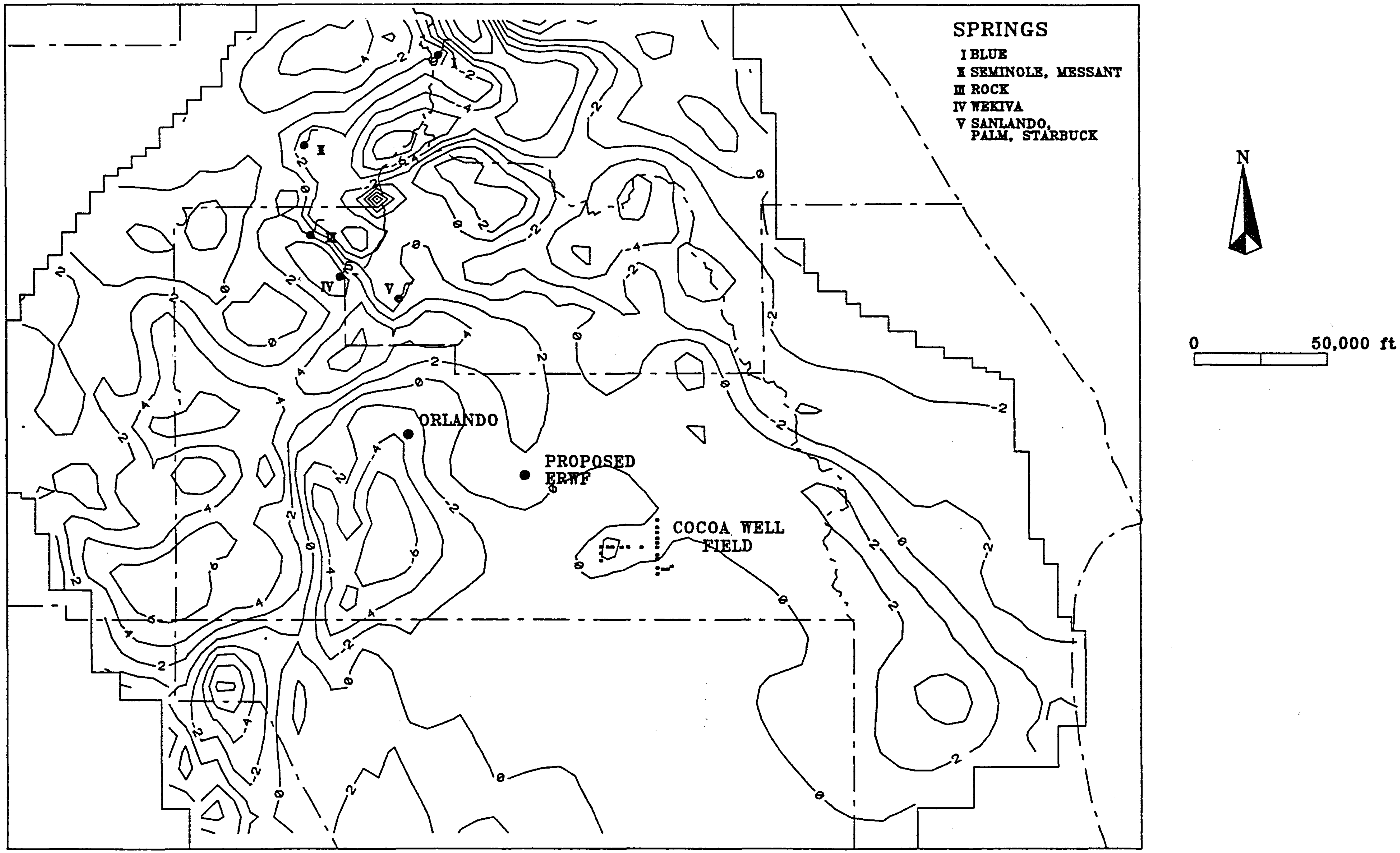

Figure 5.11. Difference between observed 1988 Upper Floridan potentiometric surface and final simulated potentiometric surface in feet above msl.

hydraulic heads do not match as closely in these regions as in others, in general the overall hydraulic gradient is preserved; it is the gradient which is of primary importance in ground-water modeling, rather than heads, because gradient determines the flux. Local discrepancies of 8 ft or more exist at Blue Spring and in the vicinity of the point where Lake, Orange and Seminole counties adjoin one another. The large differences at Blue Spring are, at least in part, due to the configuration of the observed potentiometric surface map in that region. As discussed in Section 5.4.2, the observed surface in that area may be somewhat in error.

Table 5.3 lists the percent discrepancy between the simulated discharge and observed discharge for springs within the study area for average 1988 conditions. The simulated discharge at all of the major springs within the study area (except for Blue Spring) is within 5 percent of the observed value. Model-wide the percent discrepancy in spring flows is also small (-3.4 percent). In terms of simulated spring fluxes, the calibration of the average 1988 ground-water flow model is excellent.

Figure 5.12 illustrates the simulated recharge distribution for the Upper Floridan for average 1988 conditions. The areal distribution and rates of recharge are generally within the bounds presented in Tibbals (1990). As was noted for the predevelopment calibration, there is a relatively small number of model cells in south-central Volusia County for which the model calculates discharge when in fact this region is a recharge area. This discrepancy is due to model calibration error and does not appreciably affect the simulation results.

5.4.4 Comparison of Predevelopment and Postdevelopment (1988) Calibrations

Table 5.4 presents a mass balance comparison for the predevelopment and 1988 calibrations. From predevelopment to 1988 conditions, the model simulations indicate an increase in inflow through prescribed head boundaries of 101 percent, a decrease in outflow through prescribed head boundaries of 42 percent, a decrease in spring discharge of 12 percent, an increase in areal

Table 5.3. Spring conductance, observed discharge and simulated discharge for postdevelopment (1988) model calibration.

Spring	Pool Elevation (ft above msl)	Conductance (ft^2/d)	Spring Discharge (ft^3/d)		Percent Discrepancy
			Observed	Simulated	
Camp La-No-Che	34.0	9,000	60,480	67,009	11
Blue	1.0	12,500,000	12,340,800	10,558,900	-14
Gemini	1.0	47,500	691,200	708,189	2
Messant	26.0	130,000	1,209,600	1,220,423	1
Seminole	34.0	1,500,000	3,369,600	3,229,866	-4
Island	7.0	45,000	518,400	503,826	-3
Rock	30.0	5,950,000	5,054,400	5,106,608	1
Witherington	25.0	25,000	345,600	341,044	-1
Wekiva	13.0	375,000	6,004,800	6,322,438	5
Miami	15.0	21,000	444,960	436,738	-2
Lake Jessup	3.0	1,900	56,160	61,698	10
Clifton	3.0	4,000	112,320	120,832	8
Starbuck	25.0	120,000	1,252,800	1,254,907	0
Palm	25.0	50,000	540,000	538,922	0
Sanlando	26.0	170,000	1,684,800	1,686,676	0
Apopka	67.0	4,000,000	5,292,000	5,453,125	3
Totals			38,977,920	37,611,201	-3.5

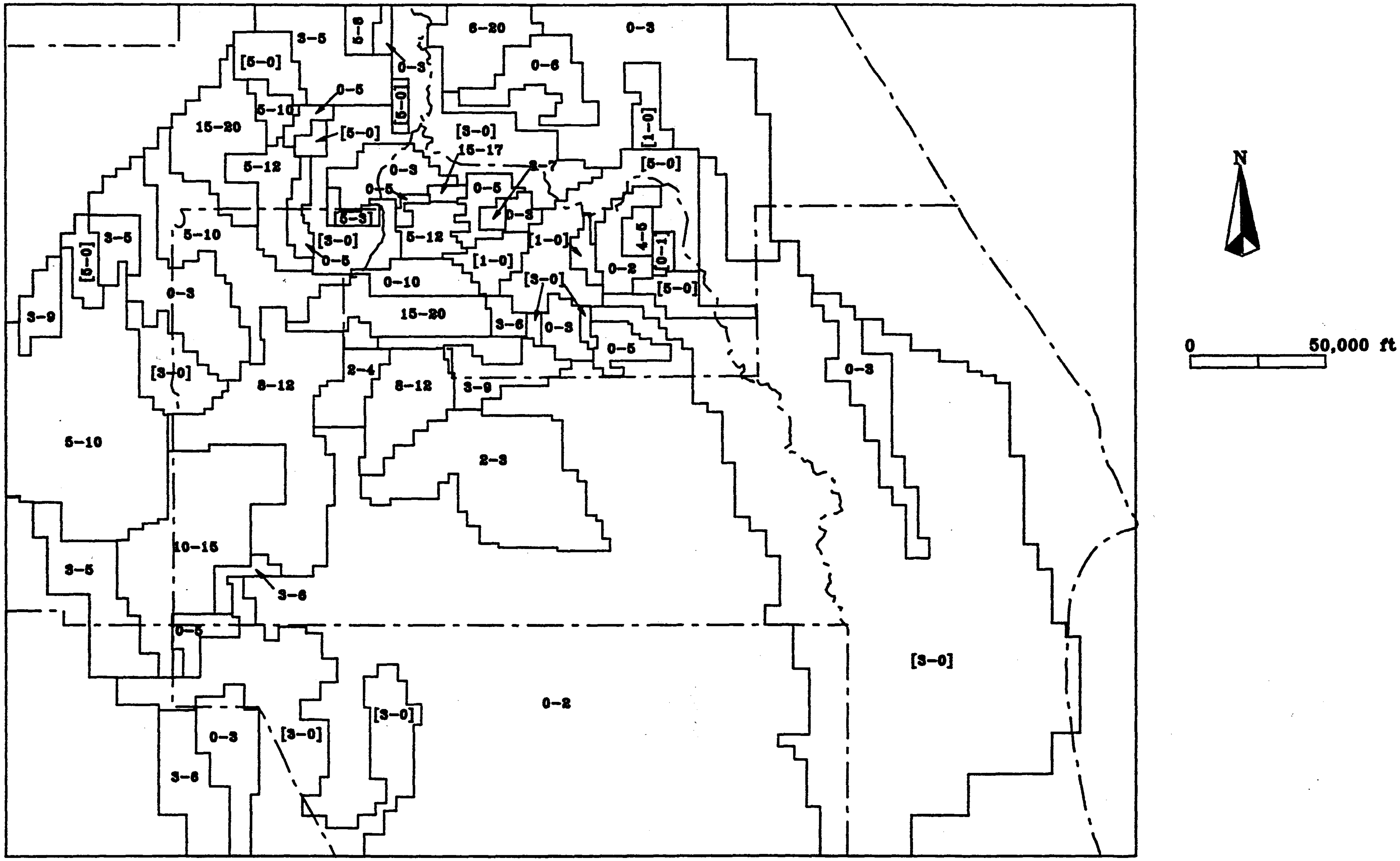

Figure 5.12. Recharge to the Upper Floridan for average 1988 conditions (inches/yr). Brackets indicate discharge.

Table 5.4. Changes in simulated ground-water flux from predevelopment to postdevelopment conditions.

Source	Predevelopment		Postdevelopment (1988)		Percent Change*
	Flux (ft^3/d)	Percent of Total Inflow/ Outflow	Flux (ft^3/d)	Percent of Total Inflow/ Outflow	
Inflow through Prescribed Head Boundaries	17,142,000	25.1	34,416,000	34.6	100.8
Outflow through Prescribed Head Boundaries	9,440,000	13.9	5,489,500	5.5	-41.8
Discharge Wells	0	--	48,058,000	48.2	--
Recharge Wells	0	--	4,411,400	4.4	--
Spring Discharge	42,594,000	62.7	37,611,000	37.8	-11.7
Areal Recharge to Upper Floridan	51,041,000	74.9	60,511,000	60.9	18.6
Areal Discharge from Upper Floridan	15,862,000	23.4	8,282,700	8.3	-47.8

* Percent change in flux from predevelopment to postdevelopment conditions calculated using

$$\left[\frac{Q_{1988} - Q_{pred}}{Q_{pred}}\right] \times 100$$

recharge to the Upper Floridan of 19 percent, and a decrease in areal discharge from the Upper Floridan of 48 percent. For 1988 conditions, nearly half of the total volume of water discharged from the Upper Floridan is attributable to groundwater pumping, and almost an additional 40 percent is attributable to springs. Figure 5.13 is a contour plot of the change in recharge to the Upper Floridan from predevelopment to 1988 conditions. The largest increases in recharge occurred in western and south-central Seminole County (up to about 8 inches/yr), in the general vicinity of Lake Apopka (up to 6 inches/yr), and in the southwest corner of Orange County (up to 10 inches/yr). Some of the regions that show the largest increases in recharge from predevelopment to 1988 conditions are regions that were actually discharge areas in the predevelopment simulation and which subsequently changed to recharge areas in 1988 due to lowering of the potentiometric surface due to pumping. Increased recharge in the vicinity of Orlando is about 2 inches/yr, and increased recharge in the vicinity of the Cocoa well field is slightly less than 1 inch/yr. The general regions and magnitude of increased recharge agree well with the predictions reported by Tibbals (1990). There are two relatively narrow regions of decreased recharge along the southwest and north-central portions of the model boundary. The recharge decreased in these regions because the 1988 average potentiometric surface is higher than the corresponding predevelopment surface. The decrease in recharge, therefore, is believed to be due to inherent errors in the potentiometric surface maps, rather than natural conditions.

A comparison of Figure 5.12 (recharge to the Upper Floridan for 1988 conditions) and Figure 5.6 (recharge to the Upper Floridan for predevelopment conditions) indicates that several regions within the study area changed from discharge to recharge from predevelopment to 1988 conditions. The largest regions where this occurred include portions of central Seminole County; the extreme southern end of Wekiva Swamp and adjoining regions in the vicinity of Miami Spring; a portion of the general region of low topographic relief that extends from the northwest shore of Lake Apopka to the southern shore of Lake Dora; various regions on the edges of Reedy Creek Swamp; and a narrow, north-south trending region just west of Lake Tohopekaliga. All of the regions that changed from Upper Floridan discharge to Upper Floridan recharge lie close to the edges of discharge areas as mapped by Tibbals (1990). It is not

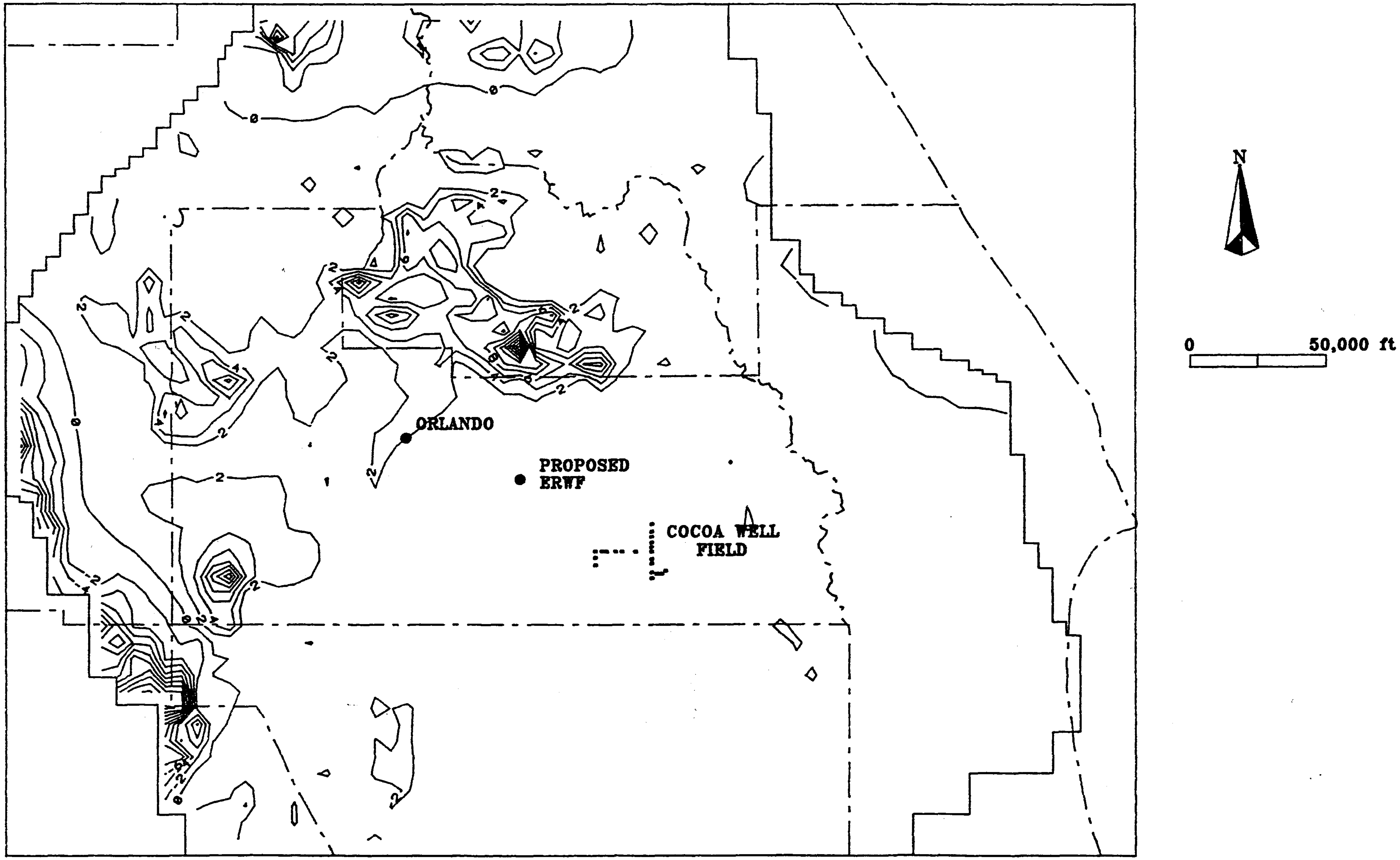

Figure 5.13. Change in recharge to the Upper Floridan from predevelopment to 1988 conditions. Contour interval is 2 inches/yr.

unreasonable that regions of marginal discharge would convert to areas of recharge as heads in the Upper Floridan became reduced due to increasing ground-water withdrawals. However, since the water-table elevations are not known for predevelopment conditions, and since many of the water-table elevations used for the 1988 calibration were rough estimates, it is not possible based on observed field data to independently delineate regions within the study area that changed from discharge to recharge conditions.

A comparison of Tables 5.2 and 5.3 will indicate that at five springs within the study area (Seminole, Rock, Wekiva, Miami and Sanlando) the conductance used for the predevelopment calibration was less (by about 10 percent) than that used for the 1988 calibration. This modeling approach was adopted based on the observation of Tibbals (1990):

> "Since about 1960, the flow of Wekiva Springs and Rock Springs has tended to be higher than in the period before 1960 despite below-normal rainfall and increased ground-water pumping. One possible explanation for increased flow is that the springs' vents were flushed of silt and debris during the period of record high flows in 1960. Such flushing could improve the conveyance of the spring vents and therefore increase spring discharge."

Although Tibbals only mentions Rock Springs and Wekiva Springs, at Seminole, Miami and Sanlando Springs the observed average 1988 discharges are higher than the predevelopment flows reported in Tibbals (1990), despite the fact that the 1988 Upper Floridan potentiometric surface is substantially lower in the vicinity of these springs then it was during predevelopment conditions. If the observed/estimated spring flows and spring pool elevations are not substantially in error, then it is reasonable to assume that the spring conductances may have been altered in response to certain hydrologic conditions (i.e., exceptionally high spring flows). In general, the predevelopment spring flows are not highly sensitive to small reductions in the conductance term, and reducing the conductance values at the listed springs decreased the percent discrepancy between simulated and observed flows by only several (1-5) percent.

5.4.5 Sensitivity Analysis

A series of ten sensitivity runs were conducted to determine how sensitive the 1988 simulated potentiometric surface is to variations in the calibrated model parameters. Sensitivity runs were not conducted for the predevelopment calibration results because the results would be similar, although perhaps less pronounced due to the lack of ground-water pumping. Because the emphasis of this modeling study was placed on developing a model simulation capability for the ground-water flow system in Orange and Seminole Counties, in the sensitivity runs the aquifer parameters were adjusted only in the center of the study region. This region, hereafter referred to as the "sub-area", is the box outlined in the following figures. The results of each of the sensitivity runs are presented in the following Sections as a series of Upper Floridan potentiometric surface difference maps. The contours in Figures 5.14 - 5.23 represent the difference between the final simulated 1988 potentiometric surface illustrated in Figure 5.9 and the potentiometric surface obtained using the adjusted input parameters. The following analysis demonstrates that the model results are highly sensitive to leakance of the upper confining unit, moderately sensitive to Upper Floridan transmissivity and spring conductances, and relatively insensitive to Lower Floridan transmissivity and leakance of the middle semiconfining unit.

5.4.5.1 Upper Floridan Transmissivity

Figures 5.14 and 5.15 illustrate the effects of a two-fold increase, and a 50 percent reduction respectively in the Upper Floridan transmissivity. It can be seen from Figure 5.14 that increasing transmissivity causes a maximum potentiometric surface increase within the sub-area of 8 ft in the vicinity of Wekiva Falls. Throughout most of the sub-area, however differences are generally on the order of 1-4 ft.

Decreasing the Upper Floridan transmissivity by 50 percent caused a decrease in the potentiometric surface of 12 ft and 6 ft in the vicinity of Wekiva Falls and the Cocoa well field,

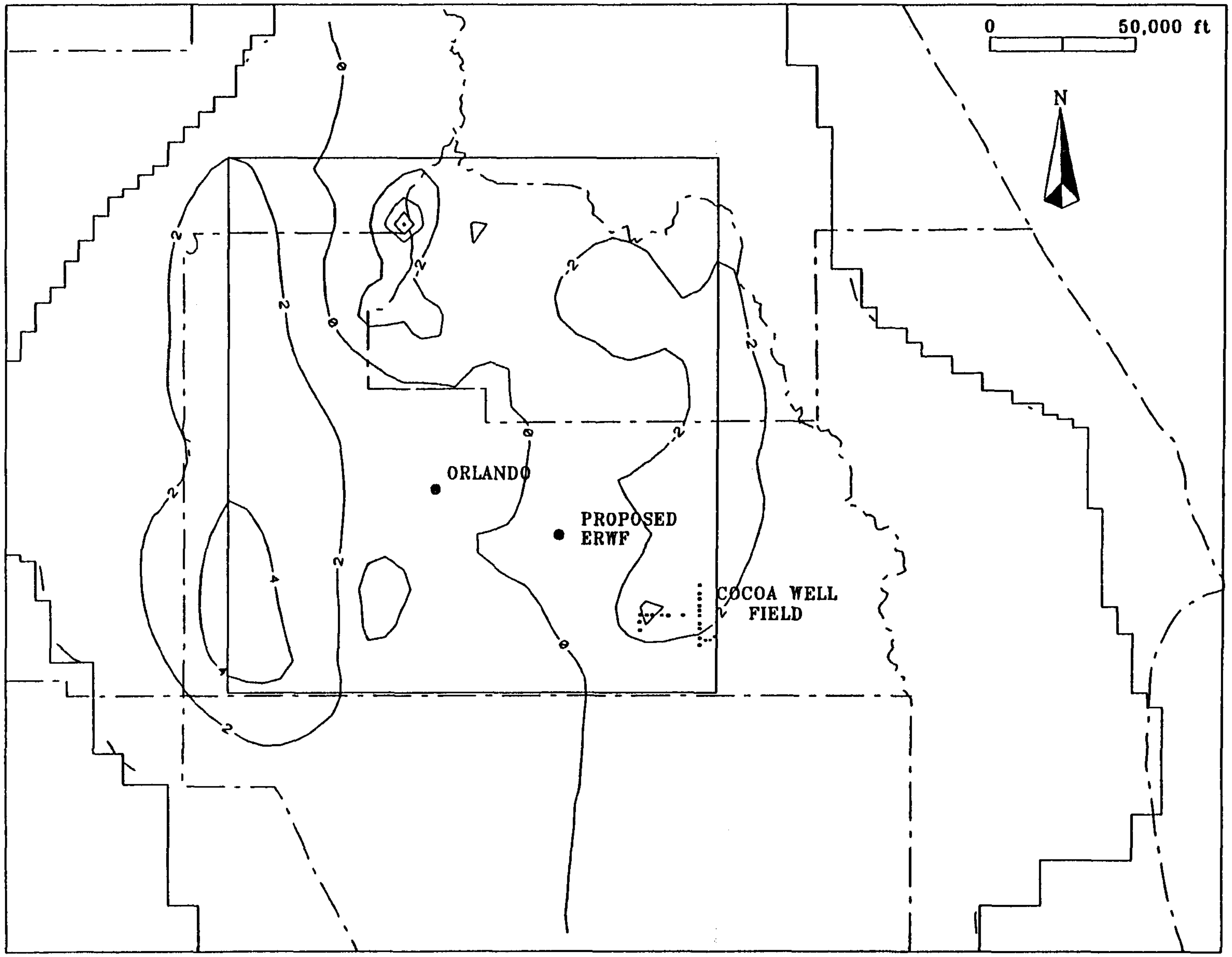

Figure 5.14. Difference between final simulated 1988 Upper Floridan potentiometric surface and potentiometric surface obtained using a two-fold increase in Upper Floridan transmissivity within the sub-area in feet above msl.

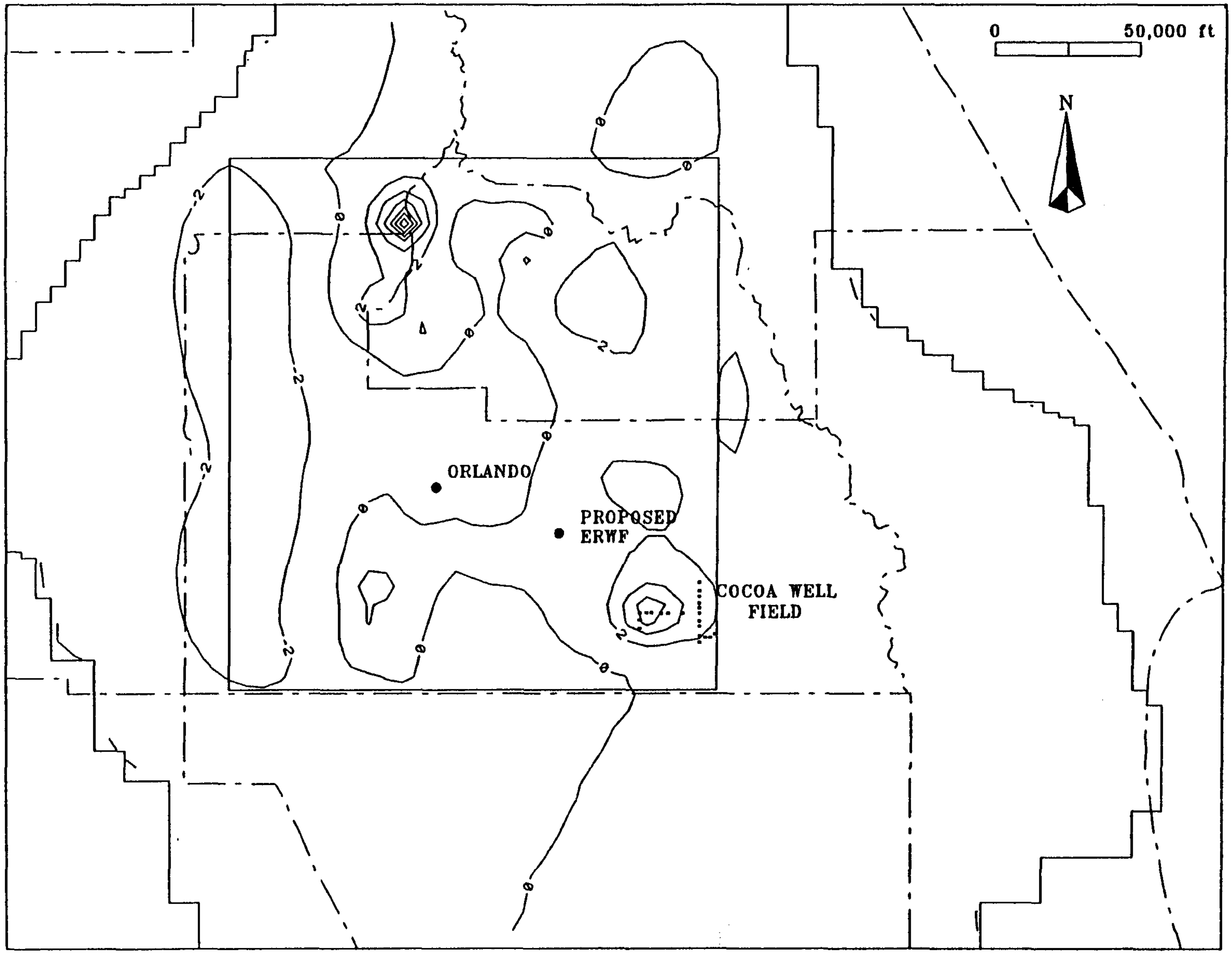

Figure 5.15. Difference between final simulated 1988 Upper Floridan potentiometric surface and potentiometric surface obtained using a 50 percent decrease in Upper Floridan transmissivity within the sub-area in feet above msl.

respectively (Figure 5.15). The change in the potentiometric surface throughout the rest of the sub-area was generally about 1-2 ft. It is evident from this analysis that the Upper Floridan potentiometric surface within the sub-area is highly sensitive to transmissivity variations within the local areas about Wekiva Falls and the Cocoa well field, but only moderately sensitive to such variations throughout the remainder of the sub-area.

5.4.5.2 Upper Confining Unit Leakance

Figures 5.16 and 5.17 illustrate the effects of a two-fold increase, and a 50 percent reduction in leakance of the upper confining unit, respectively. Increasing the upper confining unit leakance within the sub-area raised the potentiometric surface by as much as 6 ft in the vicinity of Orlando, while decreasing the upper confining unit leakance decreased the potentiometric surface by over 5 ft in the same region. Figures 5.16 and 5.17 indicate that the Upper Floridan potentiometric surface is highly sensitive to the leakance of the upper confining unit.

5.4.5.3 Leakance of Middle Semiconfining Unit

The effect of leakance of the middle semiconfining unit on the Upper Floridan potentiometric surface was investigated by increasing the leakance within the sub-area by a factor of two (Figure 5.18) and decreasing it by 50 percent (Figure 5.19). The potentiometric surface within the sub-area is relatively insensitive to the middle semiconfining unit leakance values. Hydraulic heads within the sub-area generally varied by less than 1 ft in response to changes in the leakance parameter.

5.4.5.4 Lower Floridan Transmissivity

Figures 5.20 and 5.21 illustrate the changes in the Upper Floridan potentiometric surface due to a two-fold increase and a 50 percent reduction in the transmissivity of the Lower Floridan respectively. Increasing the Lower Floridan transmissivity caused a maximum decrease in the Upper Floridan potentiometric surface of 2 ft in the southwest corner of the sub-area, and a

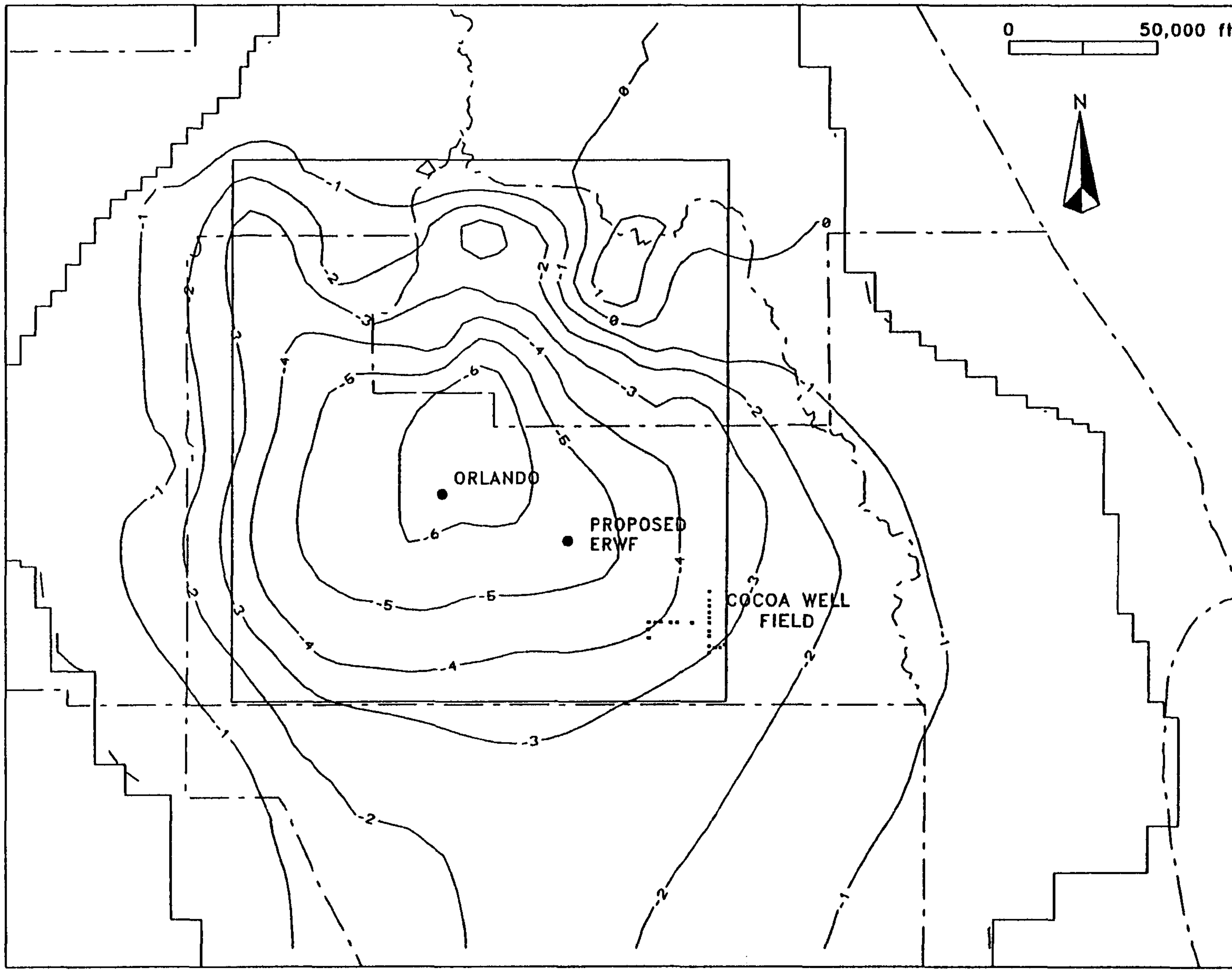

Figure 5.16. Difference between final simulated 1988 Upper Floridan potentiometric surface and potentiometric surface obtained using a two-fold increase in upper confining unit leakance within the sub-area in feet above msl.

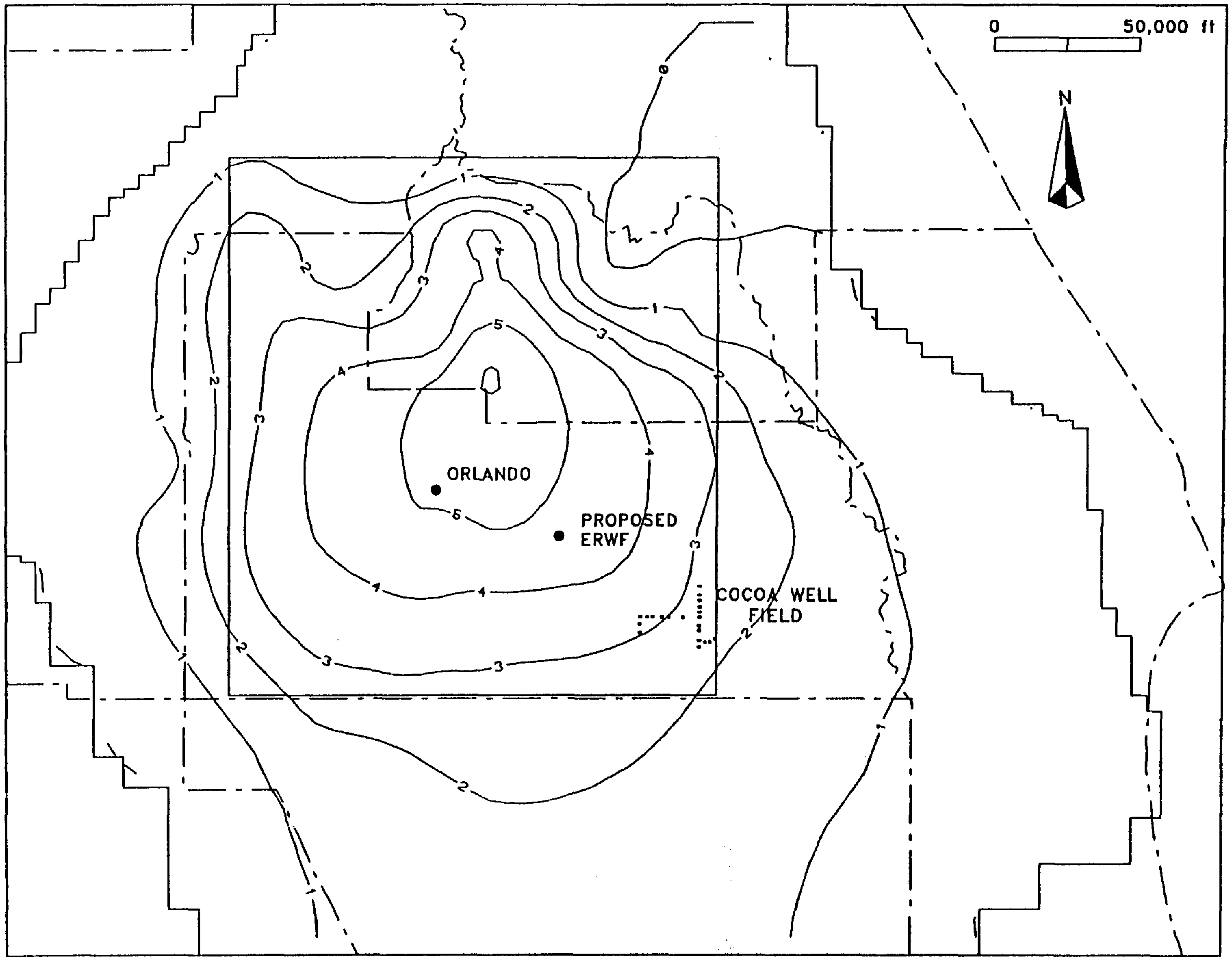

Figure 5.17. Difference between final simulated 1988 Floridan potentiometric surface and potentiometric surface obtained using a 50 percent reduction in upper confining unit leakance within the sub-area in feet above msl.

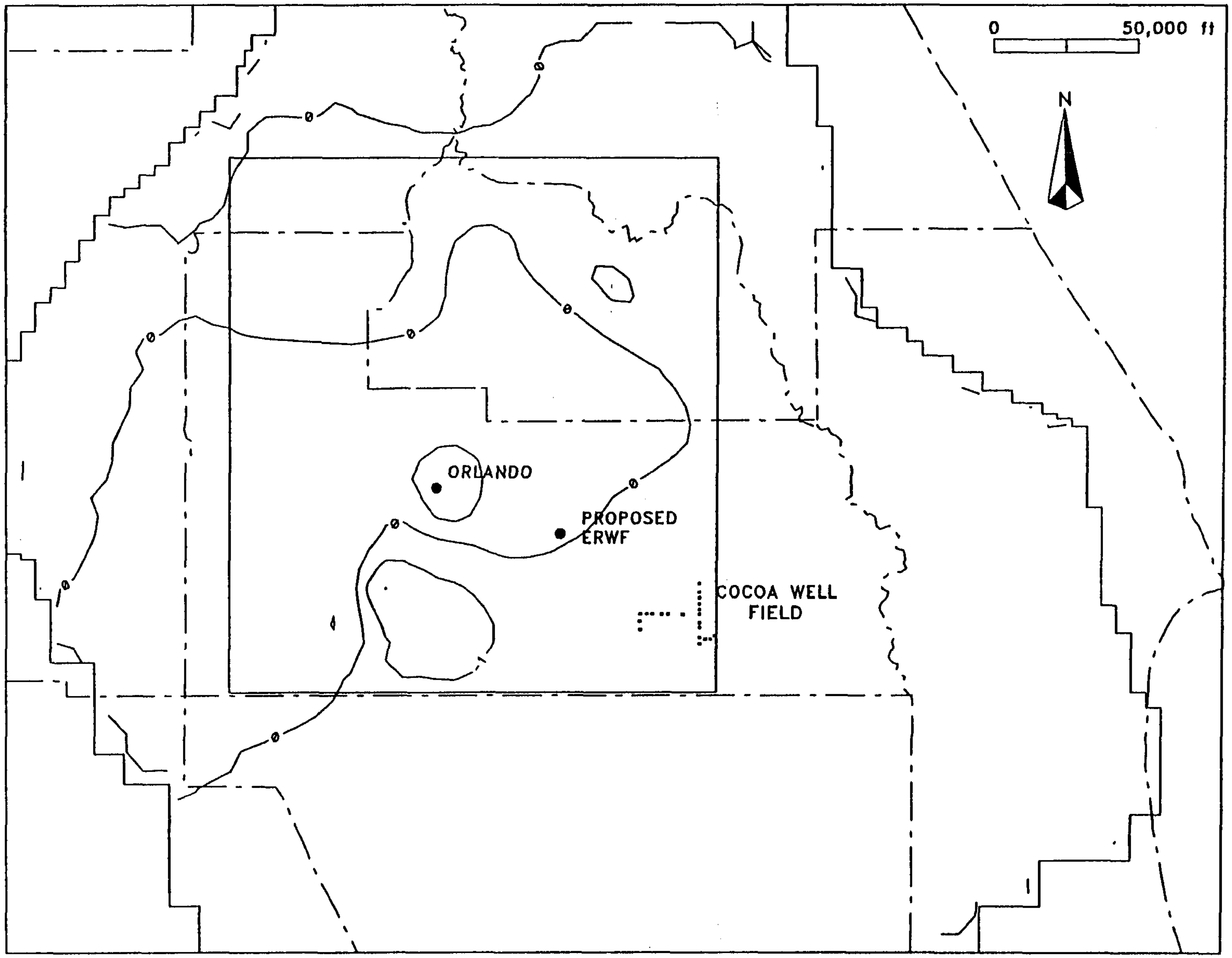

Figure 5.18. Difference between final simulated 1988 Upper Floridan potentiometric surface and potentiometric surface obtained using middle semiconfining unit leakances increased by a factor of two within the sub-area in feet above msl.

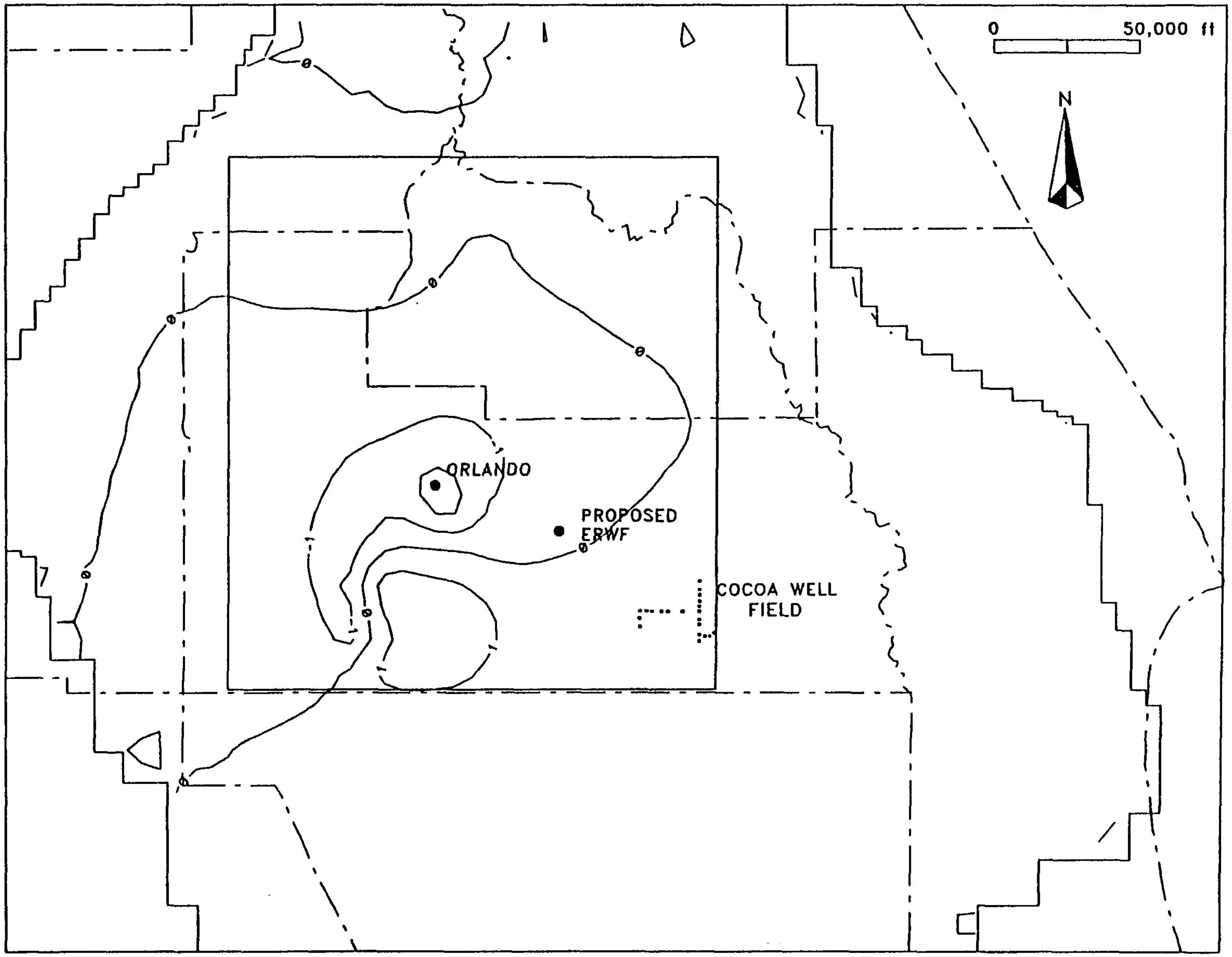

Figure 5.19. Difference between final simulated 1988 Upper Floridan potentiometric surface and potentiometric surface obtained using middle semiconfining unit leakances decreased by fifty percent within the sub-area in feet above msl.

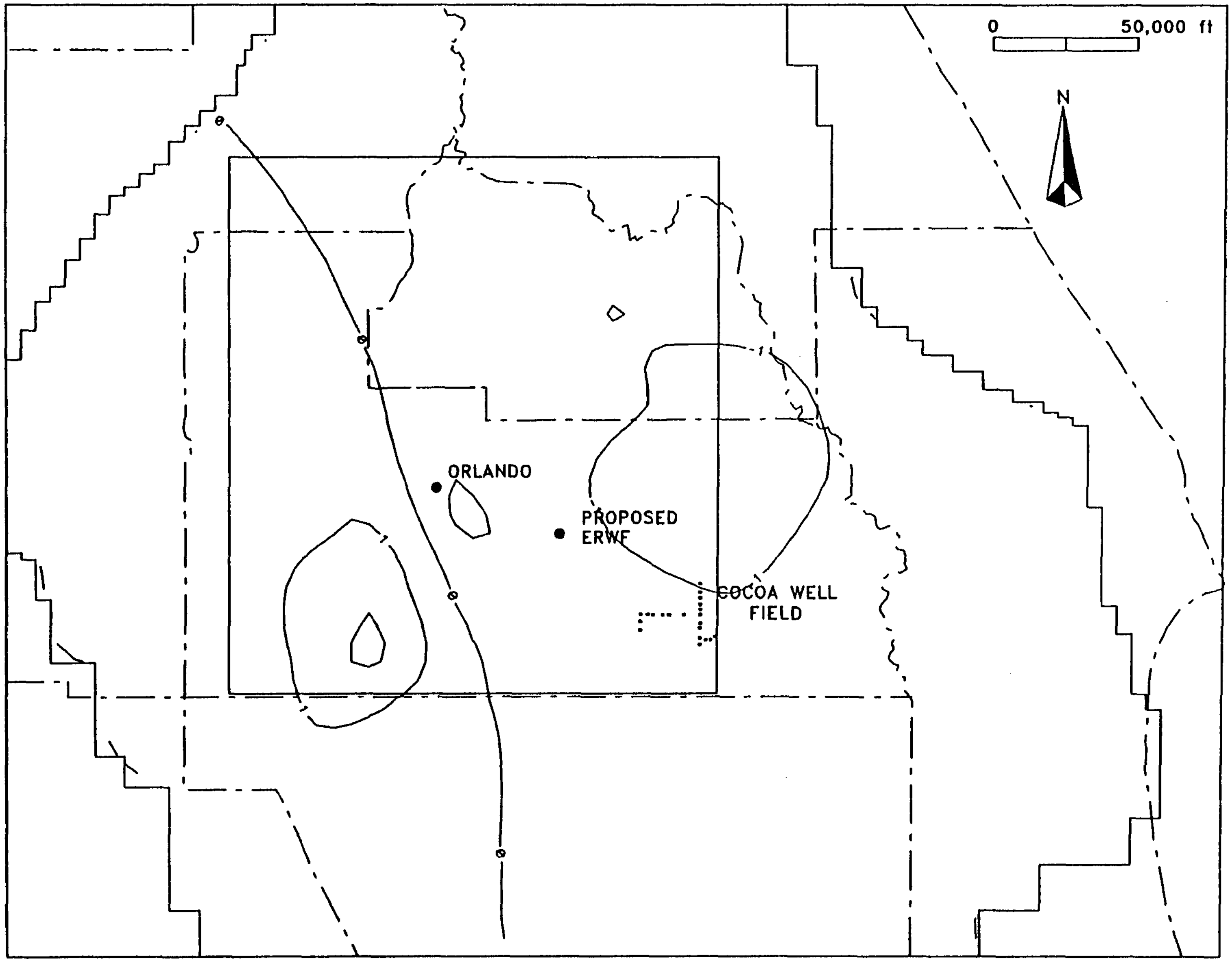

Figure 5.20. Difference between final simulated 1988 Upper Floridan potentiometric surface and potentiometric surface obtained using a two-fold increase in Lower Floridan transmissivity within the sub-area in feet above msl.

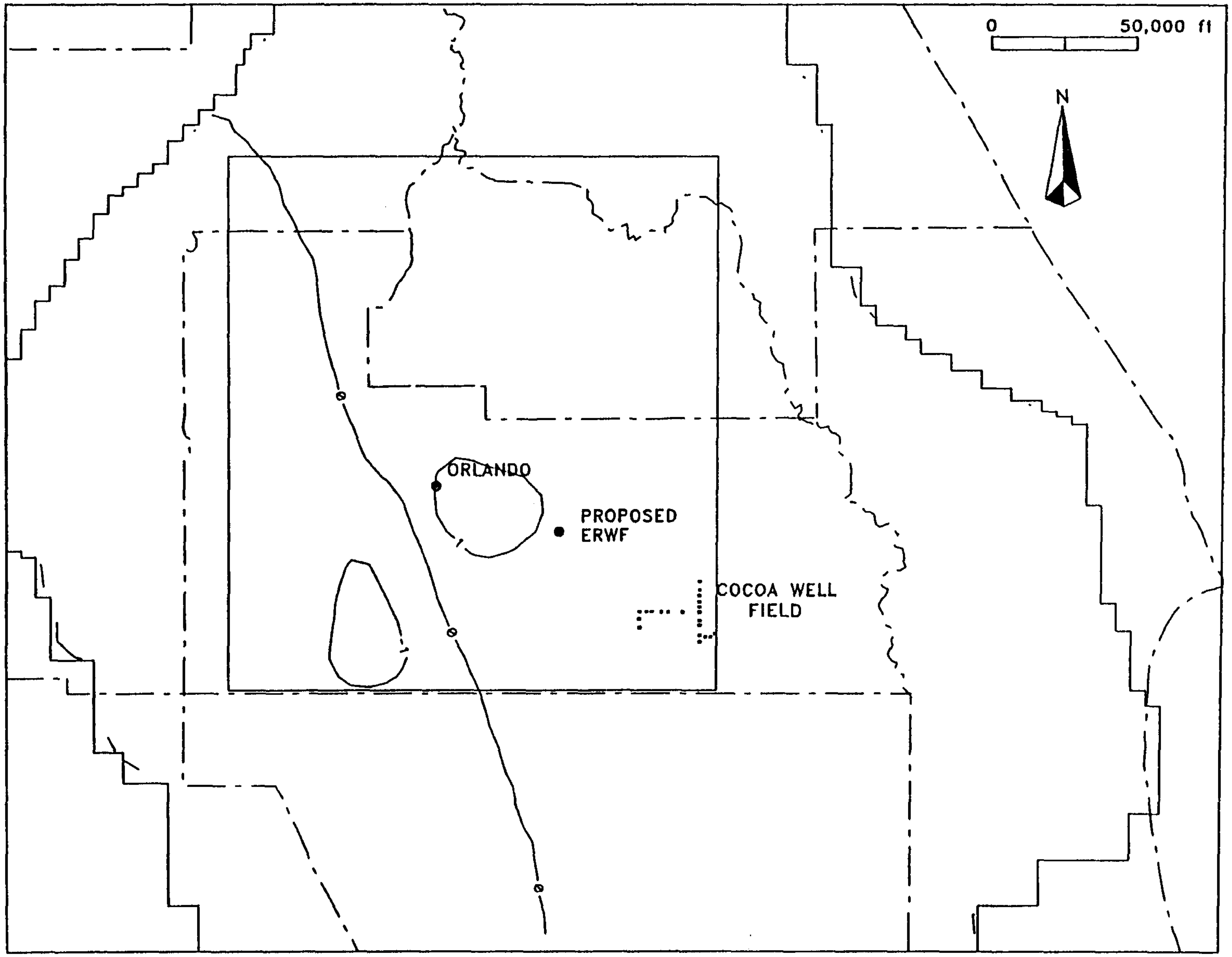

Figure 5.21. Difference between final simulated 1988 Upper Floridan potentiometric surface and potentiometric surface obtained using a 50 percent decrease in the Lower Floridan transmissivity within the sub-area in feet above msl.

maximum increase of 1 ft in the east-central corner of the sub-area. Decreasing transmissivity in the Lower Floridan induced head changes of 1 ft or less throughout the sub-area. The Upper Floridan potentiometric surface within the sub-area is very insensitive to the Lower Floridan transmissivity.

5.4.5.5 Spring Conductance

Figures 5.22 and 5.23 illustrate the changes in the Upper Floridan potentiometric surface caused by a two-fold increase, and a 50 percent reduction, respectively, of all spring conductances within the study area. Increasing the spring conductances induced a maximum decrease of the Upper Floridan potentiometric surface of 3 ft in the immediate vicinity of Wekiva, Sanlando, Palm and Starbuck Springs. The potentiometric surface at Witherington, Island and Gemini Springs was reduced 2-2.5 ft, and the potentiometric surface at Rock, Seminole, Messant, Lake Jessup and Clifton Springs declined about 1-1.5 ft. Decreasing the spring conductances had a nearly equal and opposite effect, except in the vicinity of Lake Jessup and Clifton Springs where increases in the Upper Floridan potentiometric surface were less than 1 ft.

One interesting point that is evident from Figures 5.22 and 5.23 is that the Upper Floridan potentiometric surface in the vicinity of Blue Spring and Apopka Spring is highly insensitive to the magnitude of the spring conductance used at these locations. In the vicinity of each of these springs the potentiometric surface of the Upper Floridan is not significantly higher (less than 1 ft or so) than the spring pool elevation, and it was observed during the model calibration phase of this project that the flux from these springs was more sensitive to the relative head difference between the spring pool and the Upper Floridan potentiometric surface than it was to the conductance value used.

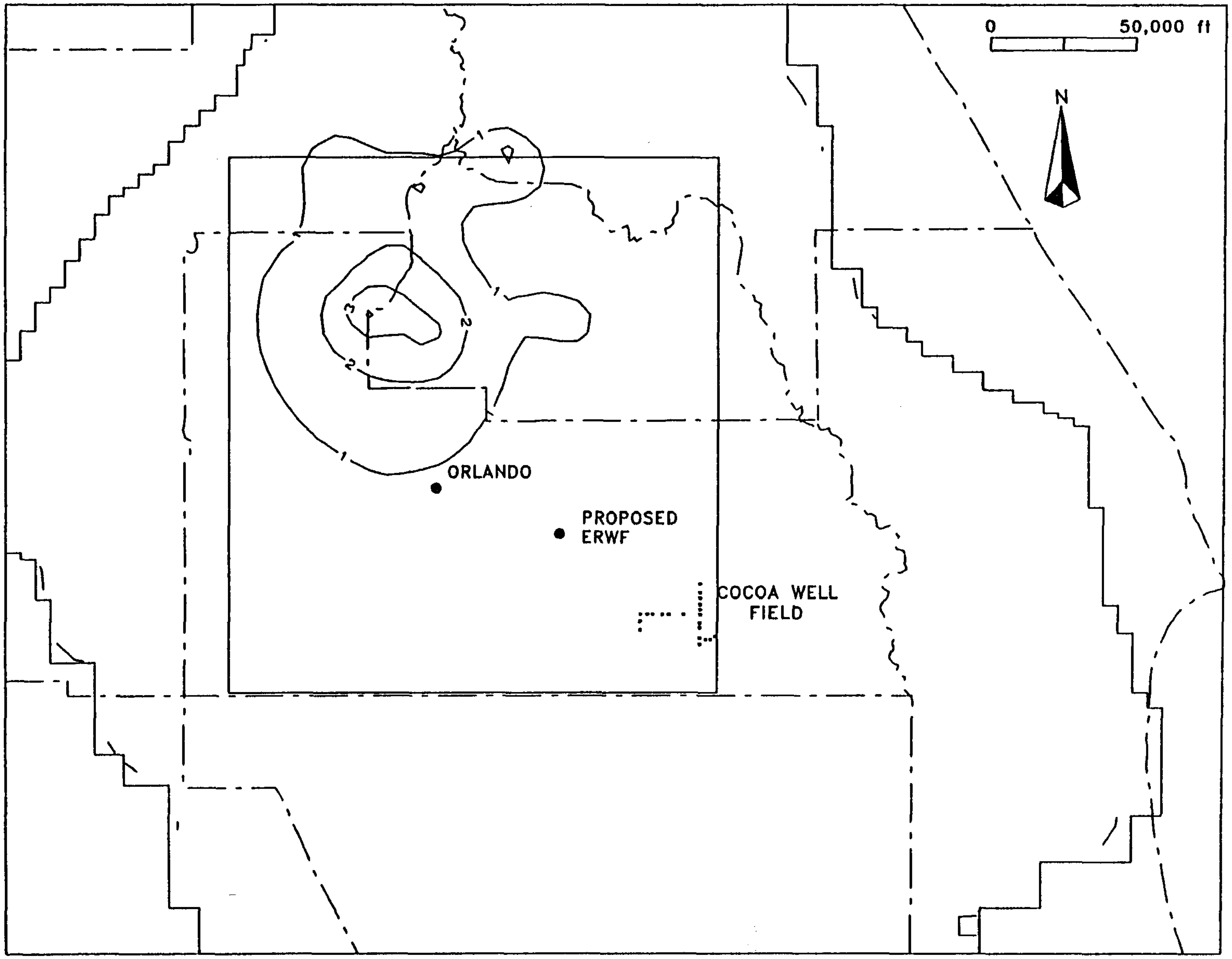

Figure 5.22. Difference between final simulated 1988 Upper Floridan potentiometric surface and potentiometric surface obtained using a two-fold increase in all spring conductances in feet above msl.

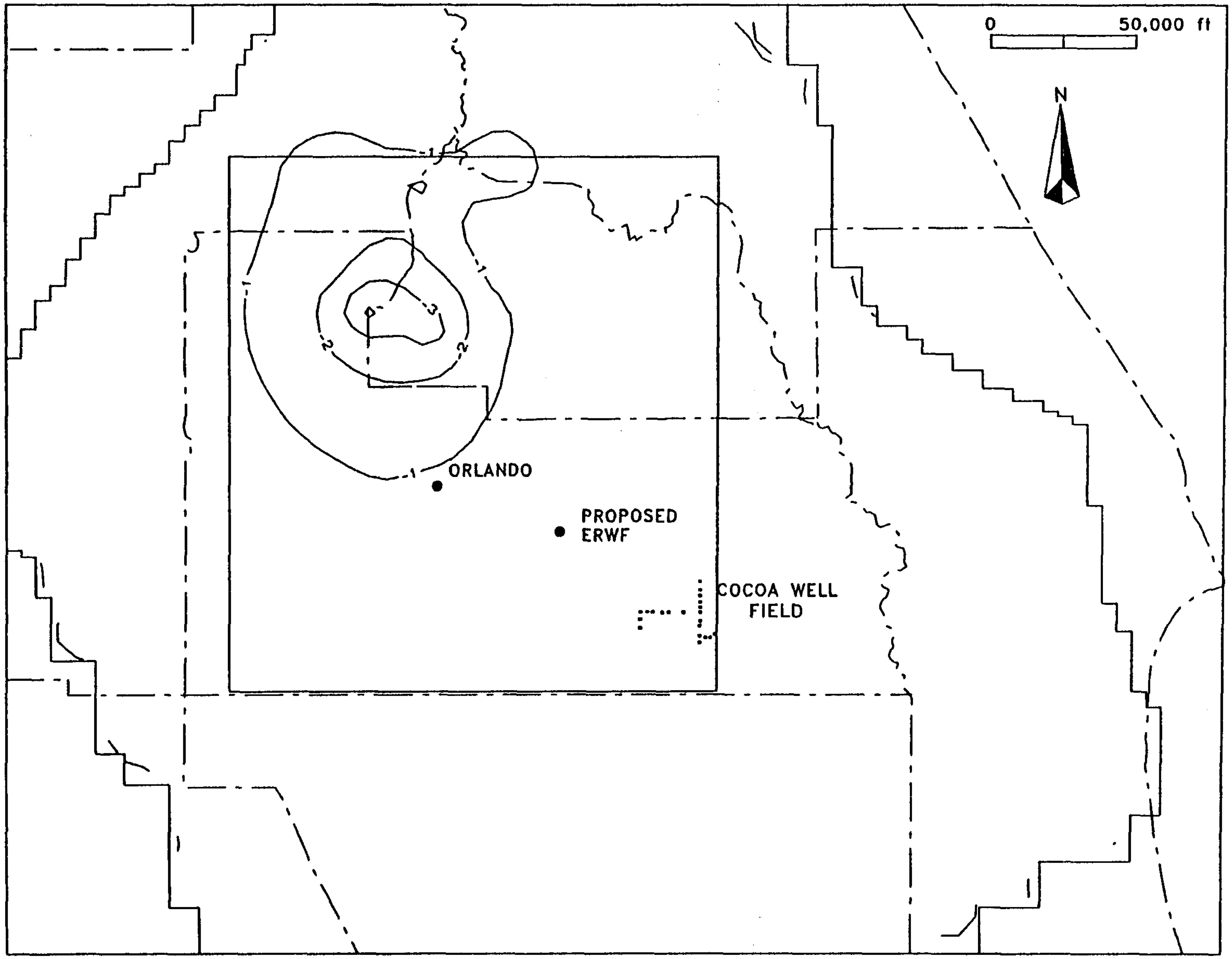

Figure 5.23. Difference between final simulated 1988 Upper Floridan potentiometric surface and potentiometric surface obtained using a 50 percent decrease in all spring conductances in feet above msl.

6 COMPARATIVE AND PREDICTIVE SIMULATIONS

6.1 CUP Comparative Simulation

One of the goals of this modeling study is to conduct a model simulation incorporating all currently permitted (as of 1991) pumpage within the study area. The data analysis and the results of this simulation are presented in the following two sections. It should be emphasized that the purpose of this section is to estimate the potential effects on the Upper Floridan potentiometric surface due to 1991 average permitted allocations, and to compare them to the simulated 1988 potentiometric surface estimated using actual withdrawals. The 1991 CUP simulation is not intended to predict the actual 1991 Upper Floridan potentiometric surface.

6.1.1 Development of CUP Withdrawal Data

The 1991 CUP discharges are presented in Table 6.1 by category. The MI CUP pumping data was supplied by the SJRWMD in the form of LOTUS spreadsheets. The total consumptive use allocation for each permit, provided in MGY, was divided by 365 to obtain permitted average daily withdrawals. In addition, some detailed data on the distribution of 1991 pumping for Orlando Utilities, Orange County and the City of Cocoa was also provided by SJRWMD based upon water use plans detailed in various reports. Orange County's proposed Eastern Regional well field (ERWF) and Western Regional well field (WRWF), and the City of Cocoa's new wells that are to be added to the West Cocoa well field, are included in the analysis. Approximately 10 percent of the 1988 withdrawals could not be matched with a permit number; at these locations the 1988 discharge values were used.

The agricultural pumping for this scenario was obtained using the IFAS files as explained in Chapter 4. The citrus permits in the IFAS files were not deleted for this run as they were for the 1988 scenario. The 1988 citrus pumping obtained from field observations of irrigated acreage, and the computed agricultural pumping due to the Duda Sod Farm and Deseret Ranches in the southeastern corner of the study area, were not incorporated into this simulation. The

Table 6.1. Total withdrawals by category used for the 1988 calibration run, the 1991 CUP comparative run, and the 2010 predictive simulations.

Category	Total Discharge (ft^3/d)		
	1988	2010	CUP (1991)
MI - Upper Floridan	24,530,781	48,621,860	30,522,593
MI - Lower Floridan	9,967,942	21,816,098	11,316,115
Agricultural - Citrus	5,368,773	5,368,773	16,717,802
Agricultural - Non-Citrus	7,921,886	7,921,886	5,793,341
Abandoned Flowing Wells	331,504	0	331,504
TOTALS	48,120,886	83,728,617	64,681,355

permitted pumpage attributable to these two sources was assumed to be contained within the IFAS data files. Discharges due to abandoned flowing wells within the study area was maintained at 1988 levels.

Permitted withdrawals within the South Florida Water Management District (SFWMD) were obtained from SFWMD permit files. Since these files do not contain latitude/longitude values for permitted well locations, the Section - Township - Range location for each well contained in the permit files was plotted on the base map, and the respective pumping was assigned to the appropriate model cell.

6.1.2 CUP (1991) Simulation

Figure 6.1 illustrates the potentiometric surface predicted using 1991 CUP withdrawals, and Figure 6.2 illustrates the difference (drawdown) between the simulated 1988 potentiometric surface and the 1991 simulated conditions obtained using permitted pumpage. Since the permitted pumpage is generally higher than the 1988 pumpage (Table 6.1), increased drawdowns of up to 6 ft in the central and southwestern regions of the study area are observed. The increased drawdowns are predominately due to increases in Upper Floridan MI pumpage (24%) and citrus pumping (211%).

Localized regions of more than 6 ft of drawdown (relative to the 1988 simulated potentiometric surface) occur at the proposed expansion of the City of Cocoa's West Cocoa well field and in the vicinity of the city of Kissimmee in Osceola County. Drawdowns greater than 4 ft were predicted at Orange County's ERWF. Pumping from the ERWF and the expansion of the West Cocoa well field were not included in the 1988 simulation because it did not exist at that time.

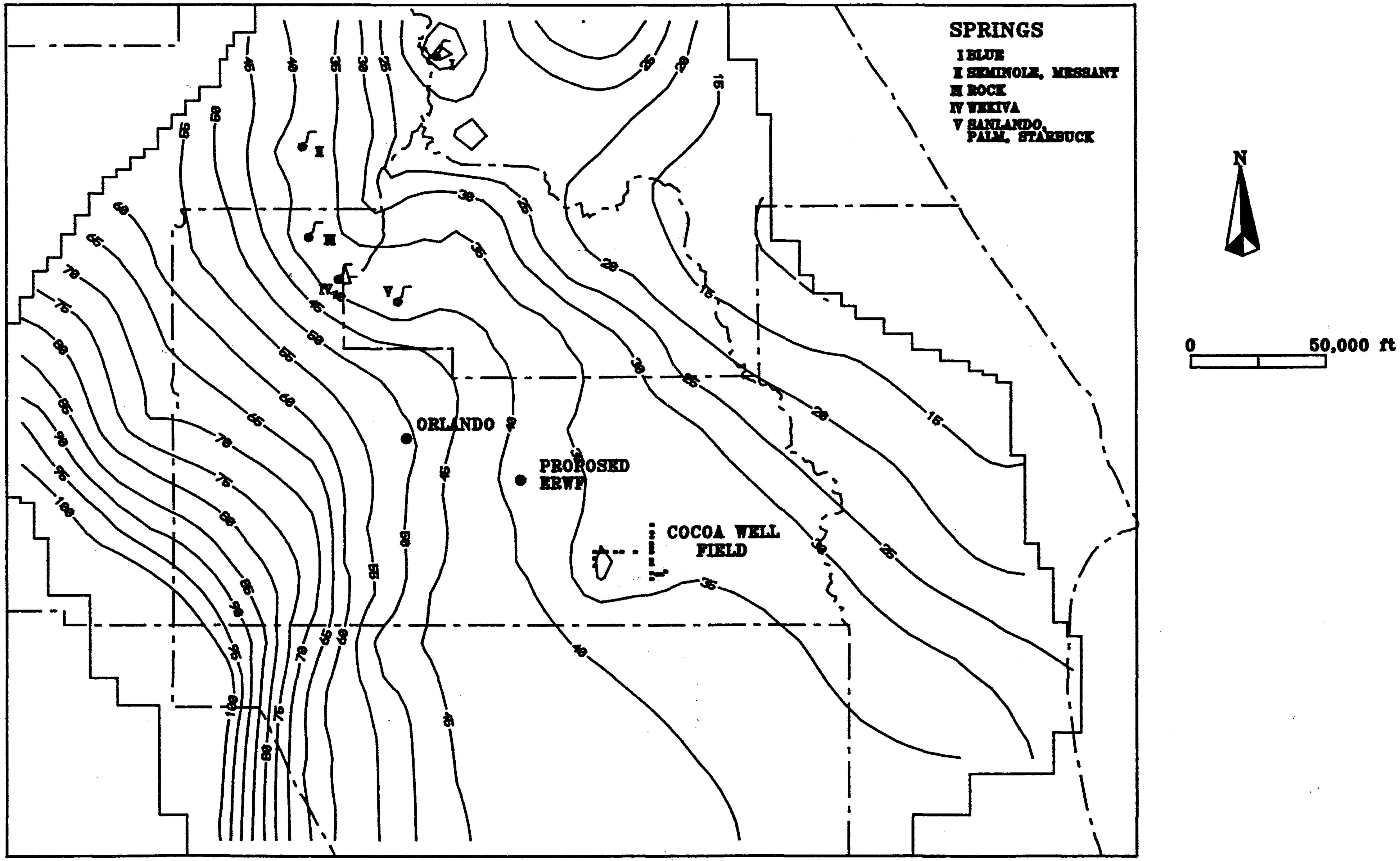

Figure 6.1. Simulated Upper Floridan potentiometric surface obtained using 1991 permitted withdrawals in feet above msl.

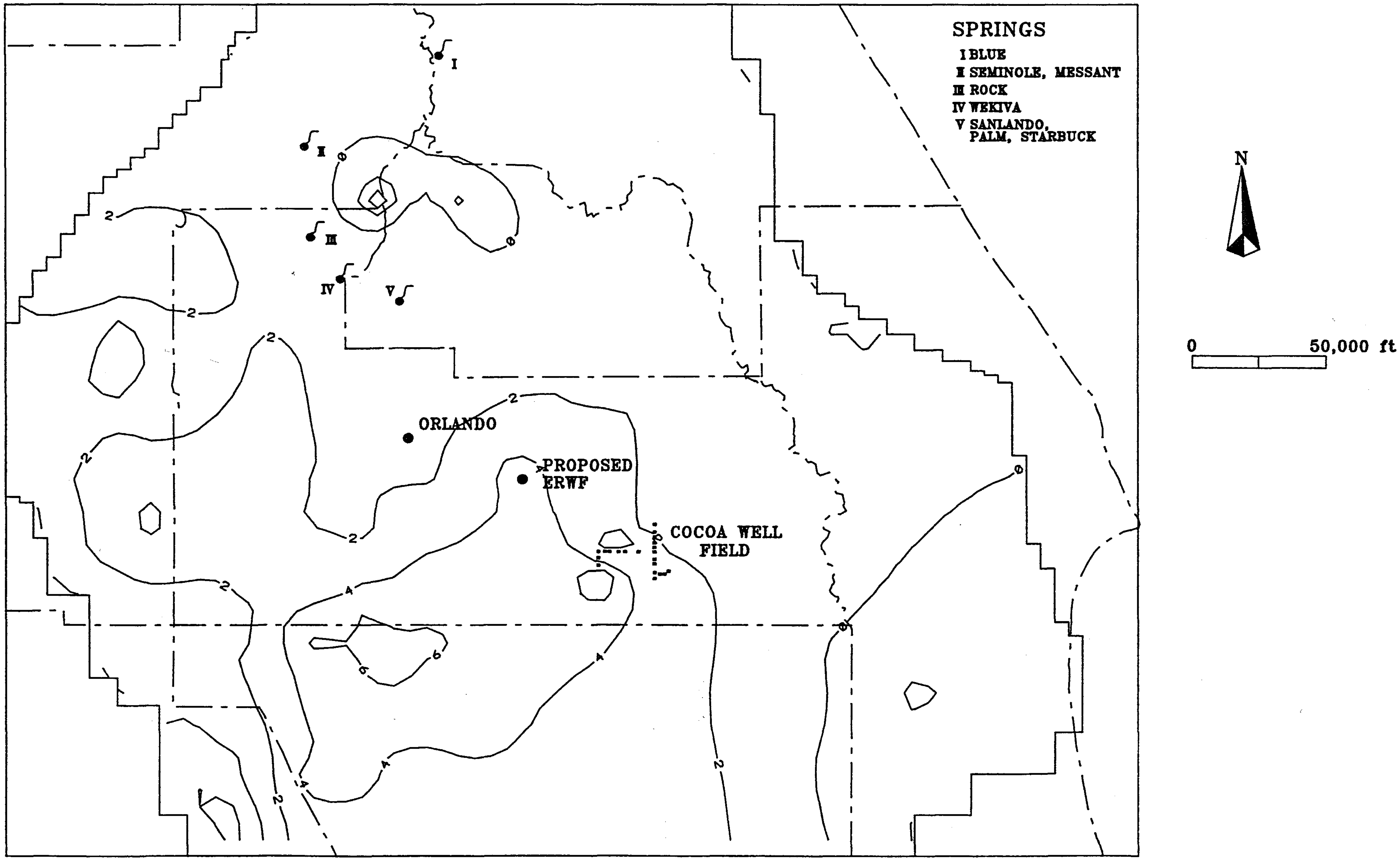

Figure 6.2. Difference between simulated 1988 potentiometric surface and 1991 (CUP) potentiometric surface of Upper Floridan in feet above msl.

6.2 Predictive Simulation for the Year 2010

The major purpose of this study is to assess the impacts of utilizing fresh ground water within the study area at projected withdrawal rates over a twenty-year planning period. These impacts were assessed by running the steady-state, 1988 calibrated ground-water flow model using estimated 2010 pumping rates. The data analysis and simulation results for this effort are discussed in the following sections.

6.2.1 Development of 2010 Withdrawal Data

Table 6.1 lists the 1988 and the corresponding (estimated) 2010 withdrawals by category. The only substantial increases are the MI withdrawals in both the Upper and Lower Floridan aquifers. The withdrawal estimates for agricultural uses (citrus and non-citrus) were not changed for 2010. This approach is consistent with data contained in the IFAS report (Lynne and Kiker, 1991). Table 6.2 lists the estimated increase (decrease) for citrus and non-citrus irrigation requirements by county over the period 1990 to 2010. One can see from Table 6.2 that the estimated irrigation requirements range from zero change for Orange County to an overall 10 percent decrease in Seminole County. For the most part, percentage increases and decreases range in the vicinity of 3-4%. Given the moderate estimated changes in irrigation requirements from current (1990) to 2010 conditions, in combination with the lack of knowledge concerning the location of future increases or decreases in irrigation requirements, the approach of maintaining agricultural withdrawals at 1988 levels for the 2010 simulation is appropriate. The discharge due to abandoned flowing wells within the study area was eliminated for the 2010 simulation, since the District plans to eventually cap these wells.

The 2010 MI pumping estimates were compiled by District staff and supplied in spreadsheet form. Numerous sources, including Kimball-Lloyd, Inc. (1991); Orlando Utilities Commission (1990); Brown and Caldwell Consultants (1987, 1988); Jammal and Associates, Inc. (1990b); Camp, Dresser and McKee, Inc. (1991) and CH2M-Hill, Inc. (1988) were used in developing the spreadsheet. Some predictions were made by District staff by comparing 1989 water

Table 6.2. Estimated percentage increase (decrease) in agricultural irrigation requirements from 1990 to 2010 (from Lynne and Kiker, 1991).

County	Percent Change for Citrus Crops	Percent Change for Non-Citrus Crops	Overall Percent Change
Orange	-1.3	0.4	0
Seminole	-8	-10.8	-10
Lake	-4.6	-0.2	-3
Volusia	18.5	3.5	4
Osceola	-3.6	7.1	7
Brevard	2	4.6	4.5
Polk	3	0	3

use and projected population data. For a relatively small number of locations, 2010 pumpage estimates were not available in the files supplied by the SJRWMD. For these locations, 1988 pumping values were used if the water use was industrial, and the 1988 pumping values were multiplied by the growth factor documented in Kimball Lloyd, Inc. (1991) if the water use was public supply. Table 6.1 indicates that the projected 2010 withdrawal rates for both the Upper and Lower Floridan aquifers are approximately twice the estimated 1988 withdrawals.

6.2.2 2010 Predictive Simulations Using Calibrated 1988 Model

Using the 1988 calibrated ground-water flow model, a predictive simulation for the year 2010 was conducted using the discharge estimates as outlined in Table 6.1. Figures 6.3 and 6.4 show the distribution of pumping for the 2010 simulations in the Upper and Lower Floridan, respectively. For the most part the spatial distribution of pumping for 2010 is very similar to that of 1988. There are however, some notable differences. For example, the 2010 simulation included Orange County's proposed new Eastern Regional (Upper Floridan) and Western Regional (Lower Floridan) well fields. A number of Orange County's other wellfields that existed in 1988 were taken off-line for the 2010 scenario, which is consistent with Orange County's master plan. For the 2010 scenario, 13 wells were also added to the south sides of the existing West and East Cocoa well fields. The recharge due to drainage wells and the prescribed head boundary values were kept the same as in the 1988 simulation.

Figures 6.5 and 6.6 illustrate the simulated Upper Floridan potentiometric surface as of 2010, and the 2010 drawdown from simulated 1988 conditions, respectively. Each figure suggests that, given the estimated 2010 pumpage estimates, there will be substantial drawdown within the Upper Floridan aquifer by the year 2010. The largest predicted drawdown of 30 ft is predicted at Orange County's proposed Eastern Regional well field (ERWF). The estimated 2010 discharge from this well field is about 6,065,000 ft^3/d (45.37 MGD), which is about 12% of the total pumping for MI within the Upper Floridan (Brown and Caldwell Consultants, 1988 and Jammal and Associates Inc., 1990b). Additional regions of substantial drawdown include northwest Seminole County in the vicinity of Sanford, and eastern Orange County in the vicinity

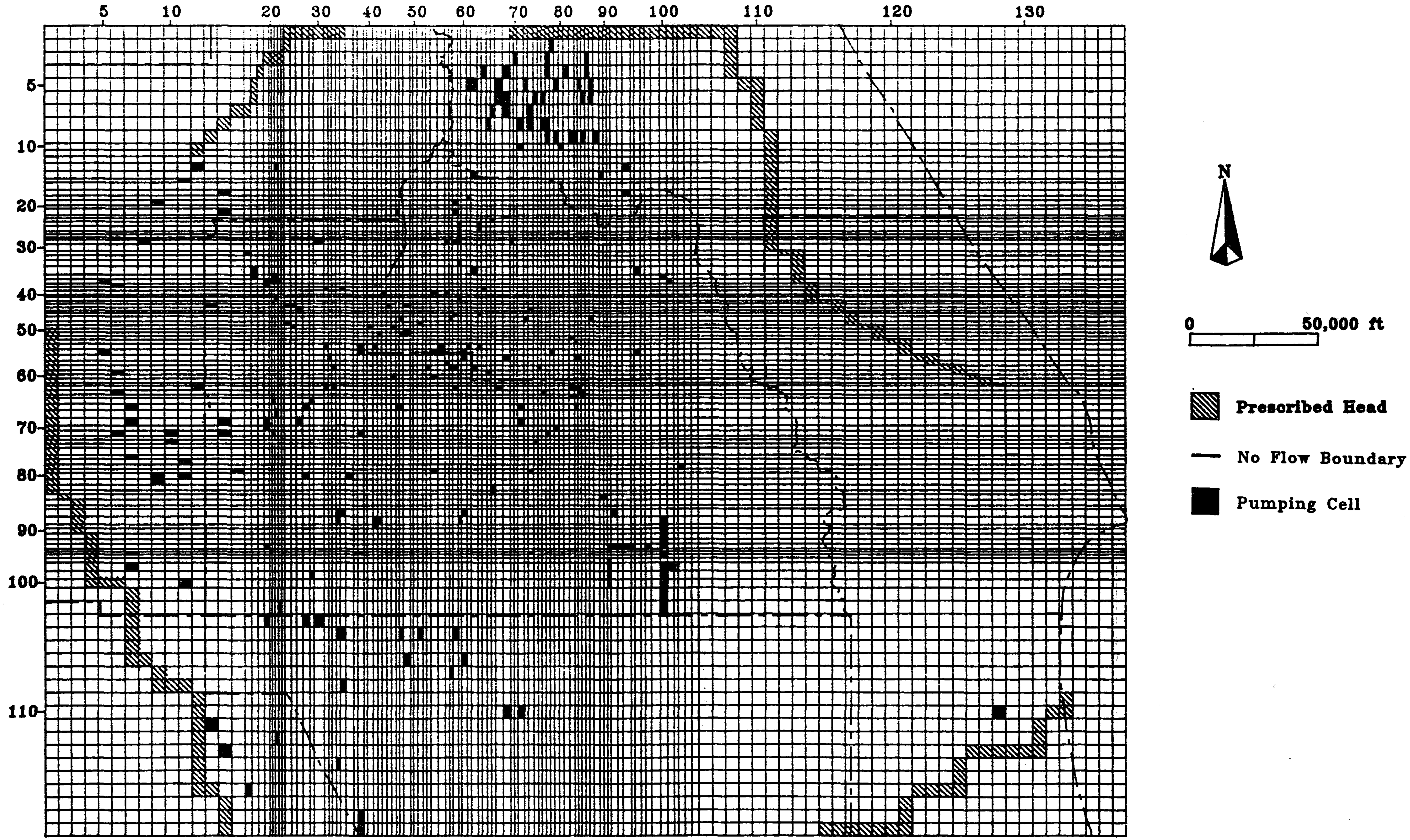

Figure 6.3. MI pumping locations in Upper Floridan for 2010 predictive simulation.

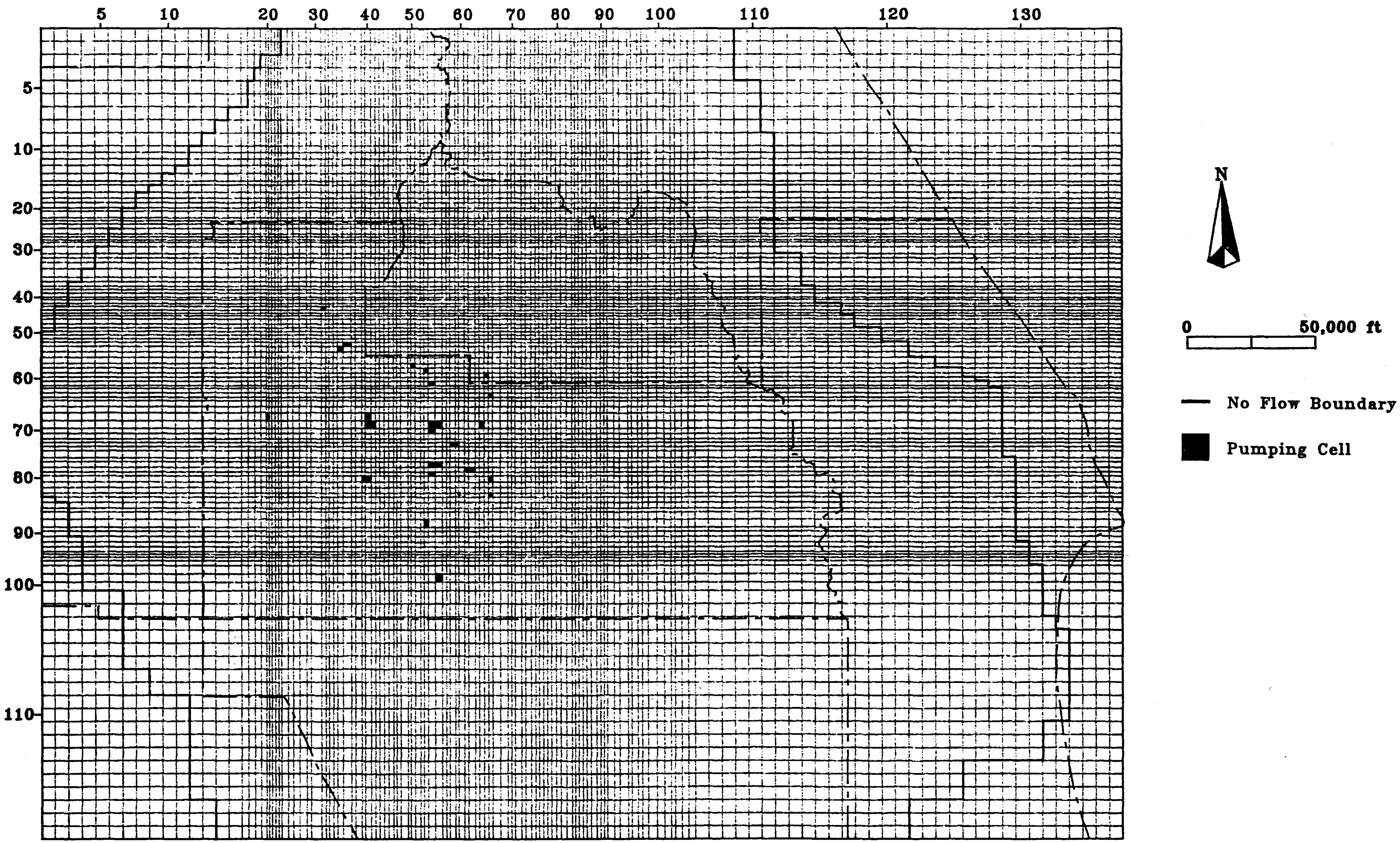

Figure 6.4. MI pumping locations in Lower Floridan for 2010 predictive simulation.

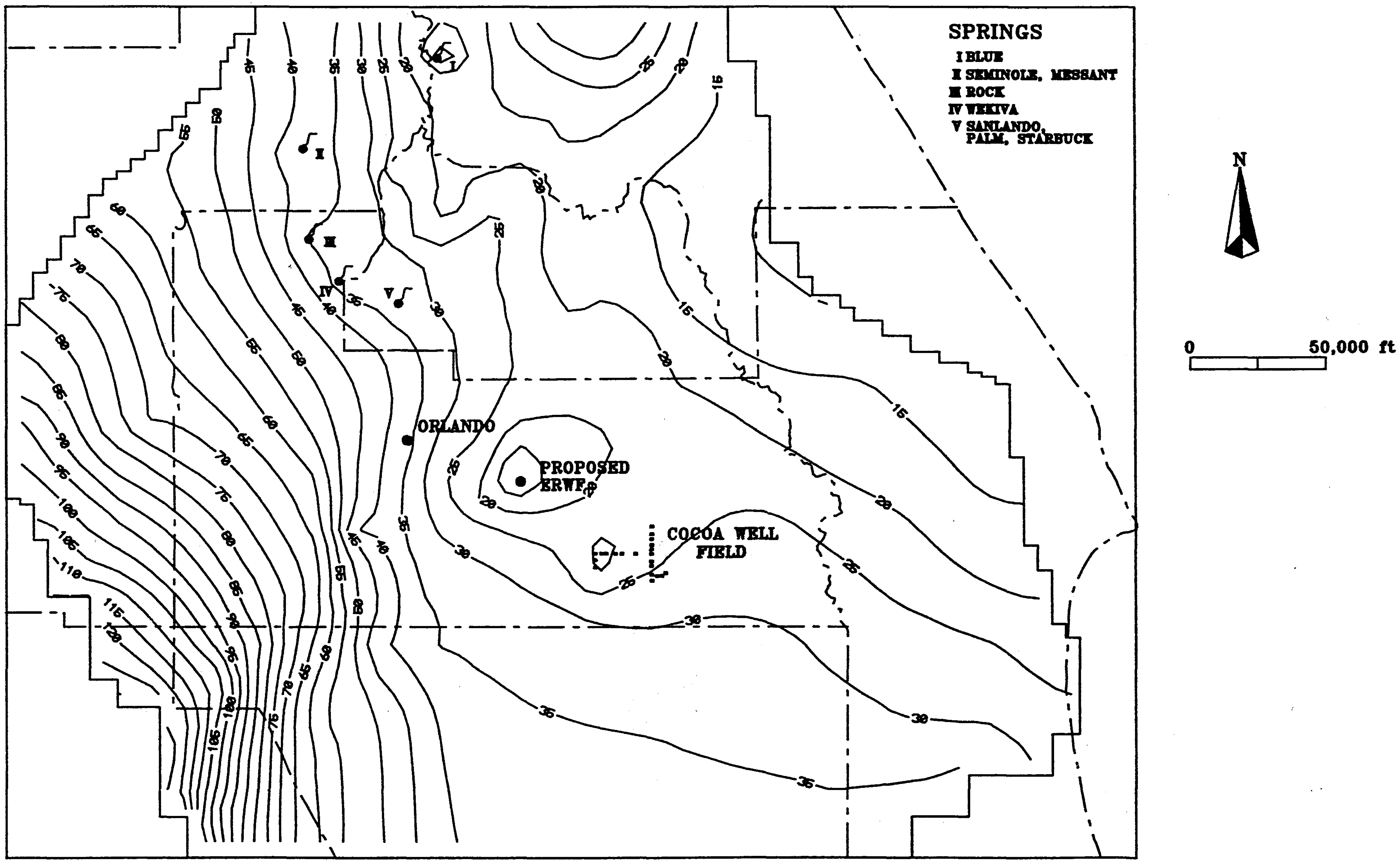

Figure 6.5. Simulated 2010 potentiometric surface for Upper Floridan using calibrated 1988 model in feet above msl.

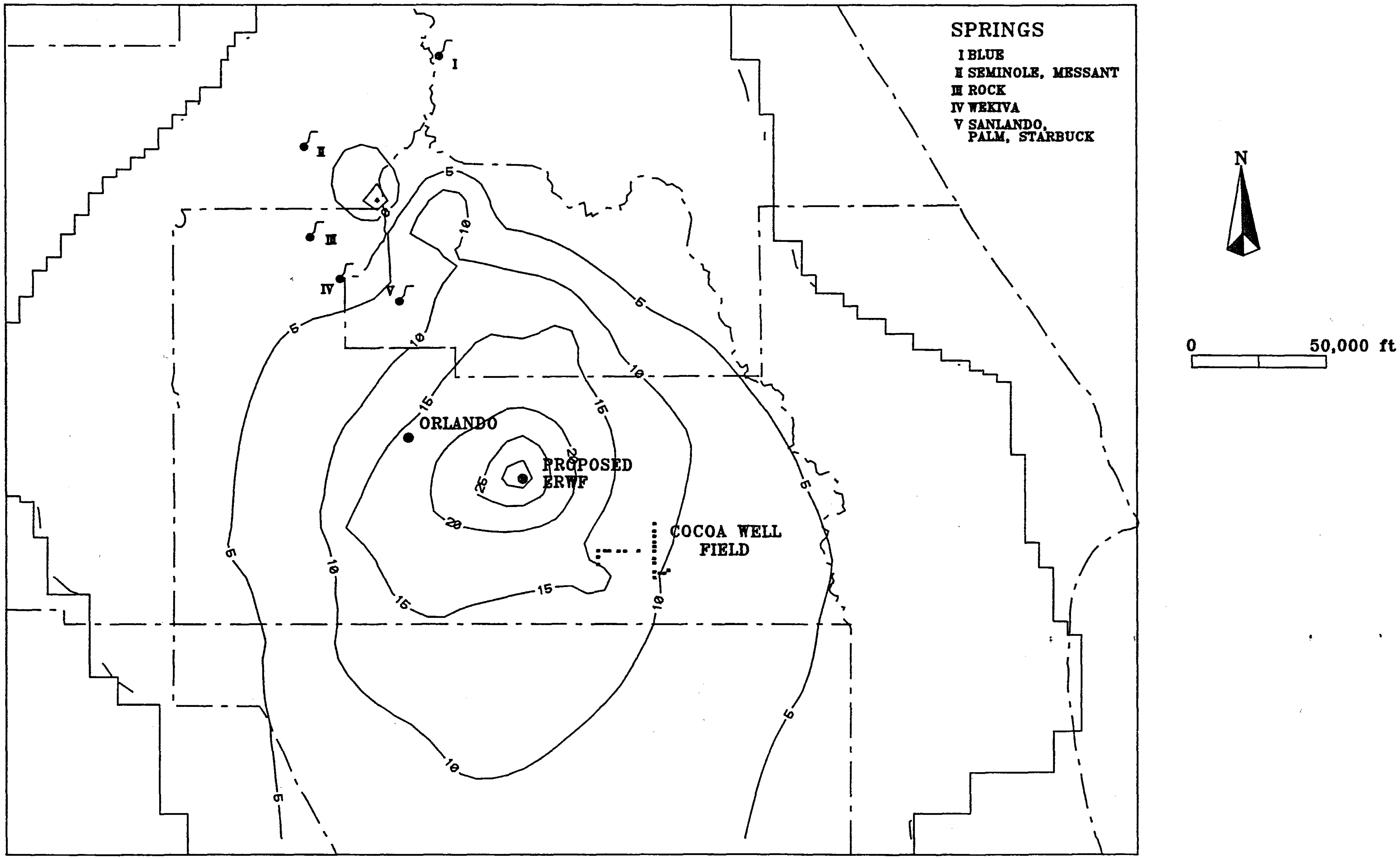

Figure 6.6. Difference between 1988 simulated potentiometric surface and 2010 simulated potentiometric surface of Upper Floridan in feet above msl.

of the proposed extension to the West Cocoa well field; predicted drawdown in each of these regions is about 15 ft.

Table 6.3 presents a mass balance analysis for the 2010 model run and the average 1988 simulation. It is evident from Table 6.3 that, in order to offset the increased pumping expected to occur by 2010, the estimated spring flows, discharge from the Upper Floridan, and outflow through prescribed head boundaries within the study area decreased by 16 percent, 27 percent and 18 percent respectively. Additional water was also supplied by increases of areal recharge to the Upper Floridan and inflow through prescribed head boundaries of 34 percent and 14 percent, respectively.

Figure 6.7 is a contour plot of the change in areal recharge to the Upper Floridan from simulated 1988 to predicted 2010 conditions. The largest increases in recharge are predicted to occur in western and south-central Seminole County; the general area northwest of Lake Apopka; and in southern Lake and southwest Orange Counties. Two relatively small areas in the vicinity of the northwest shore of Lake Apopka and southwest of the Geneva Lens, and a fairly large area in the vicinity of Reedy Creek Swamp, changed from Upper Floridan discharge regions to recharge regions for the 2010 simulation.

The effect of withdrawing such a large volume of water from an area as small as the proposed ERWF was investigated further by conducting another model run for 2010 in which pumping at the ERWF was set to zero. All other input parameters were identicle to those used for the previous 2010 predictive simulation. The results of this run are presented in Figures 6.8 and 6.9. Figure 6.9 illustrates that deleting the ERWF pumping decreased drawdowns from 1988 conditions by about 15 ft in the vicinity of ERWF and about 5 ft in southern Seminole County and central Orange County. Predicted 2010 drawdowns in northwest Seminole County remained approximately the same as in the previous simulation (about 10 ft). For this simulation the center of the 2010 cone of depression shifted from the ERWF to Orange County's Conway well field, which has a projected 2010 withdrawal rate of 1,138,657 ft^3/d divided among three Upper Floridan wells located within the same model cell.

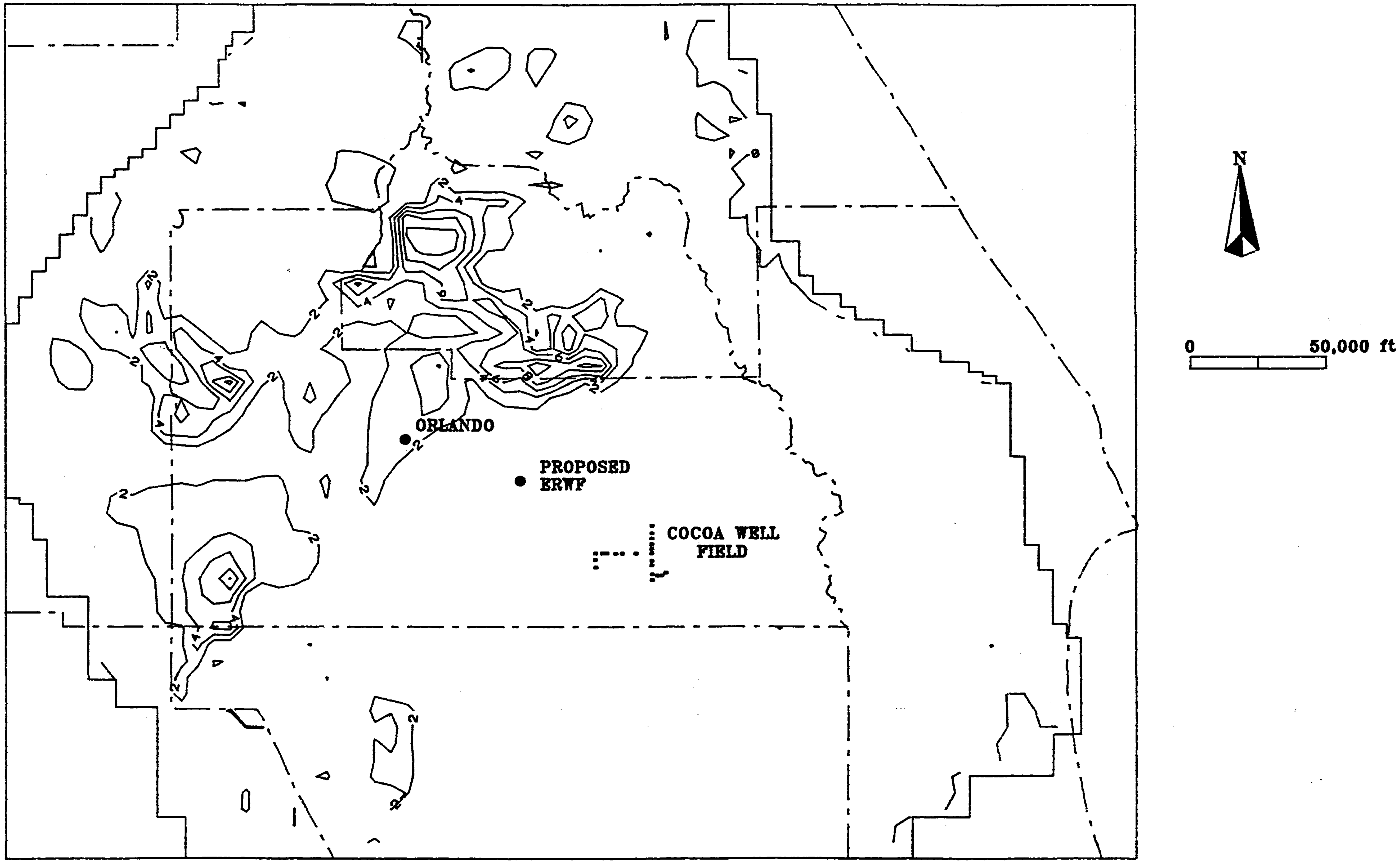

Figure 6.7. Change in recharge to the Upper Floridan from 1988 to predicted 2010 conditions. Contour interval is 2 inches/yr.

Table 6.3. Changes in simulated ground-water flux from 1988 to 2010 conditions.

Single	Postdevelopment (1988)		Predictive Simulation (2010)		Percent Change *
	Flux ft^3/d)	Percent of Total Inflow/ Outflow	Flux (ft^3/d)	Percent of Total Inflow/ Outflow	
Inflow through Prescribed Head Boundaries	34,416,000	34.6	39,345,000	31.5	14.3
Outflow through Prescribed Head Boundaries	5,489,500	5.5	4,517,500	3.6	-17.7
Discharge Wells	48,058,000	48.2	83,020,000	66.3	72.7
Recharge Wells	4,411,400	4.4	4,411,400	3.5	0
Spring Discharge	37,611,000	37.8	31,669,000	25.3	-15.8
Areal Recharge to Upper Floridan	60,511,000	60.9	81,203,000	65.0	34.2
Areal Discharge from Upper Floridan	8,282,700	8.3	6,039,200	4.8	-27.1

* Percent change in flux from predevelopment to postdevelopment conditions calculated using $\left[\frac{Q_{2010} - Q_{1988}}{Q_{1988}}\right] \times 100$

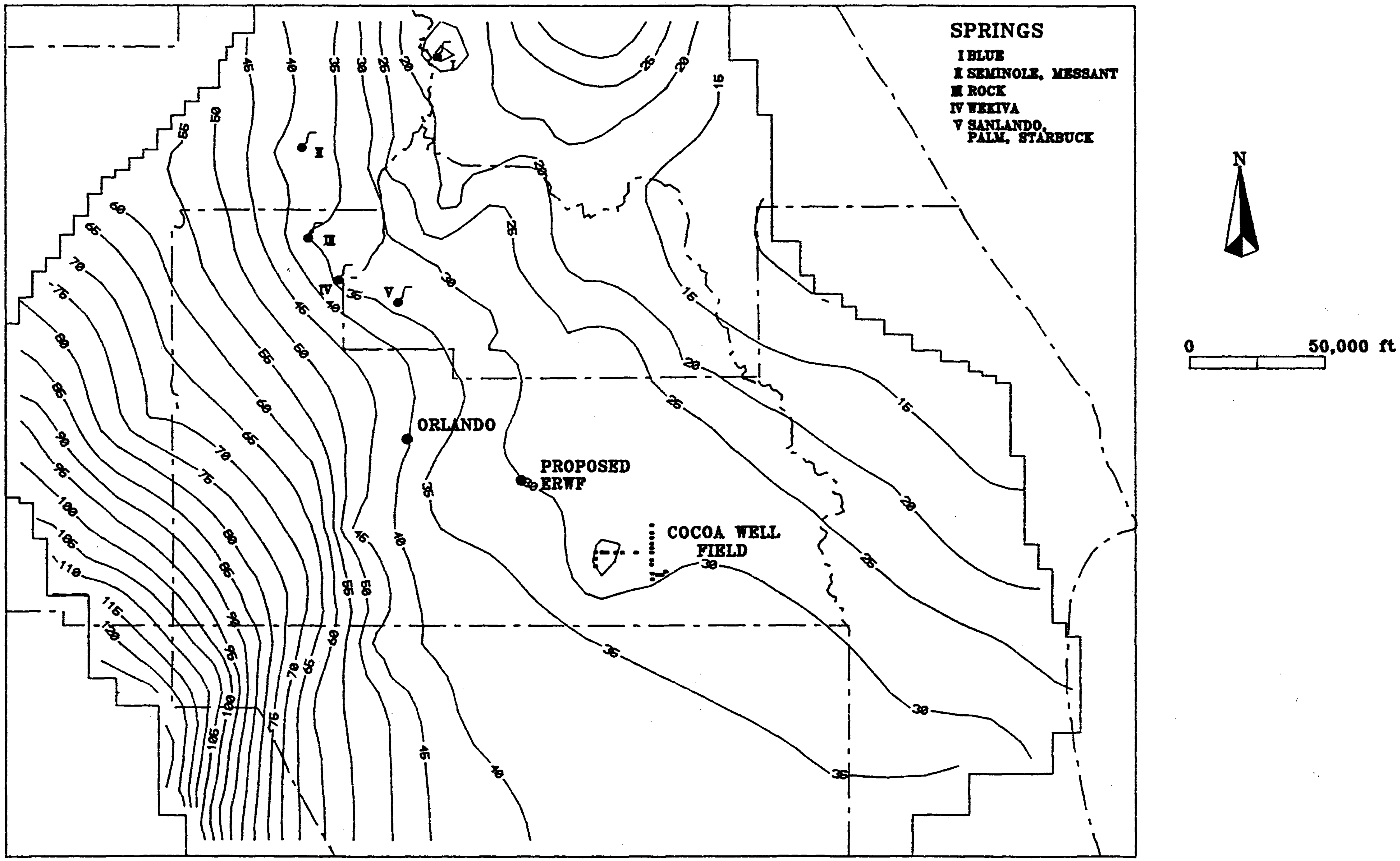

Figure 6.8. Simulated 2010 potentiometric surface for Upper Floridan in feet above msl using 1988 model with ERWF pumping deleted.

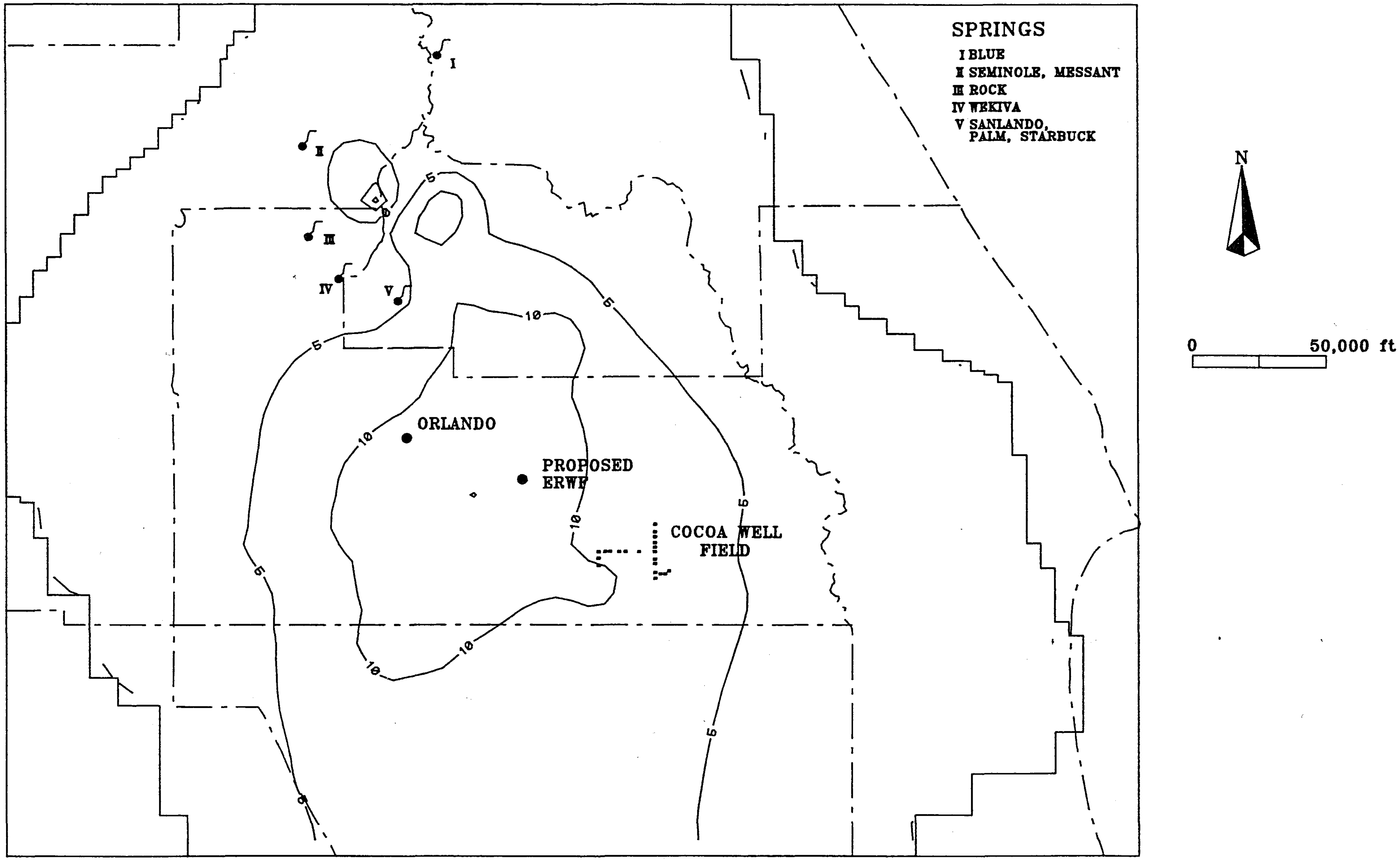

Figure 6.9. Difference between 1988 simulated potentiometric surface and 2010 simulated potentiometric surface with no ERWF pumping for Upper Floridan in feet above msl.

7 SUMMARY AND CONCLUSIONS

This study is based upon an existing ground-water flow model developed by Blandford et al. (1991) as Phase I of the District's east-central Florida ground-water modeling effort. The first portion of this study involved developing a finer discretization of the existing model grid, changing the spring discharge and recharge to the Upper Floridan to be head-dependent, and the subsequent calibration of the model to average predevelopment and average 1988 conditions. Blandford et al. (1991) had only calibrated their model to average 1988 conditions. The model calibration was conducted by varying the leakance of the upper confining unit, spring conductances, and (in limited regions) Upper Floridan transmissivity. The fine discretization of the model grid permitted most MI pumping centers to be located within individual grid blocks, which is useful because drawdown impacts due to individual users may be more easily assessed. The fact that the model could be calibrated to predevelopment, as well as postdevelopment, conditions indicates that the model may be useful for predicting ground-water flow conditions for periods of time other than 1988.

Within the primary area of interest (Orange and Seminole Counties in the vicinity of Orlando), the differences between the observed Upper Floridan potentiometric surface and that simulated by the model are generally less than about 2 ft. At some locations within the model domain, however, differences of over 8 ft exist. These large differences do not occur over substantial portions of the study area, and they tend to occur in regions of high hydraulic gradients where slight variations in potentiometric surface contours lead to comparatively large differences between simulated and observed hydraulic heads.

A subsequent sensitivity analysis conducted for 1988 conditions illustrated that the Upper Floridan potentiometric surface is highly sensitive to leakance of the upper confining unit, moderately sensitive to Upper Floridan transmissivity and spring conductance, and only slightly sensitive to transmissivity of the Lower Floridan and leakance of the middle semiconfining unit. It was important, therefore, to determine appropriate values of upper confining unit leakance, Upper Floridan transmissivity and spring conductance. Recharge, which is a direct function of leakance of the upper confining unit, was calibrated using a map provided in Tibbals (1990). This map was spot-checked using 1988 data and was found to be accurate within most parts of the study region. Furthermore, the calibrated Upper Floridan transmissivity values and spring conductances lie within a reasonable range as determined by aquifer tests and previous modeling studies (Blandford et al. 1991). It is, therefore, believed that the calibrated model parameters are reasonable on a regional scale. The lack of piezometric head data for the Lower Floridan precluded a calibration of this model layer. It would be quite useful to have more information on this aquifer, and the SJRWMD may consider more intensive data collection for the Lower Floridan in the future.

A comparative simulation was conducted using the calibrated model for all currently (1991) permitted withdrawals within the study area. All of the inputs for this simulation were the same as those for the 1988 calibration, except a pumping file consisting solely of permitted discharge values was substituted for the 1988 pumping file. The results of this simulation indicated widespread drawdowns of 2-4 ft throughout the study area when compared to 1988 conditions. The increased drawdown was due to larger permitted MI and citrus pumping in the Upper Floridan than was determined for 1988 average conditions. The pumpage for citrus irrigation obtained from the permit files appears to be especially high.

Two predictive simulations for the year 2010 were conducted using the calibrated model. Estimates of municipal and industrial pumping rates for the year 2010 were provided by the SJRWMD, and the 1988 values for agricultural pumping and drainage well recharge were used in each simulation. The first simulation incorporated all of the pumping centers expected to be operational in 2010; the results of this simulation indicate that substantial drawdowns will occur by the year 2010 throughout much of Orange and Seminole Counties. The largest drawdowns (about 30 ft) are predicted to occur at Orange County's proposed Eastern Regional well field (ERWF). Large drawdowns (15 ft) are also predicted to occur in the vicinity of the town of Sanford in the northwest Seminole County. This simulation indicated a 16 percent decrease in total spring flows throughout the study area. A second predictive simulation was run with the only difference being that the estimated 2010 ERWF withdrawal was deleted. This simulation indicated maximum drawdowns of 10-15 ft throughout central Orange County and northwest Seminole County. This simulation indicated a 13 percent decrease in total spring flows throughout the study area.

Comparison of the two 2010 predictive simulations indicates that, throughout central Orange County and south-central Seminole County, proposed withdrawals from the ERWF increase drawdowns by about 5 ft as compared to predictive drawdowns with the ERWF not in operation. Within a relatively local region in the vicinity of the ERWF, increased drawdowns (due only to the ERWF) of 10-15 ft are predicted.

The large drawdowns that presumably will occur in response to 2010 pumping warrant careful, further study. The first item to be addressed should be the accuracy of the estimated 2010 pumping values. Although MI pumping doubled overall from the 1988 to 2010 conditions, some locations had huge increases (ten to twenty times) in estimated discharge from the 1988 values. The validity of these increases should be critically examined by District staff.

If the estimated 2010 withdrawal rates are deemed to be reasonable, the District should initiate immediate action to investigate ways to mitigate the severe depletions. The first step might be to use the calibrated ground-water flow model to evaluate resource planning and utilization alternatives. An example of one such alternative would be to distribute the proposed pumping at large well fields, such as Orange County's ERWF, over a larger region. It might also be prudent to site new well fields in the western regions of the study area where the water quality is good and the recharge rates to the Upper Floridan are, or have the potential to be, high.

Finally, the results of this study indicate that it will be a difficult task for the District to effectively manage the available ground-water resources in central Seminole and Orange Counties throughout the coming years. Significant increases in withdrawals for various municipalities throughout the region, if they occur, will place a critical, and possibly irreversible stress on existing ground-water resources. Upper Floridan ground water with chloride concentrations of 250 parts per million (ppm) or greater already exists throughout significant portions of Seminole County and eastern Orange County. The extent of non-potable water in the Lower Floridan is poorly defined, but at many locations in central Orange and Seminole Counties ground water with chloride concentrations greater than 250 ppm probably underlies existing and proposed well fields. The potential for lateral encroachment and upconing of poor quality water is clearly evident. To compound the problem, most of the well fields in the identified region of concern are, or will be, located in poor recharge areas. This is important because as pumping increases, the volume of water that will be obtained from increased recharge from the surficial aquifer will be limited (at least in the immediate vicinity of the well field), and therefore larger drawdowns will occur than if the same increases in pumping had taken place in a region of high recharge potential.

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APPENDIX A

Groundwater Withdrawal Data
for 1988

Spreadsheet PH488Q: 1988 withdrawals by category for Phase IV RASI modeling in ft^3/d. Upper Floridan listed first, then Lower Floridan. Duda and Deseret Q not incorporated!

Deleted locations outside active model domain.

Row	Col	M&I	Citrus	Non-Cit.	Abandoned Wells	Total
1	28	0	0	426.7	0	-426.7
1	33	0	0	1280.4	0	-1280.4
1	60	0	0	959.9	0	-959.9
1	61	0	0	1066.5	0	-1066.5
1	62	0	0	959.9	0	-959.9
1	65	0	0	12023.9	0	-12023.9
1	66	0	0	14314.4	0	-14314.4
2	27	0	0	4266.4	0	-4266.4
2	62	0	0	3412.7	0	-3412.7
2	65	0	0	9920.2	0	-9920.2
2	71	0	0	1920.6	0	-1920.6
2	75	0	0	1391	0	-1391
2	78	17103.1	0	0	0	-17103.1
2	79	0	0	10382.7	0	-10382.7
2	80	6102.6	0	3413.8	0	-9516.4
3	43	0	0	320	0	-320
3	45	0	0	426.7	0	-426.7
3	67	0	0	5443.9	0	-5443.9
3	68	0	0	3412	0	-3412
3	70	14304.8	0	0	0	-14304.8
3	77	3342.2	0	0	0	-3342.2
4	28	0	0	0	0	-60480
4	44	0	0	5120.1	0	-5120.1
4	60	0	0	0	0	-12340800
4	64	8725.1	0	0	0	-8725.1
4	68	6319.4	0	0	0	-6319.4
4	72	0	0	3839.4	0	-3839.4
4	77	6602.1	0	0	0	-6602.1
5	18	0	0	7020.9	0	-7020.9
5	19	0	0	11298	0	-11298
5	61	2138.8	0	0	0	-2138.8
5	67	72505.2	0	0	0	-72505.2
5	72	18716.6	0	0	0	-18716.6
5	80	0	0	1919.9	0	-1919.9
5	81	0	0	1919.9	0	-1919.9
5	87	194032.7	0	0	0	-194032.7
6	22	0	0	11198.7	0	-11198.7
6	46	0	0	18558.4	0	-18558.4
6	47	0	0	8532.4	0	-8532.4
6	67	52994	0	0	0	-52994
6	68	19044.2	0	0	0	-19044.2
6	74	64677.6	0	0	0	-64677.6
6	76	64677.6	0	0	0	-64677.6
6	87	64677.6	0	0	0	-64677.6
7	27	0	0	15245.7	0	-15245.7
7	44	0	0	8532.1	0	-8532.1
7	45	0	0	5974.2	0	-5974.2

7	66	19073.4	0	0	0	-19073.4
7	68	32394.5	0	0	0	-32394.5
7	73	64677.6	0	0	0	-64677.6
7	104	0	0	51018.9	0	-51018.9
7	105	0	0	51018.9	0	-51018.9
8	15	0	0	1067.2	0	-1067.2
8	36	0	0	994	0	-994
8	43	0	0	10093.8	0	-10093.8
8	44	0	0	5046.9	0	-5046.9
8	65	18714.5	0	0	0	-18714.5
8	71	64677.6	0	0	0	-64677.6
8	73	129355.2	0	0	0	-129355.2
8	77	258710.3	0	0	0	-258710.3
8	103	0	0	17006.3	0	-17006.3
8	104	0	0	17006.3	0	-17006.3
8	105	0	0	34012.6	0	-34012.6
9	20	0	0	15231.8	0	-15231.8
9	36	0	0	1988	0	-1988
9	38	0	0	34813.6	0	-34813.6
9	79	64677.6	0	0	0	-64677.6
10	25	0	0	20189	0	-20189
10	30	0	0	5211.3	0	-5211.3
10	71	12685.5	0	0	0	-12685.5
11	19	0	0	20189	0	-20189
11	25	0	0	40378	0	-40378
11	33	0	0	51818.4	0	-51818.4
11	65	0	0	0	0	-691200
11	97	0	0	7800	0	-7800
11	98	0	0	6603.4	0	-6603.4
12	14	0	0	1524.3	0	-1524.3
12	19	0	0	22868.8	0	-22868.8
12	20	0	0	22868.8	0	-22868.8
12	34	0	0	0	0	-1209600
12	97	0	0	14403.4	0	-14403.4
12	99	0	0	39125.4	0	-39125.4
13	12	45959.1	0	0	0	-45959.1
13	19	0	0	22868.8	0	-22868.8
13	21	0	0	22868.8	0	-22868.8
13	22	178343.4	0	0	0	-178343.4
13	27	0	0	20189	0	-20189
13	28	0	0	20189	0	-20189
13	30	0	0	0	0	-3369600
13	94	2408.9	0	0	0	-2408.9
13	97	0	0	6603.4	0	-6603.4
13	99	0	0	6603.4	0	-6603.4
14	10	0	19718.7	0	0	-19718.7
14	15	0	14368.6	0	0	-14368.6
14	16	0	0	53359.9	0	-53359.9
14	62	42297.1	0	0	0	-42297.1
14	89	4278	0	0	0	-4278
15	11	164720.5	0	0	0	-164720.5
15	48	0	0	0	0	-518400
16	9	0	13451.5	0	0	-13451.5
16	12	0	18037.2	0	0	-18037.2
16	14	0	27208.7	0	0	-27208.7
16	16	0	0	94487.6	0	-94487.6
16	17	0	20024.4	0	0	-20024.4
17	10	0	0	3998.3	0	-3998.3
17	14	313620.7	0	0	0	-313620.7
17	21	0	0	4266.4	0	-4266.4

17	94	3774	0	0	0	-3774	
18	61	17468.1	0	0	0	-17468.1	
19	9	154796.2	0	0	0	-154796.2	
19	10	0	14521.5	0	0	-14521.5	
19	17	0	22623	0	0	-22623	
19	25	0	0	762.2	0	-762.2	
19	58	6625.4	0	0	0	-6625.4	
19	75	0	0	0	16334	-16334	
19	77	0	0	1724.7	0	-1724.7	
19	78	0	0	3449.3	0	-3449.3	
20	75	0	0	0	16445	-16445	
20	76	0	0	0	2283	-2283	
20	78	0	0	10347.9	0	-10347.9	
21	14	2779	0	0	0	-2779	
21	46	1704241.5	0	0	0	-1704241.5	
21	54	0	0	10672.4	0	-10672.4	
21	56	0	0	7623.1	0	-7623.1	
21	58	6017.4	0	0	0	-6017.4	
21	59	0	0	0	0	0	City of Sanford
21	62	157368	0	0	0	-157368	City of Sanford
21	64	0	0	10610.2	0	-10610.2	
21	77	0	0	6463.5	0	-6463.5	
21	80	0	0	4829.3	0	-4829.3	
21	81	0	0	508.4	0	-508.4	
22	18	0	0	80802.1	0	-80802.1	
22	62	130063	0	0	0	-130063	City of Sanford
22	68	3882.2	0	0	0	-3882.2	
22	80	0	0	2795.9	0	-2795.9	
22	81	0	0	254.2	0	-254.2	
23	17	0	0	10562.2	0	-10562.2	
23	66	16149.8	0	0	0	-16149.8	
23	80	0	0	254.2	0	-254.2	
24	63	94474	0	0	0	-94474	City of Sanford
24	82	0	0	0	7404	-7404	
25	7	0	15897.2	0	0	-15897.2	
25	25	0	0	10062.3	0	-10062.3	
25	63	55696.4	0	0	0	-55696.4	City of Sanford
26	17	0	0	15245.7	0	-15245.7	
26	18	0	0	3049	0	-3049	
27	23	0	0	30491.5	0	-30491.5	
27	58	10828	0	0	0	-10828	
28	14	17944.2	0	0	0	-17944.2	
28	53	20507.7	0	0	0	-20507.7	
28	68	106952	0	0	0	-106952	City of Sanford
29	7	0	17120.1	0	0	-17120.1	
29	12	0	21553	0	0	-21553	
29	14	0	13604.3	0	0	-13604.3	
29	17	0	0	2515.7	0	-2515.7	
29	20	0	0	1677.4	0	-1677.4	
29	27	0	0	9146.6	0	-9146.6	
29	30	25522.9	0	0	0	-25522.9	
29	56	41784.4	0	0	0	-41784.4	
29	59	66845	0	0	0	-66845	Lake Mary
29	68	136364	0	0	0	-136364	City of Sanford
29	79	0	18517	0	0	-18517	
29	81	0	0	0	4139	-4139	
30	33	0	0	0	0	-5054400	
30	24	0	0	1524.3	0	-1524.3	
30	26	0	0	5335.8	0	-5335.8	
31	7	0	15897.2	0	0	-15897.2	

31	13	0	40201.6	0	0	-40201.6
31	16	17433.3	0	5488.6	0	-22921.9
31	18	0	0	13721.8	0	-13721.8
31	20	0	0	3810.8	0	-3810.8
31	21	0	0	3810.8	0	-3810.8
31	27	0	0	10672.4	0	-10672.4
32	18	0	0	1920.6	0	-1920.6
32	25	0	0	5092.3	0	-5092.3
32	26	0	0	2546.1	0	-2546.1
32	27	0	0	28967.2	0	-28967.2
32	99	0	0	22868.4	0	-22868.4
33	13	0	0	45737.2	0	-45737.2
33	18	0	0	1219.6	0	-1219.6
33	19	0	0	7623.1	0	-7623.1
33	26	0	0	32017.3	0	-32017.3
33	27	0	0	21344.8	0	-21344.8
33	31	0	0	4573.3	0	-4573.3
33	59	168126.2	0	0	0	-168126.2
33	68	0	0	20.9	0	-20.9
33	93	0	0	67771	0	-67771
34	5	0	19871.5	0	0	-19871.5
34	13	0	0	108599.4	0	-108599.4
34	17	23071.1	0	0	0	-23071.1
34	23	0	0	3049	0	-3049
34	30	0	0	44417.3	0	-44417.3
34	35	0	0	0	0	-345600
34	54	0	0	15245.7	0	-15245.7
34	55	0	0	15245.7	0	-15245.7
34	62	1940.9	0	0	0	-1940.9
34	96	5823.3	0	0	0	-5823.3
35	12	0	0	1715.9	0	-1715.9
35	14	0	0	5761.1	0	-5761.1
35	17	4578.1	0	12721.2	0	-17299.3
35	21	7974.2	0	0	0	-7974.2
35	22	7974.2	0	0	0	-7974.2
35	30	0	0	18112	0	-18112
35	55	0	0	15245.7	0	-15245.7
35	100	1336.8	0	0	0	-1336.8
36	5	94371.9	0	0	0	-94371.9
36	12	0	0	8618.9	0	-8618.9
36	13	0	0	67228.2	0	-67228.2
36	14	0	0	101100.9	0	-101100.9
36	19	7974.2	0	0	0	-7974.2
36	20	7974.2	0	0	0	-7974.2
36	21	7974.2	0	0	0	-7974.2
36	22	71767.6	0	0	0	-71767.6
36	23	7974.2	0	0	0	-7974.2
36	100	0	0	12958.5	0	-12958.5
36	101	2673.6	0	0	0	-2673.6
37	6	41967.5	0	0	0	-41967.5
37	13	0	0	101100.9	0	-101100.9
37	19	7974.2	0	0	0	-7974.2
37	88	0	0	15245.7	0	-15245.7
38	12	0	0	5761.8	0	-5761.8
38	13	0	0	41112.6	0	-41112.6
38	31	26476.8	0	0	0	-26476.8
38	35	582.3	0	0	0	-582.3
38	39	0	0	0	0	-6004800
38	42	0	0	0	0	-444960
38	64	78258.7	0	0	0	-78258.7

38	71	0	0	0	0	-56160
39	4	0	25527.3	0	0	-25527.3
39	5	0	37603	0	0	-37603
39	12	0	0	2880.9	0	-2880.9
39	23	0	0	5304	0	-5304
39	28	0	0	59967.8	0	-59967.8
39	31	0	0	8766.8	0	-8766.8
39	43	752700.7	0	0	0	-752700.7
39	54	454358.2	0	0	0	-454358.2
39	56	167027.6	0	0	0	-167027.6
39	82	0	14038.5	0	0	-14038.5
39	86	0	11454.7	0	0	-11454.7
40	4	0	0	34384.3	0	-34384.3
40	28	0	0	2053.5	0	-2053.5
40	31	0	0	8766.8	0	-8766.8
40	71	2646.1	0	0	0	-2646.1
41	22	2164.5	0	0	0	-2164.5
41	25	0	0	3811.2	0	-3811.2
41	59	104259.5	0	0	0	-104259.5
41	77	0	0	0	0	-112320
41	82	0	0	3621.1	0	-3621.1
41	83	0	0	3621.1	0	-3621.1
41	85	0	0	10283.8	0	-10283.8
41	86	0	0	23392.2	0	-23392.2
41	87	0	0	3119	0	-3119
42	21	14920.9	0	0	0	-14920.9
42	22	0	0	18294.4	0	-18294.4
42	51	0	0	0	0	-1252800
42	85	0	0	12475.8	0	-12475.8
42	86	0	0	12475.8	0	-12475.8
43	4	0	26597.3	0	0	-26597.3
43	5	0	15897.2	0	0	-15897.2
43	13	2406.2	0	0	0	-2406.2
43	19	0	0	6097.6	0	-6097.6
43	20	0	0	16786.5	0	-16786.5
43	21	0	0	1906.3	0	-1906.3
43	22	0	0	13720	0	-13720
43	23	0	0	19805.1	0	-19805.1
43	25	14296	0	0	0	-14296
43	26	14099	0	0	0	-14099
43	38	175992	0	0	0	-175992
43	44	2819.8	0	0	0	-2819.8
43	48	32665.8	0	0	0	-32665.8
43	51	0	0	0	0	-540000
43	85	0	0	3119	0	-3119
43	86	0	0	4678.4	0	-4678.4
44	22	0	0	2286.8	0	-2286.8
44	23	0	0	2345.8	0	-2345.8
44	27	8387	0	0	0	-8387
44	36	0	0	2104.1	0	-2104.1
44	44	0	0	16769.3	0	-16769.3
44	51	0	0	0	0	-1684800
44	73	8680	0	0	0	-8680
44	84	0	0	31369.8	0	-31369.8
44	85	0	0	6722.1	0	-6722.1
45	22	0	0	2286.8	0	-2286.8
45	23	0	0	2345.8	0	-2345.8
45	63	239116.5	0	0	0	-239116.5
45	66	83092.6	0	0	0	-83092.6
46	26	0	0	5335.5	0	-5335.5

46	29	0	0	1524.3	0	-1524.3
46	30	0	0	5335.8	0	-5335.8
46	36	0	0	1570.1	0	-1570.1
46	37	0	0	3567.2	0	-3567.2
46	46	4431.6	0	0	0	-4431.6
46	87	0	0	84766.7	0	-84766.7
47	30	0	0	42687.5	0	-42687.5
47	35	0	0	7625.3	0	-7625.3
47	36	0	0	7621.6	0	-7621.6
47	45	5336.2	0	0	0	-5336.2
47	47	3149.4	0	0	0	-3149.4
47	57	3735.3	0	0	0	-3735.3
47	72	235471.9	0	0	0	-235471.9
47	87	4871.1	0	6708.2	0	-11579.3
47	89	0	0	12941	0	-12941
48	25	15382.4	0	99097.9	0	-114480.3
48	29	0	0	18294.7	0	-18294.7
48	30	0	0	7073.3	0	-7073.3
48	51	58776.4	0	0	0	-58776.4
48	54	86425.1	0	0	0	-86425.1
48	89	0	0	2156.8	0	-2156.8
49	26	20251.3	0	0	0	-20251.3
49	30	0	0	6646.6	0	-6646.6
49	40	67345.7	0	0	0	-67345.7
49	45	10913	0	0	0	-10913
49	89	0	0	2156.8	0	-2156.8
50	26	0	17817.8	0	0	-17817.8
50	28	0	19154.2	0	0	-19154.2
50	48	43359.1	0	0	0	-43359.1
50	57	12890.5	0	0	0	-12890.5
50	77	0	0	22391.9	0	-22391.9
50	81	0	0	1643.3	0	-1643.3
51	7	0	15285.8	0	0	-15285.8
51	9	0	14980.1	0	0	-14980.1
51	42	8312.9	0	0	0	-8312.9
51	47	42077.3	0	0	0	-42077.3
51	48	55480.6	0	0	0	-55480.6
51	77	0	0	31562	0	-31562
51	80	0	0	4140.1	0	-4140.1
52	34	0	0	13416.3	0	-13416.3
52	45	511190.1	0	0	0	-511190.1
52	63	32344.2	0	0	0	-32344.2
52	74	0	0	5190.8	0	-5190.8
52	76	0	0	9088	0	-9088
52	77	0	0	18176.1	0	-18176.1
52	80	0	0	8280.1	0	-8280.1
52	81	0	0	2846.8	0	-2846.8
52	82	104442.6	0	0	0	-104442.6
53	3	0	0	4053.6	0	-4053.6
53	26	0	0	7623.1	0	-7623.1
53	64	32344.2	0	0	0	-32344.2
53	76	0	0	0	10587	-10587
53	77	0	0	4544	0	-4544
53	81	0	0	8800.9	0	-8800.9
53	82	0	0	1466.8	0	-1466.8
53	83	50097.3	0	0	0	-50097.3
53	115	0	16403	0	0	-16403
53	118	0	15491.8	0	0	-15491.8
54	9	0	0	17744.3	0	-17744.3
54	27	0	0	16007.9	0	-16007.9

54	30	0	0	57416.1	0	-57416.1
54	31	2681.7	0	0	0	-2681.7
54	34	0	0	25308.4	0	-25308.4
54	38	5676.8	0	0	0	-5676.8
54	41	8898.9	0	0	0	-8898.9
54	55	409347.6	0	0	0	-409347.6
54	61	170360.1	0	0	0	-170360.1
54	76	0	0	0	5775	-5775
54	79	0	0	12077	0	-12077
54	96	1941.1	0	0	0	-1941.1
55	26	0	0	69263.3	0	-69263.3
55	30	0	0	10977.1	0	-10977.1
55	33	0	0	28203.9	0	-28203.9
55	34	0	0	41773.3	0	-41773.3
55	38	14283.6	0	0	0	-14283.6
55	54	18347	0	0	0	-18347
55	55	18054.1	0	0	0	-18054.1
55	62	75300.3	0	0	0	-75300.3
55	75	0	0	6957.2	0	-6957.2
55	76	0	0	13914.4	0	-13914.4
55	78	5347.2	0	0	0	-5347.2
55	79	0	0	3250.1	0	-3250.1
55	80	0	0	6945.1	0	-6945.1
55	81	0	0	4141.5	0	-4141.5
55	96	52294.5	0	0	0	-52294.5
56	8	0	19412.9	0	0	-19412.9
56	28	0	0	6860.5	0	-6860.5
56	30	0	0	3250.1	0	-3250.1
56	33	0	0	28203.9	0	-28203.9
56	34	0	0	22044.7	0	-22044.7
56	36	0	0	320.5	0	-320.5
56	46	194029.9	0	0	0	-124029.9
56	60	180428.8	0	0	0	-180428.8
56	68	356796.7	0	0	0	-356796.7
56	79	0	0	8125.2	0	-8125.2
56	80	0	0	8570.2	0	-8570.2
56	83	17138.6	0	0	0	-17138.6
56	84	11425.7	0	0	0	-11425.7
57	6	0	0	7478.4	0	-7478.4
57	27	0	0	46496.1	0	-46496.1
57	34	0	0	3048.6	0	-3048.6
57	56	54926.5	0	0	0	-54926.5
57	80	0	0	1625	0	-1625
57	105	0	0	312911.6	0	-312911.6
58	33	5786.1	0	0	0	-5786.1
58	35	0	0	6194	0	-6194
58	53	27463.3	0	0	0	-27463.3
58	57	54926.5	0	0	0	-54926.5
58	58	54926.5	0	0	0	-54926.5
58	62	238804.4	0	0	0	-238804.4
58	75	20910.5	0	0	0	-20910.5
59	2	0	16202.9	0	0	-16202.9
59	6	14977.9	0	0	0	-14977.9
59	9	0	27208.7	0	0	-27208.7
59	27	0	0	36087	0	-36087
59	29	0	0	42992.6	0	-42992.6
59	65	144808.8	0	0	0	-144808.8
60	27	0	0	11191	0	-11191
60	45	2820.1	0	0	0	-2820.1
60	54	80895.4	0	0	0	-80895.4

61	7	0	0	4433	0	-4433
61	44	0	0	7172.9	0	-7172.9
62	2	0	23081.5	0	0	-23081.5
62	38	0	0	54140.4	0	-54140.4
62	82	8197	0	0	0	-8197
62	99	0	23757.1	0	0	-23757.1
63	8	0	20483	0	0	-20483
63	12	16589.2	0	0	0	-16589.2
63	31	119310.6	0	0	0	-119310.6
63	33	9141.5	0	0	0	-9141.5
63	58	330795.9	0	0	0	-330795.9
63	67	1648.1	0	0	0	-1648.1
63	82	16393.9	0	0	0	-16393.9
63	83	8197	0	0	0	-8197
63	84	16393.9	0	0	0	-16393.9
64	37	0	0	10032.2	0	-10032.2
64	76	70092.3	0	0	0	-70092.3
64	84	16393.9	0	0	0	-16393.9
64	85	8197	0	0	0	-8197
65	26	0	0	3043.9	0	-3043.9
65	64	0	0	846.8	0	-846.8
65	82	8197	0	0	0	-8197
65	83	8197	0	0	0	-8197
65	85	8197	0	0	0	-8197
65	97	0	35932.6	0	0	-35932.6
65	99	0	30735.8	0	0	-30735.8
66	8	0	15285.8	0	0	-15285.8
66	13	0	20177.2	0	0	-20177.2
66	21	5114.8	0	0	0	-5114.8
66	23	0	15744.4	0	0	-15744.4
66	29	38250.4	0	0	0	-38250.4
66	86	99140.3	0	0	0	-99140.3
67	7	25488.1	0	0	0	-25488.1
67	28	38250.4	0	0	0	-38250.4
67	46	1604.2	0	0	0	-1604.2
67	71	17797.7	0	0	0	-17797.7
67	83	133666	0	0	0	-133666
68	2	0	0	19820.5	0	-19820.5
68	8	0	35157.3	0	0	-35157.3
68	12	0	41271.6	0	0	-41271.6
68	11	0	0	0	0	-1010880
68	22	3442.7	0	0	0	-3442.7
68	23	0	19412.9	0	0	-19412.9
68	26	0	21975.3	0	0	-21975.3
68	64	26778.6	0	0	0	-26778.6
69	7	121544.5	0	0	0	-121544.5
69	14	19775.2	0	0	0	-19775.2
69	15	0	36685.9	0	0	-36685.9
69	17	0	15285.8	0	0	-15285.8
69	19	37554.6	0	0	0	-37554.6
69	27	88915.4	0	0	0	-88915.4
69	71	26110.7	0	0	0	-26110.7
69	94	0	0	21315.6	0	-21315.6
70	14	0	14368.6	0	0	-14368.6
70	19	37554.6	0	0	0	-37554.6
70	79	30032.2	0	0	0	-30032.2
71	6	69213.4	0	0	0	-69213.4
71	21	250339.9	0	0	0	-250339.9
71	38	13220.1	0	0	0	-13220.1
71	77	30032.2	0	0	0	-30032.2

71	85	0	0	180662.5	0	-180662.5	
72	3	0	23387.3	0	0	-23387.3	
72	14	0	13757.2	0	0	-13757.2	
72	19	0	22011.5	0	0	-22011.5	
72	23	0	24763	0	0	-24763	
72	26	0	31181.2	0	0	-31181.2	
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72	85	0	0	180662.5	0	-180662.5	
73	74	477772.8	0	0	0	-477772.8	
74	93	0	0	410357.3	0	-410357.3	
75	2	0	13298.6	0	0	-13298.6	
75	13	0	18342.9	0	0	-18342.9	
75	15	0	37450.2	0	0	-37450.2	
75	17	0	26138.7	0	0	-26138.7	
75	19	0	67868.9	0	0	-67868.9	
75	23	0	33628.7	0	0	-33628.7	
75	26	0	13363.4	0	0	-13363.4	
75	28	0	19599.6	0	0	-19599.6	
75	30	0	15590.6	0	0	-15590.6	
76	7	12744	0	0	0	-12744	
77	5	0	0	1219.6	0	-1219.6	
77	9	0	60226	0	0	-60226	
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77	30	29739	0	0	0	-29739	
78	8	0	18037.2	0	0	-18037.2	
78	10	0	34545.9	0	0	-34545.9	
78	12	0	32864.4	0	0	-32864.4	
78	15	0	53500.3	0	0	-53500.3	
78	24	0	15438.7	0	0	-15438.7	
78	63	0	0	53238.1	0	-53238.1	
78	103	17834.4	0	0	0	-17834.4	
79	15	4944.3	0	0	0	-4944.3	
79	27	3872.6	0	0	0	-3872.6	
79	54	8822	0	0	0	-8822	
80	2	0	13757.2	0	0	-13757.2	
80	4	0	17272.9	0	0	-17272.9	
80	6	0	27361.6	0	0	-27361.6	
80	8	0	20177.2	0	0	-20177.2	
80	9	0	30113	0	0	-30113	
80	11	165379.6	0	0	0	-165379.6	
80	12	0	15897.2	0	0	-15897.2	
80	13	0	0	2231.9	0	-2231.9	
80	19	0	25680.1	0	0	-25680.1	
80	23	0	15285.8	0	0	-15285.8	
80	28	1684.6	0	0	0	-1684.6	
80	33	0	0	66889.4	0	-66889.4	
80	36	13274	0	0	0	-13274	
80	63	0	0	53238.1	0	-53238.1	
81	28	1875.7	0	0	0	-1875.7	
82	23	2122.9	0	0	0	-2122.9	
82	36	31557.1	0	0	0	-31557.1	<=Hidden Springs
82	66	22155.6	0	0	0	-22155.6	
83	2	0	16355.8	0	0	-16355.8	
83	4	0	16814.4	0	0	-16814.4	
83	5	0	23998.7	0	0	-23998.7	
83	6	0	17120.1	0	0	-17120.1	

83	17	0	18495.8	0	0	-18495.8	
83	19	0	58544.6	0	0	-58544.6	
83	23	0	15285.8	0	0	-15285.8	
83	66	297804	0	0	0	-297804	<= Conway
83	68	0	0	2287.6	0	-2287.6	
84	3	0	0	3102.8	0	-3102.8	
84	89	26861.4	0	0	0	-26861.4	
84	90	26861.4	0	0	0	-26861.4	
85	4	0	13604.3	0	0	-13604.3	
85	19	0	36533	0	0	-36533	
85	23	0	29501.6	0	0	-29501.6	
85	26	0	17966.3	0	0	-17966.3	
85	28	0	30884.3	0	0	-30884.3	
85	36	0	0	28574.1	0	-28574.1	
85	60	0	14848.2	0	0	-14848.2	
87	5	0	30418.7	0	0	-30418.7	
87	8	0	21705.8	0	0	-21705.8	
87	26	0	40387.1	0	0	-40387.1	
87	28	0	30735.8	0	0	-30735.8	
87	34	237388.4	0	0	0	-237388.4	
87	35	237388.4	0	0	0	-237388.4	
87	60	3515.6	0	0	0	-3515.6	
87	92	29406.5	0	0	0	-29406.5	
88	4	0	16508.7	0	0	-16508.7	
88	6	0	33017.3	0	0	-33017.3	
88	17	0	32864.4	0	0	-32864.4	
88	19	0	19565.8	0	0	-19565.8	
88	23	0	49678.8	0	0	-49678.8	
88	34	237388.4	0	0	0	-237388.4	
88	41	408822.7	0	0	0	-408822.7	
88	42	408822.7	0	0	0	-408822.7	
88	59	7104.4	0	0	0	-7104.4	
88	100	28051.6	0	0	0	-28051.6	
89	41	408822.7	0	0	0	-408822.7	
89	60	0	0	6466.8	0	-6466.8	
89	100	22228.8	0	0	0	-22228.8	
90	4	0	20941.5	0	0	-20941.5	
90	5	0	17272.9	0	0	-17272.9	
90	6	0	38520.2	0	0	-38520.2	
90	8	0	23234.4	0	0	-23234.4	
90	9	0	0	0	0	0	<= CONSERV II
90	17	0	19412.9	0	0	-19412.9	
90	23	0	33475.9	0	0	-33475.9	
90	26	0	17075.4	0	0	-17075.4	
90	50	0	0	4662.1	0	-4662.1	
90	100	25561.3	0	0	0	-25561.3	
91	100	9960.9	0	0	0	-9960.9	
92	5	0	27820.1	0	0	-27820.1	
92	6	0	35615.9	0	0	-35615.9	
92	8	0	38061.6	0	0	-38061.6	
92	9	0	23540.1	0	0	-23540.1	
92	10	0	19718.7	0	0	-19718.7	
92	12	0	31794.4	0	0	-31794.4	
92	13	0	12381.5	0	0	-12381.5	
92	14	0	22928.7	0	0	-22928.7	
92	15	0	23693	0	0	-23693	
92	100	17285	0	0	0	-17285	
92	126	0	0	0	28875	-28875	
92	128	0	0	0	24062	-24062	
93	19	731885	0	0	0	-731885	

93	91	382797.5	0	0	0	-382797.5	
93	92	416708.3	0	0	0	-416708.3	
93	93	418466.1	0	0	0	-418466.1	
93	94	337094.7	0	0	0	-337094.7	
93	95	220494	0	0	0	-220494	
93	98	30724.9	0	0	0	-30724.9	
93	100	60351.1	0	0	0	-60351.1	
94	40	157794.1	0	0	0	-157794.1	<= Orangewood
94	91	346579.5	0	0	0	-346579.5	
95	7	100249.5	0	0	0	-100249.5	
95	37	53466.4	0	0	0	-53466.4	
95	38	120299.4	0	0	0	-120299.4	
95	73	4534	0	0	0	-4534	
96	8	0	15132.9	0	0	-15132.9	
96	9	0	34851.6	0	0	-34851.6	
96	10	0	34545.9	0	0	-34545.9	
96	36	0	14551.2	0	0	-14551.2	
96	44	0	0	41417.4	0	-41417.4	
96	61	0	0	17746	0	-17746	
96	97	0	15590.6	0	0	-15590.6	
96	100	61742.7	0	0	0	-61742.7	
97	91	187645.1	0	0	0	-187645.1	
98	7	116146.6	0	0	0	-116146.6	
98	8	0	0	156575.2	0	-156575.2	
98	10	0	31335.9	0	0	-31335.9	
98	38	0	0	33085.8	0	-33085.8	
98	100	101622.8	0	0	0	-101622.8	
98	101	77965.7	0	0	0	-77965.7	
98	102	37023.7	0	0	0	-37023.7	
99	29	343584	0	0	0	-343584	
99	30	76040.2	0	0	0	-76040.2	
99	36	51710.8	0	0	0	-51710.8	
99	100	108690.6	0	0	0	-108690.6	
100	9	0	0	62296	0	-62296	
100	10	0	26903	0	0	-26903	
100	13	0	25680.1	0	0	-25680.1	
100	15	0	31488.7	0	0	-31488.7	
100	30	0	0	143592.4	0	-143592.4	
100	73	0	31626.7	0	0	-31626.7	
101	10	0	16814.4	0	0	-16814.4	
101	11	0	21094.4	0	0	-21094.4	
101	13	0	22775.8	0	0	-22775.8	
101	14	0	17120.1	0	0	-17120.1	
101	15	0	46774.5	0	0	-46774.5	
101	30	0	0	28574.1	0	-28574.1	
101	31	140365.8	0	0	0	-140365.8	
101	57	10170.7	0	0	0	-10170.7	
101	77	0	39496.2	0	0	-39496.2	
101	116	0	0	0	19250	-19250	
101	128	0	0	0	19250	-19250	
102	23	1589749	0	0	0	-1589749	
102	44	15945.8	0	0	0	-15945.8	
102	77	0	44544.6	0	0	-44544.6	
102	92	0	16778.5	0	0	-16778.5	
103	19	128180.2	0	0	0	-128180.2	
103	28	40774	0	0	0	-40774	
103	30	211192.3	0	0	0	-211192.3	
103	35	0	0	1503.9	0	-1503.9	
103	122	0	0	0	42350	-42350	
103	128	0	0	0	38500	-38500	

104	11	0	47997.4	0	0	-47997.4
104	12	0	45398.8	0	0	-45398.8
104	43	0	0	43702.5	0	-43702.5
104	34	121578.2	0	0	0	-121578.2
104	35	10402.9	0	0	0	-10402.9
104	47	274700.1	0	0	0	-274700.1
104	51	11144.8	0	0	0	-11144.8
104	58	204655.8	0	0	0	-204655.8
105	11	0	23693	0	0	-23693
105	12	0	68480.3	0	0	-68480.3
105	40	0	0	341.7	0	-341.7
105	80	0	15887.6	0	0	-15887.6
106	12	0	32558.7	0	0	-32558.7
106	26	0	0	4381.2	0	-4381.2
106	48	236997.1	0	0	0	-236997.1
106	58	0	15145.2	0	0	-15145.2
106	60	12762	0	0	0	-12762
106	77	0	12621	0	0	-12621
106	80	0	13363.4	0	0	-13363.4
106	127	0	0	0	48125	-48125
106	128	0	0	0	48125	-48125
107	57	25524	0	0	0	-25524
107	61	0	13957.3	0	0	-13957.3
108	12	0	19107.2	0	0	-19107.2
108	35	28358.8	0	0	0	-28358.8
108	63	0	13957.3	0	0	-13957.3
108	77	0	17966.3	0	0	-17966.3
109	13	0	70030.7	0	0	-70030.7
109	14	0	17804.4	0	0	-17804.4
109	15	0	17295.7	0	0	-17295.7
109	17	0	17804.4	0	0	-17804.4
109	63	0	13565.3	0	0	-13565.3
109	77	0	45104.5	0	0	-45104.5
109	80	0	13734.8	0	0	-13734.8
110	13	0	30013.2	0	0	-30013.2
110	68	160599.6	0	0	0	-160599.6
110	71	80299.8	0	0	0	-80299.8
110	74	0	16108.8	0	0	-16108.8
110	83	0	0	3285.9	0	-3285.9
111	13	75329.8	20517.5	0	0	-95847.3
111	38	0	0	7667.1	0	-7667.1
111	74	0	15260.9	0	0	-15260.9
111	77	0	46291.5	0	0	-46291.5
111	86	0	15769.6	0	0	-15769.6
111	90	0	16278.3	0	0	-16278.3
112	13	0	27300.1	0	0	-27300.1
112	14	0	16108.8	0	0	-16108.8
112	17	0	26621.8	0	0	-26621.8
112	22	23391.6	0	0	0	-23391.6
112	55	0	18991.4	0	0	-18991.4
112	77	0	31369.7	0	0	-31369.7
113	13	0	16108.8	0	0	-16108.8
113	14	15463	0	0	0	-15463
113	23	0	19160.9	0	0	-19160.9
113	55	0	14921.8	0	0	-14921.8
113	58	0	29843.6	0	0	-29843.6
113	61	0	14582.7	0	0	-14582.7
113	63	0	0	36378	0	-36378
113	83	0	80882.9	0	0	-80882.9
113	86	0	44426.3	0	0	-44426.3

113	89	0	29674	0	0	-29674
114	13	0	24247.9	0	0	-24247.9
114	14	0	40695.8	0	0	-40695.8
114	34	54981.4	0	0	0	-54981.4
114	58	0	14074	0	0	-14074
114	82	0	15769.6	0	0	-15769.6
114	86	0	17126.2	0	0	-17126.2
114	89	0	14413.1	0	0	-14413.1
115	13	0	29674	0	0	-29674
115	14	0	59178.5	0	0	-59178.5
115	64	0	13565.3	0	0	-13565.3
115	68	0	18313.1	0	0	-18313.1
115	74	0	22552.3	0	0	-22552.3
115	80	0	34930.6	0	0	-34930.6
115	115	0	37643.6	0	0	-37643.6
116	14	0	53243.7	0	0	-53243.7
116	15	0	29843.6	0	0	-29843.6
116	16	71096.3	0	0	0	-71096.3
116	17	0	29334.9	0	0	-29334.9
116	19	0	14921.8	0	0	-14921.8
116	33	0	0	15039	0	-15039
116	47	0	17126.2	0	0	-17126.2
116	80	0	22891.4	0	0	-22891.4
117	15	0	35778.4	0	0	-35778.4
117	17	0	17974	0	0	-17974
117	19	0	59687.2	0	0	-59687.2
117	58	0	47648	0	0	-47648
117	71	0	22043.6	0	0	-22043.6
118	19	0	74778.5	0	0	-74778.5
118	38	8658.9	0	0	0	-8658.9
118	80	0	35948	0	0	-35948
118	83	0	29504.4	0	0	-29504.4
118	87	0	25265.3	0	0	-25265.3
119	15	0	17465.3	0	0	-17465.3
119	19	0	48665.4	0	0	-48665.4
119	38	17317.7	0	0	0	-17317.7
119	87	0	42900.2	0	0	-42900.2
Totals		24530781.	5368773.3	5756902.6	331504	-35987961.9

====================== LOWER FLORIDAN Q ======================

Row	Col	M&I	Citrus	Non-Cit.	Abandoned Wells	Total
43	31	277402.7	0.0	0.0	0.0	-277402.7
46	63	52489.0	0.0	0.0	0.0	-52489.0
53	36	277402.7	0.0	0.0	0.0	-277402.7
53	65	38813.0	0.0	0.0	0.0	-38813.0
56	46	194029.9	0.0	0.0	0.0	-194029.9
58	53	82389.8	0.0	0.0	0.0	-82389.8
59	65	104861.5	0.0	0.0	0.0	-104861.5
61	54	394516.1	0.0	0.0	0.0	-394516.1
64	66	678657.1	0.0	0.0	0.0	-678657.1
68	20	117479.6	0.0	0.0	0.0	-117479.6
68	40	748328.2	0.0	0.0	0.0	-748328.2
69	40	374164.1	0.0	0.0	0.0	-374164.1
69	41	374164.1	0.0	0.0	0.0	-374164.1

69	54	308389.2	0.0	0.0	0.0	-308389.2
69	55	462583.8	0.0	0.0	0.0	-462583.8
69	64	186363.4	0.0	0.0	0.0	-186363.4
70	54	308389.2	0.0	0.0	0.0	-308389.2
73	58	357858.7	0.0	0.0	0.0	-357858.7
73	59	715717.3	0.0	0.0	0.0	-715717.3
77	54	748236.6	0.0	0.0	0.0	-748236.6
77	55	374118.3	0.0	0.0	0.0	-374118.3
78	61	445089.5	0.0	0.0	0.0	-445089.5
78	62	890178.9	0.0	0.0	0.0	-890178.9
79	54	8822.0	0.0	0.0	0.0	-8822.0
80	39	558076.9	0.0	0.0	0.0	-558076.9
80	40	279038.5	0.0	0.0	0.0	-279038.5
82	36	189276.0	0.0	0.0	0.0	-189276.0
83	66	135365.4	0.0	0.0	0.0	-135365.4
94	40	78897.4	0.0	0.0	0.0	-78897.0
99	36	206843.2	0.0	0.0	0.0	-206843.2
Totals		9967942	0.0	0.0	0.0	-9967941.7

APPENDIX B

Recharge Due to Drainage Wells

Recharge to Upper Floridan due to drainage wells

LAYER	ROW	COL	Q ft^3/d
1	29	67	10355.5
1	35	17	10355.5
1	39	30	10355.5
1	45	25	10355.5
1	47	30	10355.5
1	47	32	10355.5
1	48	32	10355.5
1	48	34	10355.5
1	48	38	10355.5
1	48	55	10355.5
1	49	44	10355.5
1	51	38	10355.5
1	52	36	10355.5
1	53	43	10355.5
1	55	53	20711.0
1	56	62	10355.5
1	57	45	10355.5
1	57	54	10355.5
1	58	54	10355.5
1	58	62	31066.5
1	59	37	10355.5
1	59	40	10355.5
1	59	42	10355.5
1	59	60	10355.5
1	60	44	10355.5
1	60	55	10355.5
1	61	45	10355.5
1	61	49	10355.5
1	61	55	10355.5
1	61	61	10355.5
1	61	62	10355.5
1	62	55	10355.5
1	62	56	10355.5
1	63	40	10355.5
1	63	46	10355.5
1	63	50	10355.5
1	63	52	10355.5
1	63	62	10355.5
1	63	63	10355.5
1	64	46	10355.5
1	64	48	10355.5
1	64	51	10355.5
1	64	54	20711.0
1	64	56	31066.5
1	64	58	20711.0
1	64	62	10355.5
1	64	98	20711.0
1	65	39	10355.5
1	65	41	10355.5
1	65	50	10355.5
1	65	51	10355.5
1	65	55	10355.5
1	65	56	10355.5
1	66	33	10355.5
1	66	40	10355.5

1	66	49	10355.5
1	66	53	10355.5
1	66	54	20711.0
1	66	55	10355.5
1	67	24	10355.5
1	67	30	10355.5
1	67	31	10355.5
1	67	40	20711.0
1	67	46	20711.0
1	67	47	10355.5
1	67	49	20711.0
1	67	52	10355.5
1	67	53	41422.0
1	67	54	41422.0
1	67	55	10355.5
1	67	56	10355.5
1	67	62	10355.5
1	68	23	10355.5
1	68	25	10355.5
1	68	26	10355.5
1	68	27	10355.5
1	68	33	10355.5
1	68	50	31066.5
1	68	51	20711.0
1	68	53	31066.5
1	68	54	51777.5
1	68	55	20711.0
1	68	56	20711.0
1	68	57	10355.5
1	68	58	10355.5
1	68	59	10355.5
1	68	60	10355.5
1	69	40	10355.5
1	69	44	10355.5
1	69	48	20711.0
1	69	50	20711.0
1	69	52	10355.5
1	69	54	51777.5
1	69	55	10355.5
1	69	58	51777.5
1	69	59	20711.0
1	69	60	10355.5
1	70	15	10355.5
1	70	22	10355.5
1	70	43	10355.5
1	70	48	10355.5
1	70	49	10355.5
1	70	51	10355.5
1	70	52	10355.5
1	70	54	51777.5
1	70	55	20711.0
1	70	56	20711.0
1	70	57	10355.5
1	70	58	20711.0
1	70	61	20711.0
1	70	62	10355.5
1	70	64	10355.5
1	71	31	10355.5
1	71	33	10355.5
1	71	40	10355.5
1	71	44	10355.5

1	71	47	10355.5
1	71	49	10355.5
1	71	51	51777.5
1	71	52	31066.5
1	71	53	31066.5
1	71	54	20711.0
1	71	55	10355.5
1	71	56	20711.0
1	71	57	41422.0
1	71	58	41422.0
1	71	59	31066.5
1	71	60	31066.5
1	71	62	20711.0
1	71	63	10355.5
1	71	65	20711.0
1	72	39	10355.5
1	72	41	20711.0
1	72	45	10355.5
1	72	48	20711.0
1	72	50	10355.5
1	72	51	31066.5
1	72	52	31066.5
1	72	53	72488.5
1	72	54	31066.5
1	72	55	31066.5
1	72	56	10355.5
1	72	57	10355.5
1	72	59	20711.0
1	72	60	10355.5
1	72	61	20711.0
1	72	67	10355.5
1	73	38	10355.5
1	73	49	10355.5
1	73	50	10355.5
1	73	51	20711.0
1	73	52	20711.0
1	73	53	20711.0
1	73	54	41422.0
1	73	55	31066.5
1	73	56	10355.5
1	73	57	20711.0
1	73	65	10355.5
1	73	66	10355.5
1	74	18	10355.5
1	74	48	20711.0
1	74	49	10355.5
1	74	51	31066.5
1	74	52	41422.0
1	74	53	41422.0
1	74	54	20711.0
1	74	55	10355.5
1	74	56	51777.5
1	74	61	10355.5
1	74	62	10355.5
1	75	18	10355.5
1	75	30	10355.5
1	75	35	10355.5
1	75	45	10355.5
1	75	47	10355.5
1	75	50	20711.0
1	75	51	20711.0

1	75	52	41422.0
1	75	53	10355.5
1	75	54	72488.5
1	75	55	93199.5
1	75	56	62133.0
1	75	60	10355.5
1	75	61	10355.5
1	75	64	31066.5
1	76	30	10355.5
1	76	51	20711.0
1	76	52	10355.5
1	76	53	10355.5
1	76	54	20711.0
1	76	55	10355.5
1	76	60	20711.0
1	77	22	10355.5
1	77	45	10355.5
1	77	50	20711.0
1	77	51	10355.5
1	77	52	31066.5
1	77	53	20711.0
1	77	54	20711.0
1	77	55	20711.0
1	77	56	31066.5
1	77	57	10355.5
1	77	58	10355.5
1	77	59	10355.5
1	77	60	10355.5
1	77	62	31066.5
1	77	68	10355.5
1	78	18	10355.5
1	78	42	10355.5
1	78	45	10355.5
1	78	50	10355.5
1	78	51	20711.0
1	78	53	20711.0
1	78	58	10355.5
1	78	60	10355.5
1	79	39	20711.0
1	79	43	10355.5
1	79	44	10355.5
1	79	54	10355.5
1	79	55	20711.0
1	79	60	10355.5
1	79	63	10355.5
1	80	42	20711.0
1	80	45	10355.5
1	80	48	31066.5
1	80	51	10355.5
1	80	59	10355.5
1	80	62	10355.5
1	80	64	10355.5
1	81	44	10355.5
1	81	48	20711.0
1	81	49	10355.5
1	81	57	10355.5
1	81	66	10355.5
1	82	48	10355.5
1	82	52	10355.5
1	83	51	10355.5
1	83	58	10355.5

1	84	51	10355.5
1	84	57	10355.5
1	84	65	10355.5
1	85	51	10355.5
1	85	52	10355.5
1	85	53	10355.5
1	85	54	10355.5
1	85	60	10355.5
1	85	61	10355.5
1	86	28	20711.0
1	86	55	10355.5
1	87	28	10355.5
1	87	51	20711.0
1	87	55	20711.0
1	87	60	10355.5
1	88	50	10355.5
1	88	56	20711.0
1	90	33	10355.5
1	91	55	20711.0
1	92	28	10355.5
1	93	55	20711.0
1	94	36	10355.5
1	100	48	10355.5
1	100	53	10355.5

		Total	4411440.0 ft^3/d (= 33 MGD)

APPENDIX C

Finite Difference (MODFLOW)
Model Grid

*************** MODFLOW finite diffrence grid parameters *****************

Col No.	dx (ft)	cum dx (ft)
1	5280	5280
2	5280	10560
3	5280	15840
4	5280	21120
5	5280	26400
6	5280	31680
7	5280	36960
8	5280	42240
9	5280	47520
10	5280	52800
11	5280	58080
12	5280	63360
13	5280	68640
14	5280	73920
15	5280	79200
16	2640	81840
17	2625	84465
18	2475	86940
19	2175	89115
20	1050	90165
21	1125	91290
22	1350	92640
23	1275	93915
24	1125	95040
25	2550	97590
26	2100	99690
27	2550	102240
28	2850	105090
29	1725	106815
30	4125	110940
31	1725	112665
32	1275	113940
33	1650	115590
34	1575	117165
35	2175	119340
36	3225	122565
37	1650	124215
38	2475	126690
39	1350	128040
40	2325	130365
41	1800	132165
42	1650	133815
43	1875	135690
44	1875	137565
45	1950	139515
46	1275	140790
47	1575	142365
48	2835	145200
49	1140	146340
50	1650	147990
51	2100	150090
52	1350	151440
53	1650	153090
54	2700	155790

Row No.	dy (ft)	cum dy (ft)
1	5280	5280
2	5280	10560
3	5280	15840
4	5280	21120
5	5280	26400
6	5280	31680
7	5280	36960
8	5280	42240
9	5280	47520
10	2640	50160
11	2640	52800
12	2625	55425
13	3300	58725
14	3075	61800
15	1575	63375
16	2925	66300
17	2400	68700
18	1800	70500
19	2100	72600
20	1350	73950
21	2700	76650
22	1200	77850
23	1350	79200
24	1800	81000
25	2175	83175
26	1200	84375
27	1275	85650
28	900	86550
29	1800	88350
30	2775	91125
31	1725	92850
32	1875	94725
33	2550	97275
34	3375	100650
35	1800	102450
36	1875	104325
37	1275	105600
38	1500	107100
39	1650	108750
40	975	109725
41	1575	111300
42	1125	112425
43	1500	113925
44	1275	115200
45	975	116175
46	1350	117525
47	2025	119550
48	1575	121125
49	1425	122550
50	1425	123975
51	1500	125475
52	1425	126900
53	1650	128550
54	2250	130800

55	2775	158565	55	2250	133050
56	1650	160215	56	2400	135450
57	1350	161565	57	1800	137250
58	2175	163740	58	2025	139275
59	1275	165015	59	1725	141000
60	2250	167265	60	1650	142650
61	1650	168915	61	1800	144450
62	2700	171615	62	1050	145500
63	1650	173265	63	1800	147300
64	1950	175215	64	1800	149100
65	1650	176865	65	1350	150450
66	1650	178515	66	2400	152850
67	3000	181515	67	2475	155325
68	3000	184515	68	3225	158550
69	1500	186015	69	3075	161625
70	1425	187440	70	2025	163650
71	2625	190065	71	2250	165900
72	1650	191715	72	1425	167325
73	2250	193965	73	1650	168975
74	1725	195690	74	1650	170625
75	1425	197115	75	2850	173475
76	1650	198765	76	1575	175050
77	1650	200415	77	2250	177300
78	1650	202065	78	1875	179175
79	1950	204015	79	1575	180750
80	1875	205890	80	2475	183225
81	2250	208140	81	2250	185475
82	2175	210315	82	2250	187725
83	1275	211590	83	1575	189300
84	1350	212940	84	2175	191475
85	1575	214515	85	2325	193800
86	1500	216015	86	1500	195300
87	1650	217665	87	3000	198300
88	2325	219990	88	3225	201525
89	1575	221565	89	1575	203100
90	1425	222990	90	2100	205200
91	1350	224340	91	2250	207450
92	2625	226965	92	1950	209400
93	2100	229065	93	1950	211350
94	3300	232365	94	1125	212475
95	1425	233790	95	1125	213600
96	2400	236190	96	1425	215025
97	1650	237840	97	1950	216975
98	2325	240165	98	3375	220350
99	3450	243615	99	3300	223650
100	2850	246465	100	3390	227040
101	2625	249090	101	5280	232320
102	1725	250815	102	5280	237600
103	2625	253440	103	5280	242880
104	2640	256080	104	5280	248160
105	2640	258720	105	5280	253440
106	5280	264000	106	5280	258720
107	5280	269280	107	5280	264000
108	5280	274560	108	5280	269280
109	5280	279840	109	5280	274560
110	5280	285120	110	5280	279840
111	5280	290400	111	5280	285120
112	5280	295680	112	5280	290400
113	5280	300960	113	5280	295680
114	5280	306240	114	5280	300960

115	5280	311520
116	5280	316800
117	5280	322080
118	5280	327360
119	5280	332640
120	5280	337920
121	5280	343200
122	5280	348480
123	5280	353760
124	5280	359040
125	5280	364320
126	5280	369600
127	5280	374880
128	5280	380160
129	5280	385440
130	5280	390720
131	5280	396000
132	5280	401280
133	5280	406560
134	5280	411840
135	5280	417120
136	5280	422400
137	5280	427680

Total =	81 mi	

115	5280	306240
116	5280	311520
117	5280	316800
118	5280	322080
119	5280	327360

Total =	62 mi	